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Agroforestry Systems in the Tropics

P.K.R. NAIR
editor

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Agroforestry Systems in the Tropics

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Preface

This book consolidates the descriptive results of a pantropical project called Agroforestry Systems Inventory (AFSI), undertaken by the International Council for Research in Agroforestry (ICRAF) from 1982 to 1987. Since agroforestry was a relatively new term when the project was initiated, the main objective was to increase the understanding of and provide a state-of-the-art information base on existing agroforestry systems. Therefore, the project was designed to systematically collect, collate, synthesize, and disseminate information on existing agroforestry systems in developing countries. One of the major results of the project, descriptions of existing agroforestry systems, was published as a series of articles in *Agroforestry Systems*. These system descriptions form the bulk of this book. Other products of the project include a microcomputer database on agroforestry systems, practices and components, and voluminous unpublished reports and records.

Perhaps the title of the book is misleading in that the book does not include or cover *all* existing agroforestry systems in the tropics and geographical regions in the tropics. Additionally, some of the systems described are outside the tropical boundaries of 23.5 N and S latitudes. For the purpose of this book, the word tropics is used in a general sense to also include subtropical developing countries that have agro-ecological and socio-economic characteristics and land-use problems similar to those of the countries within the geographical limits of the tropical belt. In this vast geographical area, mixed land-use systems in which "trees" are intentionally grown in intimate association with crops and/or animals are so many that it would be impossible to include detailed descriptions of all of them in a book like this. In spite of this seemingly large number, there are enough structural and functional similarities among these systems that it is probably unnecessary to include descriptions of all the innumerable systems in order to portray the nature of their complexities, diversities, and characteristics. Therefore, the basic consideration of this book was to include examples of systems from as many geographical and ecological regions as possible.

However, there are a few notable inadequacies. For example, the site-specific agroforestry systems existing in the Middle East and China are not included because the AFSI project could not collect information from these regions. Also, agroforestry systems from the American tropics are not adequately covered either. However, this deficiency is somewhat rectified by a recent publication titled *Sistemas Agroforestales* produced jointly by OTS and CATIE, 1986. The inclusion of a report of the 'dehesa' systems from Spain (Chapter 26) under Part 4 may appear out of context. The dehesa is a popular agrosilvopastoral system in some North-African countries and a better description of it could not be obtained. The systems and the

related studies described in the chapter have relevance to such systems practised in Africa and other places. While several other descriptions of agroforestry systems have been published in *Agroforestry Systems* and elsewhere, only those that have been published as AFSI outputs are included in this book.

In spite of these inadequacies and drawbacks, the book presents the diversity and complexity of tropical agroforestry systems. The descriptions and their analyses show their potentials on the one hand, and the obvious gaps in our understanding of these systems on the other. This points out the need to undertake systematic research efforts to fill these voids and improve the functioning of these low-input traditional systems that provide sustenance to millions of poorer sections of people in many developing countries of the world.

Several people contributed to the production of this book. The various authors who contributed the system descriptions have been identified by name in the respective chapters. Chapters 1, 2, and 36 have been adapted from ICRAF sources other than AFSI; the sources of these as well as all other chapters have been duly acknowledged. Many project staff and consultants provided the inputs in collection, compilation, synthesis, and evaluation of the data; but two of them deserve special mention: Eric C. M. Fernandes, the project research assistant from 1982 to 1985, and Peter A. Oduol, who succeeded Mr. Fernandes. The entire manuscript of the book was word-processed most efficiently and expeditiously by Mrs. Thecla Lohay of ICRAF, and copy-edited by Mrs. Caroline Agola, Nairobi. Mrs. Lohay also superbly co-ordinated the fast movement of manuscripts between the copy-editor in Nairobi, the scientific editor in Gainesville, Florida, and the publisher in Dordrecht, the Netherlands. Last, but by no means least, a note of special thanks to Dr. Bjorn Lundgren, Director-General, ICRAF for his splendid support and perseverance throughout the entire term of the AFSI project and the publication of this book.

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Gainesville, Florida, USA
September 1988

P.K.R. Nair

Part 1

Introduction

1. The history of agroforestry*

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Throughout the world, at one period or another in its history, it has been the practice to cultivate tree species and agricultural crops in intimate combination. The examples are numerous. It was the general custom in Europe, at least until the Middle Ages, to clear-fell derelict forest, burn the slash, cultivate food crops for varying periods on the cleared areas, and plant or sow tree species before, along with, or after the sowing of the agricultural crop. This "farming system" is, of course, no longer popular in Europe. But it was still widely followed in Finland up to the end of the last century, and was being practised in a few areas in Germany as late as the 1920s (King 1968).

In tropical America, many societies have traditionally simulated forest conditions in their farms in order to obtain the beneficial effects of forest structures. Farmers in Central America, for example, have long imitated the structure and species diversity of tropical forests by planting a variety of crops with different growth habits. Plots of no more than one-tenth of a hectare contained, on average, two dozen different species of plants each with a different form, together corresponding to the layered configuration of mixed tropical forests: coconut or papaya with a lower layer of bananas or citrus, a shrub layer of coffee or cacao, tall and low annuals such as maize, and finally a spreading ground cover of plants such as squash (Wilken 1977).

In Asia, the Hanunoo of the Philippines practised a complex and somewhat sophisticated type of shifting cultivation. In clearing the forest for agricultural use, they deliberately left certain selected trees which, by the end of the rice-growing season, would "provide a partial canopy of new foliage" to prevent excessive exposure to the sun "at a time when moisture is more important than sunlight for the maturing grain". Nor was this all. Trees were an indispensable part of the Hanunoo farming system and were either planted or conserved from the original forests to provide food, medicines, construction wood and cosmetics, in addition to their protective services (Conklin 1957).

The situation was little different in Africa. In southern Nigeria, yams, maize, pumpkins and beans were typically grown together under a cover of

* Adapted from the chapter by the author in *Agroforestry: a decade of development*, edited by H.A. Steppler and P.K.R. Nair (ICRAF, Nairobi, 1987).

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scattered trees (Forde 1937). In Zambia, in addition to the main crop in the homestead, there were traditionally numerous subsidiary crops that were grown in a mixture with tree species (British Government 1938). Indeed, the Yoruba of western Nigeria, who have long practised an intensive system of mixed herbaceous, shrub and tree cropping, explain that the system is a means of conserving human energy by making full use of the limited space laboriously won from the dense forest. They compare the method to a multistoreyed building in a congested area in which expansion must perforce be vertical rather than horizontal. They also claim that it is an inexpensive means of combating erosion and leaching, and of maintaining soil fertility (Ojo 1966). As they picturesquely described it, "the plants eat and drink, as it were, not from one table, but from many tables under the same sky" (Henry 1949).

These examples indicate the wide geographical coverage of the system and its early origins. What is more important, perhaps, they clearly point to the fact that the earliest practitioners of what has now become known as agroforestry* perceived food production as the system's *raison d'être*. Trees were an integral part of a farming system. They were kept on established farmland to support agriculture. The ultimate objective was not tree production but food production.

By the end of the nineteenth century, however, the establishment of forest plantations had become the dominant objective wherever agroforestry was being utilized as a system of land management. This change of emphasis was not, at first, deliberate. It began fortuitously enough in a far-flung outpost of the British Empire. In 1806, U Pan Hle, a Karen in the Tonze forests of Thararrawaddy Division in Burma, established a plantation of teak through the use of what he called the "taungya" method† and presented it to Sir Dietrich Brandis. Brandis is alleged to have prophesied that "this, if the people can ever be brought to do it, is likely to become the most efficient way of planting teak" (Blanford 1958).

The taungya system spread to other parts of Burma, Schlich recording in 1867 that he had been shown a taungya teak plantation in its second year in the Kabaung forests of the Taungoo Division.

From these beginnings, the practice became more and more widespread. It was introduced into South Africa as early as 1887 (Hailey 1957) and was taken from Burma to the Chittagong area in India in 1890 and to Bengal in 1896 (Raghavan 1960).

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* One of the first definitions of agroforestry reads as follows: "Agroforestry is a sustainable land management system which increases the yield of the land, combines the production of crops (including tree crops) and forest plants and/or animals simultaneously or sequentially on the same unit of land, and applies management practices that are compatible with the cultural practices of the local population" (King and Chandler 1978; Bene *et al.* 1977). (See the following chapter for a discussion on the definition of agroforestry.)

† Taungya is a Burmese word which literally means hill cultivation (*taung* – hill, *ya* – cultivation).

It must not be imagined that, once introduced, the system was practised continuously in India. It was abandoned both in Bengal and in the Chittagong, and was not resumed until 1908 and 1912, respectively. In the second decade of the twentieth century, however, the system became more and more popular with foresters as a relatively inexpensive method of establishing forests, and as Shebbeare (1932) puts it, it "became a full and rising flood". In 1920 it was adopted in Travancore (now Kerala), in 1923 in the United Province (now Uttar Pradesh), and in 1925 in the Central Provinces (now Madhya Pradesh) (Raghavan 1960).

This period also saw its wider dispersal in Africa, and today it is practised in varying degrees in all the tropical regions of the world.* Teak is, of course, not the only forest species which is being established by the use of this agroforestry method. Indeed, the evidence suggests that if the system is utilized for the sole purpose of establishing forest plantations, that is only until the first closure of the forest canopy is attained, then it may be used in the establishment of forest plantations of most species.

It cannot be overemphasized, however, that for more than a hundred years, in the period 1856 to the mid-1970s, little or no thought appears to have been given, in the practice of the system, to the farm, to the farmer, and to his agricultural outputs. The system was designed and implemented solely for the forester. Indeed, some have asserted that in many parts of the world local farmers were exploited in pursuit of the goal of establishing cheap forest plantations (King 1968). Be that as it may, it was often stated that the socio-economic conditions that were necessary for the successful initiation of the system were land hunger and unemployment. It was sometimes said that another essential prerequisite was a standard of living which was low enough to border on poverty.

It is perhaps not surprising that nowhere in the relatively extensive literature which relates to this period are the positive soil-conservation aspects of the system mentioned, let alone emphasized. As the sole purpose of the exercise was to establish forests (which it was thought protected soils by their very existence), and as it was the undoubted policy of most forestry administrations

---

* The terms used to describe the system vary enormously. In German-speaking countries it is called *baumfeldwirtschaft brandwirtschaft*, or *waldfeldbau*. In francophone countries it is referred to as *cultures sylvicole et agricole combinées, culture intercalaires, méthode sylvo agricole, système sylvo-bananier, plantation sur culture*, etc. The Dutch name is *Bosakkerbouw*. In Puerto Rico it is called the *parcelero* system, and in Brazil *consorciacao*. The name in Libya is *tahmil*, in the Philippines *kaingining*, in Malaya *ladang*, in Kenya the *shamba* system, in Jamaica *agricultural contractors' system* in Sri Lanka *chena* and in Tanzania the *licensed cultivator system*. In India it is variously described as *dhya, jhooming, kumri, punam, taila*, and *tuckle*. In the greatest number of countries in the world it is called taungya. In 1968, King (1968) suggested that the genetic term "agrisilviculture" be generally employed. From 1977, when the deliberations for establishing the International Council for Research in Agroforestry began, the term agroforestry began to become popular.

to remove the farmer from the forest estate as soon as possible, the problems of man-induced soil erosion did not loom large in the thought processes of those tropical foresters who were involved with the system.

In order to fully appreciate the implications of this state of affairs, four factors must be clearly understood. First, it was considered that the forest estate should be inviolable. Secondly, it was perceived that the threat to the forest estate came mainly from peasants, particularly those who practised shifting cultivation. Thirdly, it was recognized that in many instances it would be advantageous to replace derelict or low-yielding natural forests with forest plantations. And fourthly, it had been demonstrated that the establishment of forest plantations was a costly business, especially because of their long gestation period, i.e., the long delays before returns were obtained from the initial investment.

So the ruling philosophy was to establish forest plantations whenever possible through the utilization of available unemployed or landless labourers. These labourers, in return for the forestry tasks which they were called upon to undertake, would be allowed to cultivate land between the rows of the forest-tree seedlings and would be permitted to retain their agricultural produce. This is, of course, a simplification of a system which varied from country to country and from locality to locality. Nevertheless, it is a fair representation of its bare bones.

As a result of these preoccupations with the forests and the forest estate, the research which was undertaken was designed to ensure that little or no damage occurred to the forest-tree species; that the rates of growth of the forest-tree species were not unduly inhibited by competition from the agricultural crop; that the optimum time and sequence of planting of either the tree or agricultural crop be ascertained in order to ensure the survival and rapid growth of the tree crop; that forest species that were capable of withstanding competition from agricultural species be identified; and that the optimum planting-out espacements for the subsequent growth of the tree crop be ascertained.

In short, the research which was conducted was undertaken for forestry by foresters who, it appears, never envisaged the system as being capable of making a significant contribution to agricultural development, and indeed of becoming a land-management system (as opposed to a narrow forestry system) in its own right.

It would appear at first glance that a quite disparate set of factors has contributed to the now general acceptance of agroforestry as a system of land management that is applicable both in the farm and in the forest. Among these factors were re-assessment of the development policies of the World Bank by its President, Robert McNamara; a re-examination by the Food and Agriculture Organization of the United Nations of its policies pertaining to forestry; the establishment by the International Development Research Centre

(IDRC) of a project for the identification of tropical forestry research priorities; a re-awakening of interest in both intercropping and farming systems; the deteriorating food situation in many areas of the developing world; the increasing spread of ecological degradation; and the energy crisis.

At the beginning of the 1970s, serious doubts were being expressed about the relevance of current development policies and approaches. In particular, there was concern that the basic needs of the poorest of the poor, especially perhaps the rural poor, were neither being considered nor adequately addressed. McNamara (1973) had stated the problem quite clearly:

> Of the two billion persons living in our developing member countries, nearly two-thirds, or some 1.3 billion, are members of farm families, and of these are some 900 million whose annual incomes average less than $100 . . . . for hundreds of millions of these subsistence farmers life is neither satisfying nor decent. Hunger and malnutrition menace their families. Illiteracy forecloses their futures. Disease and death visit their villages too often, stay too long and return too soon.
>
> The miracle of the Green Revolution may have arrived, but, for the most part, the poor farmer has not been able to participate in it. He cannot afford to pay for the irrigation, the pesticide, the fertiliser, or perhaps for the land itself, on which his title may be vulnerable and his tenancy uncertain.

It was against this backdrop of concern for the rural poor that the World Bank actively considered the possibility of supporting nationally oriented forestry programmes. As a result, it formulated a new Forestry Sector Policy paper which is still being used as the basis for much of its lending in the forestry sub-sector. Indeed, its social forestry programme, which has expanded considerably over the last decade or so, not only contains many elements of agroforestry but is designed to assist the peasant and the ordinary farmer to increase food production and to conserve the environment as much as it helps the traditional forest services to produce and convert wood (see, for example, Spears 1987).

It is perhaps not unnatural that, on the appointment in 1974 of a new Assistant Director-General with responsibility for forestry, FAO made a serious assessment of the forestry projects which it was helping to implement in the developing countries, and of the policies which it had advised the Third World to follow. It soon became clear that although there had been notable successes there also had been conspicuous areas of failure. As Westoby (1978) so aptly expressed it:

> Because nearly all the forest and forest industry development which has taken place in the underdeveloped world over the last decades has been externally oriented . . . the basic forest products needs of the peoples of the underdeveloped world are further from being satisfied than ever . . . .

> Just because the principal preoccupation of the forest services in the underdeveloped world has been to help promote this miscalled forest and forest industry development, the much more important role which forestry could play in supporting agriculture and raising rural welfare has been either badly neglected or completely ignored.

FAO therefore redirected its th. ~t and assistance in the direction of the rural poor. Its new policies, while not abandoning the traditional areas of forestry development, emphasized the importance of forestry for rural development, the benefits which could accrue to both the farmer and the nation if greater attention was paid to the beneficial effects of trees and forests on food and agricultural production, and advised land managers in the tropics to "eschew the false dichotomy between agriculture and forestry" (King 1979). They also stressed the necessity of devising systems which would provide food and fuel and yet conserve the environment.

As a result of this change in policy, FAO prepared a seminal paper "Forestry for Rural Development" (FAO 1976) and, with funding from the Swedish International Development Authority (SIDA), organized a series of seminars and workshops on the subject in all the tropical regions of the world, and formulated and implemented a number of rural forestry projects throughout the developing world. In these projects, as with the World Bank's social forestry projects, agroforestry plays a pivotal role (Spears 1987). FAO also utilized the Eighth World Forestry Congress, which was held in Jakarta, Indonesia, in 1978, to focus the attention of the world's leading foresters on the important topic of agroforestry. The central theme of the Congress was "Forests for People", and a special section was devoted to "Forestry for Rural Communities".

To these two strands of forest policy reforms, which evolved independently in an international funding agency and in one of the specialized agencies of the United Nations, was added a Canadian initiative which, some affirm, might transform tropical land use in the coming years.

In July 1975 the International Development Research Centre commissioned John Bene to undertake a study to:

1. Identify significant gaps in world forestry research and training;
2. Assess the interdependence between forestry and agriculture in low-income tropical countries and propose research leading to the optimization of land use;
3. Formulate forestry research programmes which promise to yield results of considerable economic and social impact on developing countries;
4. Recommend institutional arrangements to carry out such research effectively and expeditiously; and
5. Prepare a plan of action to obtain international donor support.

Although the initial assignment stressed the identification of research priorities in tropical forestry, Bene's team came to the conclusion that first priority should be given to combined production systems which would integrate forestry, agriculture and/or animal husbandry in order to optimize tropical land use (Bene *et al.* 1977). In short, there was a shift in emphasis from forestry to broader land-use concepts because the latter were perceived as being of both more immediate and long-term relevance.

How was the agroforestry research that was proposed by Bene and his team to be undertaken? Bene and his colleagues stated in the report:

> It is clear that the tremendous possibilities of production systems involving some combination of trees with agricultural crops are widely recognized, and that research aimed at developing the potential of such systems is planned or exists in a number of scattered areas. Equally evident is the inadequacy of the present effort to improve the lot of the tropical forest dweller by such means.
>
> A new front can and should be opened in the war against hunger, inadequate shelter, and environmental degradation. This war can be fought with weapons that have been in the arsenal of rural people since time immemorial, and no radical change in their life style is required. This can best be accomplished by the creation of an internationally financed council for research in agroforestry, to administer a comprehensive programme leading to better land-use in the tropics.

It was apparent that, despite the growing awareness of the need for factual information on which agroforestry systems might be effectively based, very little research was being undertaken. The research that was being conducted was haphazard, unplanned and unco-ordinated. The IDRC Project Report therefore recommended the establishment of an internationally financed organization, now known as the International Council for Research in Agroforestry (ICRAF), which would support, plan and co-ordinate, on a world-wide basis, research in *combined* land-management systems of agriculture and forestry. This proposal was generally well received by international and bilateral agencies and, subsequently, ICRAF was established in 1977. Thus agroforestry – an old practice – was institutionalized for the first time.

At the same time as these hectic institution-building activities were being undertaken, there was renewed and heightened interest in the concepts of intercropping and integrated farming systems. It was being demonstrated, for example, that intercropping may have several advantages over sole cropping. Preliminary results from research that was being conducted in different parts of the world had indicated that in intercropping systems more effective use was made of the natural resources of sunlight, land and water; that intercropping systems might exercise beneficial effects on pest and disease problems;

that there were advantages in growing legumes and non-legumes in mixture; and that, as a result of all this, higher yields were being obtained per area even when multi-cropping systems were compared to sole cropping systems. And it became obvious then that although a great deal of experimentation was being carried out in the general field of intercropping, there were many gaps in our knowledge. In particular, it was felt that there was need for a more scientific approach to intercropping research, and it was suggested that there should be greater concentration on crop physiology, agronomy, yield stability, nitrogen fixation by legumes, and plant protection. Concurrently, the International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria, was extending its work on farming systems to include agroforestry, and many research organizations had begun serious work on, for example, the integration of animals with plantation tree crops such as rubber, and the intercropping of coconuts (Nair 1979).

This congruence of men and of concepts and of institutional change provided the material and the basis for the development of agroforestry since then. Although many individuals and institutions have made valuable contributions to the understanding and expansion of the concept of agroforestry since the 1970s, it is perhaps true to assert that ICRAF has played the leading role in collecting information, conducting research, disseminating research results, pioneering new approaches and systems, and in general, by the presentation of hard facts, in attempting to reduce the doubts still held by a few sceptics.

Today, agroforestry is taught as a part of forestry and agriculture degree courses in many universities in both the developing and developed world, and specific degrees in agroforestry are already offered in a few. Today, instead of agroforestry being merely the handmaiden of forestry, the system is being more and more utilized as an *agricultural* system, particularly for small-scale farmers. Today, the potential of agroforestry for soil conservation is generally accepted. Indeed, agroforestry is fast becoming recognized as a system which is capable of yielding both wood and food and at the same time of conserving and rehabilitating ecosystems.

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2. Agroforestry defined

P.K.R. NAIR

As described in the previous chapter, agroforestry (AF) is a relatively new name for a set of old practices. The word and concept attained some acceptability in international land-use parlance after encountering more than its share of difficulty and time lag before becoming accepted among the community of experts both as a word and a concept. Undoubtedly a lot of ambiguity and confusion as to "what is AF?" existed in the minds of even those people who were supposed to be knowledgeable about AF in the late 1970s and early 1980s. Perhaps as a manifestation of this, most of the writings on agroforestry during this period contained at least one definition and often some imaginative and fascinating elucidations of the concept of agroforestry. The situation was reviewed in an editorial, appropriately titled "What is agroforestry", in the inaugural issue of *Agroforestry Systems* (Vol. 1, No. 1, pp. 7–12; 1982). A random selection of the definitions of agroforestry proposed by various individuals was included in this editorial, and these are reproduced below with permission:

1. Agroforestry is a land-use system that involves socially and ecologically acceptable integration of trees with agricultural crops and/or animals, simultaneously or sequentially, so as to get increased total productivity of plant and animal in a sustainable manner from a unit of farmland, especially under conditions of low levels of technology inputs and marginal lands (P.K.R. Nair, ICRAF).
2. Agroforestry is a sustainable land-management system which increases the overall yield of the land, combines the production of crops (including tree crops) and forest plants and/or animals simultaneously or sequentially, on the same unit of land, and applies management practices that are compatible with the cultural practices of the local population (K.F.S. King and M.T. Chandler, ICRAF).
3. Agroforestry is a form of land use that successfully satisfies the needs of the crop farmer, forester and/or stock farmer (K.G. Mafura, Lesotho).
4. Agroforestry is any land-use system that:

   Provides fuel as well as tree/shrub products (or the environmental benefits that may accrue from growing trees/shrubs);
   Involves multiple mixed or zonal cropping, with or without animal production, in which woody perennials are grown for more than one

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purpose together with herbaceous crops or grasses. Through these combinations agroforestry aims to:

> Maximize use of radiant energy, minimize losses of plant nutrients in the system, as well as optimize water-use efficiency and minimize run-off and soil loss. Thus it retains any benefits in these respects that may be conferred by woody perennials compared with conventional agricultural crops, and so maximizes total output of benefits from the land whilst conserving and improving it (P.A. Huxley, ICRAF).

5. Agroforestry is not any one system, but a principle common to many potential and existing systems which:

   - Display ecological and economical durability by virtue of their biological architecture including short-cycle plants, long-cycle plants and animals;
   - Warrant social acceptability by breaking up long-term ecological cycles in a sequence of easy-to-understand daily and seasonal activities, moulded upon local tradition but conceived so as to increase efficiency;
   - Aim at complete use of all inorganic resources in all available niches for useful plants and animals, as long as recycling of these resources is maximized;
   - Diminish risks for the individual farmer by means of a wide variety of useful plant and animal species enlarging the range of products, providing a self-protecting system and enhancing the quality of the daily environment (R.A.A. Oldeman, The Netherlands).

6. Agroforestry is a land use system (a) in which woody perennials and herbaceous crops are grown together in mixtures, zonally and/or sequentially, with or without animals, and (b) which provides greater benefits for the land use than agriculture or forestry alone, including one or more of the following: sustained soil fertility, soil conservation, increased yield, diminished risk of crop failure, ease of management, pest and disease control, and/or greater fulfilment of the socio-economic needs of the local population (Melvin G.R. Cannell, United Kingdom).
7. Agroforestry is the growing of trees in combination or in sequence with agricultural crops and/or pastures on small holdings or large estates. It is not synonymous with community forestry but is often an appropriate means of implementing a community forestry project (Laurence Roche, United Kingdom).
8. Agroforestry:

   1. The art, and eventually, the science of combining herbaceous crops and/or animals with trees on the same unit of land in order to optimize multi-purpose production and put it on a sustainable yield footing.

2. A new scientific paradigm which has arisen to fill the gap created by the time honoured separation of agriculture and forestry.
3. Any hybrid land-use system spawned by the unbridled interaction of agriculture, forestry and allied disciplines (J.B. Raintree, ICRAF).

9. Agroforestry systems are comprised of tree and non-tree components grown in close association. Their objective is the maximization of the long-term yield of desired products. Yield is generally drawn from both tree and non-tree components, directly or indirectly via grazing animals, although on occasions one component, generally the tree, may be included only to improve the performance of the other. The essential feature of these systems is the close interaction, competitive or complementary, between the tree and the non-tree components. The contrasts between the components in their physical dimensions, their life span and their physiological responses provide additional complexity which sets these associations aside from the general concerns of either forestry or agronomy (D.J. Connor, Australia).
10. Agroforestry is not a new enterprise since it has been practised under different conditions and in diverse locations for more than a century. The system originated with the Burmese hill-farming experience using teak as the forest crop. Since then, the system, though called by different names, has spread throughout Asia, and to Africa and Latin America. The basic conditions that favour its adoption are those of unemployment and shortage of farmlands. However, over the last two decades during which critical political decisions have had to be made under severe socio-economic climate, agroforestry has become increasingly popular, not merely as a regeneration technique but increasingly as a comprehensive rural development programme. The tremendous employment opportunities generated as well as the social infrastructures and multiple effects thereof have enhanced the popularity of the scheme. The real increase in the quantity and variety of foodstuffs due to agroforestry in addition to its role in soil rehabilitation and in conjunction with other land-use agents are now widely recognized. The potentialities of agroforestry compel a land-use management which eschews the false dichotomy of agriculture and forestry which conserves the ecosystem, and which at one and the same time provides food and wood. Therefore, there is an urgent need for a new cadre of forest managers not only trained in multiple production systems but also fully aware of the significant role of the pertinent socio-economic inputs. The future of agroforestry is intimately related to the development of appropriate expertise and implementation techniques (S. Kolade Adeyoju, Nigeria).
11. The term "agroforestry" covers a variety of land-use systems combining forestry with agriculture or range management on the same land.

Agroforestry aims at solving problems of rural development, predominantly in the tropics, by:

- Increasing and improving the yields of food production;
- Safeguarding local energy supply;
- Production of timber and a variety of other raw materials for the farmer's subsistence, for industrial use and – if applicable – exports;
- Protection and improvement of the production potential of a given site and environment; increasing the human-ecological carrying capacity;
- Safeguarding sustainability through appropriate intensification of land use;
- Improving social and economic conditions in rural areas by creation of jobs and income and reduction of risks;
- Development of land-use systems which make optimal use of modern technologies and traditional local experience and which are compatible with the cultural and social life of the people concerned (H.-J. von Maydell, FRG).

12. Agroforestry denotes systems of land management which involve the use of trees and shrubs in combination with agricultural food or fodder crops and livestock and are designed to promote output of usable products, and to maintain or improve the productivity of the soil.

In its narrow sense, agroforestry refers to systems in which trees and agricultural crops including pastures and range species are grown simultaneously, in relay, or sequentially on the same piece of land and used for a range of purposes.

In its wider sense, agroforestry develops the concept of using trees as a component of the overall management of land resources to meet the needs of the people for food, fuel, shelter and income. The systems used need to be socially, culturally and economically acceptable, to maximize total output at given inputs levels, and to minimize damage to the total environment.

In agroforestry, all trees and shrubs are regarded as crops and their mananagement varies according to their main uses and the needs of the associated plants and animals. For the traditional agriculturalist, agroforestry corrects a long-time neglect of trees as soil improvers, soil protectors, producers of fodder, food, fuel wood, timber and other useful products. For the forester, agroforestry corrects a long-time lack of intimate concern for the welfare of rural people as distinct from guarding and managing forest resources "for the benefit of society".

Agroforestry in its applied aspects is a set of management techniques combining elements of agronomy, animal production and silviculture with

those arising from the interaction of plant and animal species of different sizes, growth patterns and requirements.

Agroforestry is a complex applied science requiring knowledge of the environment, agriculture, forestry and people. Although much is known about the components individually, relatively little is known about the interactions between them apart from largely empirical observations. Hence, existing knowledge needs to be examined afresh and new knowledge sought on the interactions between the components. Agroforestry thus provides an important additional dimension to the scientific approach to natural resources management (R.B. Contant, ISNAR).

In summarizing the above definitions, B. Lundgren of ICRAF stated that:

There is a frequent mixing up of *definition*, *aims* and *potentials* of agroforestry. It is, for example, rather presumptious to *define* agroforestry as a successful form of land use which achieves increased production and ecological stability, etc. We may indeed *aim* for this, and in many ecological and socio-economic settings agroforestry approaches have a higher *potential* to achieve this than most other approaches to land use. But, with the wrong choice of species combinations, management practices and lack of peoples' motivation and understanding, agroforestry may indeed fail just like any other form of land use may fail, and it will still be agroforestry in the objective sense of the word.

A strictly scientific definition of agroforestry should stress two characteristics common to all forms of agroforestry and separate them from other forms of land use, namely:

- The *deliberate* growing of woody perennials on the same unit of land as agricultural crops and/or animals, either in some form of spatial mixture or in sequence;
- There must be a *significant interaction* (positive and/or negative) between the woody and non-woody components of the system, either ecological and/or economical.

When promoting agroforestry one should then stress the potential of it to achieve certain aims, not only by making theoretical and qualitative remarks about the benefits of trees, but also, and more importantly, by providing quantitative information.

These ideas of B. Lundgren were later refined through "in-house" discussions in ICRAF, and the following definition was suggested:

Agroforestry is a collective name for land-use systems and technologies where woody perennials (trees, shrubs, palms, bamboos, etc.) are deliberately used on the same land-management units as agricultural crops and/or animals, in some form of spatial arrangement or temporal sequence. In agroforestry systems there are both ecological and economical interactions between the different components (Lundgren and Raintree 1982).

This definition implies that:

1. AF normally involves two or more species of plants (or plants and animals), at least one of which is a woody perennial;
2. An AF system always has two or more outputs;
3. The cycle of an AF system is always more than one year; and
4. Even the most simple AF system is more complex, ecologically (structurally and functionally) and economically, than a monocropping system.

Although this definition may not be "perfect" in all respects, it became increasingly used in the publications from ICRAF and thus achieved wide acceptability.

In the meanwhile, the surge of enthusiasm for defining AF has subsided. The concepts and principles of AF have been well elucidated in several publications from ICRAF and other organizations, and, equally importantly, its limitations also have been more and more appreciated. Thus, agroforestry is no longer a "new" term. It is widely accepted as an approach to land use involving deliberate admixture of trees with crops and/or animals.

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Part 2

Agroforestry systems inventory

3. ICRAF's Agroforestry Systems Inventory project

P.K.R. NAIR

In order to increase understanding about existing agroforestry systems in the tropics and subtropics, ICRAF undertook an inventory of AF systems. Known as the Agroforestry Systems Inventory (AFSI), the project was in operation for five years from September 1982, with partial financial assistance from the US Agency for International Development (USAID).

Rationale and purpose

The rationale for undertaking the inventory was that although agroforestry was said to be one of the oldest land-use systems in the world, the information base on these systems had been very unsatisfactory. For example, a survey on "agroforestry" undertaken as a pre-establishment activity before ICRAF was formally established focused only on "agri-silviculture" in general and taungya in particular. Some regional and international conferences organized in the late 1970s and early 1980s brought together substantial amounts of information on existing agroforestry systems. Notable among these were:

1. The Workshop on Agroforestry Systems in Latin America, CATIE, Turrialba, March 1979 (de las Salas 1979);
2. The International Conference on International Co-operation in Agroforestry, ICRAF, Nairobi, July 1979 (Chandler and Spurgeon 1979);
3. The Kenya National Seminar on Agroforestry, ICRAF, Nairobi, November 1980 (Buck 1981);
4. The Workshop on Agroforestry in the African Humid Tropics, IITA, Ibadan, Nigeria, April 1981 (MacDonald 1982); and
5. The Workshop on Agroforestry in the Pacific, Suva, Fiji, March 1982 (Schirmer 1982).

(See Nair 1987b for details of other workshops, seminars and conferences organized by ICRAF.)

Nevertheless, most of this information had been limited to descriptive and qualitative accounts. The accounts were not collected or organized according to any uniform framework and format, so that it was not possible to compare, collate, synthesize and evaluate them uniformly. It was not known whether they had reached their maximum operating potential, whether they were disappearing as a result of increasing population pressure or other factors, or

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if they could be improved and extended to other situations. In order to address these issues and provide ideas for innovations which could make these systems more productive and more protective of the environment, as well as make the localized systems more widely adoptable, a basic knowledge of the existing agroforestry systems presented in a uniform format was required.

The inventory was also critical to the success of the majority of ICRAF's other programmes in that it was intended to fulfil one of the three overall objectives of ICRAF's work, namely, the development of a problem-oriented interdisciplinary capacity and methodology to assess constraints in land-use systems and to identify agroforestry potentials in these systems.

Thus the purpose of the AFSI project was to systematically collect data on important and promising agroforestry systems throughout the developing world in order to bring relevant information on these systems together for evaluation and dissemination. It was also envisaged that, based upon this information, research and development priorities would be identified and a systems register and data bank established to record and update global statistics and trends in agroforestry.

Objectives and methods

In order to accomplish this task, the objectives of the inventory were set as:

1. To assemble and catalogue information on the functioning of different agroforestry systems around the world;
2. To evaluate this information in order to identify the weaknesses and constraints of the systems, as well as their potential for improvement and wider applicability;
3. To identify research topics for overcoming the constraints and improving the systems;
4. To establish an agroforestry-systems register and data bank to record and update global statistics on trends in agroforestry; and,
5. To disseminate as much quantitative and descriptive information as possible on world-wide agroforestry practices for the use of researchers and development workers.

The method of the inventory consisted of:

1. Data collection through the collective efforts of ICRAF and a group of qualified Regional Co-ordinators (one in each of the seven designated geographical regions)* and other individual and institutional contacts as well as through field visits, mail survey, literature search, etc.;

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* The geographic regions were: the Pacific, Southeast Asia, South Asia, Mediterranean and the Middle East, East and Central Africa, western and southern Africa, and the American tropics.

2. Evaluation of the primary data and step-by-step synthesis of the data into a more homogenous format, and eventual computerization and storage of the data; and
3. Periodic publication of salient results of the inventory.

The major inventory instruments were the following:

1. An AFSI questionnaire (primary data collection format) was finalized in the first Project Planning Meeting held in Nairobi, in December 1982, attended by all the then-identified Regional Co-ordinators, a data evaluation consultant and ICRAF staff. This formed the basic survey instrument, and it was distributed world-wide. It is given as Appendix 3.1 to this chapter.
2. The primary data obtained for different systems were quite variable in quality and content depending on the diversity of the conditions in which the systems exist, the extent of the system's development and therefore data availability, and above all, the various types of personnel involved in data gathering. In order to narrow down these differences and make the data sheets more homogeneous, a secondary data format was devised, and the primary data, after initial evaluation, were transferred to this secondary format. A copy of the secondary format is attached as Appendix 3.2.
3. A computer program (data base) for storing system data (system register). This was developed and made operational in mid-1985.
4. A format for system descriptions for journal publication of prominent and promising AF systems (since 1984).

The project was widely publicized through individual contacts and announcements in various international journals.

Salient outputs and results

The major documented results of the inventory are the various publications by the project staff and the computerized Agroforestry Systems Register. The publications include the AF System Description Series and other miscellaneous papers. The former consist of a series of concise descriptions of prominent and promising AF systems that exist in various parts of the world, authored by experienced experts from the respective regions, and published serially in *Agroforestry Systems* since early 1984. These system descriptions form the major part of this book (Parts 3, 4 and 5). The miscellaneous publications include various conference papers, book chapters and journal articles (Nair 1987a), and their salient contents have been included in Parts 2 and 6 of this book.

The AF Systems Register consists of a computerized database, built up after repeated evaluation of the inventory data on systems (Oduol *et al.* 1988). It contains data entries on over 150 systems from various geographical and ecological regions, and each entry consists of information (as much as is available) on the general background and ecological aspects, components and their management, socio-economic aspects, and an assessment of the system's merits, weaknesses and research needs. The register allows easy retrieval of the information on any of these aspects. Some examples of the system data files in the AF Systems Register and lists of woody and herbaceous species identified as components of different agroforestry systems are included as Appendices to this book (pp. 619–659).

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Appendix 3.1

ICRAF'S GLOBAL INVENTORY OF AGROFORESTRY SYSTEMS

Data Collection Guidelines

I. General considerations on data collection

1. The scope of the exercise is to have a reconaissance, state-of-the-art, description of the existing agroforestry systems around the world. The data collection has, therefore, to be organized to fulfill this objective.
2. It is expected that professionals at various levels will be involved in the data collection exercise. But it is important that the surveyors have a reasonably acceptable level of understanding of the concepts and practices of land use systems in general and agroforestry in particular.
3. A definition of agroforestry that can be used for the purpose of data collection is: "Agroforestry is a collective name for land use systems in which woody perennials are deliberately grown in the same piece of land as agricultural crops and/or animals, either in some form of spatial arrangements or in sequence. In agroforestry systems, the woody component interacts ecologically and economically with the crop and/or animal components. Such interactions will take many different forms, both positive and negative, and they need not remain stable over time.

   The aim and rationale of most agroforestry systems are to optimize the positive interactions in order to obtain a higher total, a more diversified and/or a more sustainable production from the available resources than is possible with other forms of land use under prevailing ecological, technological and socio-economic conditions."

   The underlying principles and concepts of agroforestry rather than a definition *per se* should be the main consideration. Thus, a general criterion could be that any multiple land use system, in which woody perennials constitute one of the discernible components by performing a clearly distinguishable function can be considered agroforestry for the purpose of this project. Here again, it is up to the technical discretion of the individuals who collect the data to set the limits and criteria to decide which of the practices can be included in this project.

4. The enclosed data collection format provides a general framework for the survey. It consists of three parts: the first one is intended to assemble general description of the area and other background information that are relevant to a description of dominant "agroforestry" systems and practices: the second deals with describing the structure, performance, dynamics, socio-economics and other operational features of the identified systems and practices in as much detail as possible with emphasis on quantitative data; and the third part aims at an analysis of the system in terms of its merits, constraints, weaknesses, extrapolability, potentials for improvements, research needs, etc. However, since the type of information to be gathered and the nature of questions to be addressed to accomplish the task will vary depending upon a number of local factors, the surveyors are free to deviate from the format as deemed necessary. The questionnaire may be considered as a purely explanatory guide to prepare an account of the system/practice that is being described.
5. The data collection format may appear to be rather exhaustive, and it may not be possible to get answers, especially in quantitative terms, to all questions that are posed. However, answers to all points may not be necessary to prepare an overview of the system.
6. A flexible procedure may be adopted also for classifying the systems. Several criteria could be used, for example: the role or function of woody perennials in such systems, proportion of land used by the woody components, type of output, level of management, temporal and spatial admixture pattern of components, etc. But the lack of a unified classification system should not be a major problem in the early data collection phase, and the strategy should be to collect all possible information on all types of agroforestry systems and practices that are currently being practised or tried.
7. The size of the basic data collection unit is yet another issue to be considered, if not resolved. Since the project's objective is to collect a comprehensive account of the systems, rather than aiming at in-depth studies or farm-to-farm surveys on any particular system or sub-system, it can be contended that the basic unit should be broad enough to substantiate the prevalence of the practice over a reasonable extent of area. Moreover, the boundaries of the system will also vary depending upon the question that is being addressed. For example, for the general description of the background information, the boundary will be the whole locality or area where the system is practised. On the other hand, for answering specific questions relating to an operational unit, the boundaries will refer to those of the farm or the field that constitutes such a basic unit. Again, the prudence and discretion of the persons who collect the data will be the major decisive factors in this respect.
8. The purpose of system descriptions is not necessarily to compare one system with another. Therefore the approach should be to give physical

and quantitative data (to the extent possible) than to engage in comparative narrations.

II. Data collection format

Part I

Background information

This refers to a locality or sub-region where agroforestry-type land use systems and practices are known to exist. A general account of the location may be given on the following aspects with a view to concentrating on agroforestry systems/practices and describing them in more detail as outlined in the later sections.

1.1. *Description of the area/region*

1.1.1. Geographic
Country
Province
District/Location
Altitude
Latitude(s)
Longitude(s)
Other description

1.1.2. Biophysical environment
1.1.2.1. Climatic (rainfall pattern, temperature regimes, other distinct climatic features).
1.1.2.2. Edaphic factors (soil types, topographic patterns).
1.1.2.3. Ecology (climax vegetation, distinct ecological features).

1.2. *Land use systems*
(Give general but brief descriptions of the major land use systems of the locality.)

1.2.1. Agriculture (general situation, major crops, cropping systems, livestock production system).

1.2.2. Forestry (natural forests, plantation forestry, social forestry, farm forestry).

1.2.3. Commercial production systems

1.2.4. Integrated production systems

1.3. *Agroforestry-type systems/practices*
Give brief and general account of the currenty practised land use systems and practices that have relevance to agroforestry; detailed description of the systems to be given in later sections.

- Shifting cultivation
- Taungya
- Farm forestry
- Smallholder plantation crop production systems
- Tree integration on farmlands
- Silvopastoral
- Shelterbelts
- Others

Part II

System description

This part may be completed separately for each of the major identified agroforestry-type land use system/practice within each locality/subregion.

NAME: (Give an abstract or descriptive name of the system/practice.)

2.1. *Additional baseline data*

2.1.1. Environment (agro-ecological zone, special soil/climate/topography conditions/other distinct features).

2.1.2. Socio-economic characteristics

- Size of the management unit (range as well as mean)
- Approximate area and number of people involved in/supported by the system/practice
- Land tenure system
- Demographic factors
  Population density, land pressure (number of people or families per unit of cultivable land), migration patterns, sex ratio, etc.
- General level of farming/development activities
- Marketing facilities (excellent/good/fair/poor)
- Credit facilities (excellent/good/fair/poor)

- Roads and other infrastructure (remoteness of the area) (excellent/good/fair/poor)
- Cooperatives (excellent/good/fair/poor)
- Other special socio-economic features, if any

2.2. *Structure of the system*
(This will essentially refer to the basic (representative) agroforestry unit – a farm or a field.)

2.2.1. Biological components of the system
2.2.1.1. Crops (species, varieties, their management aspects, number of crops per year, cropping pattern/rotation/mixture).
2.2.1.2. Trees and other woody perennials (species, varieties, products, tree management, average life cycle of the tree as well as its production cycle within years/seasons).
2.2.1.3. Other plant species (including weeds) that are dominant or have a useful function.
2.2.1.4. Animals (type and role, number per farm/family, feeding pattern)

2.2.2. Arrangements of components

- in time } describe with the example of a farm/field
- in space }
- (number of components, admixture pattern)

2.2.3. Interactions (in time, or space)

- Nature of interactions

e.g. – direct (fodder trees for cattle)
– cyclic (crop residues for cattle)
– competitive (crops vs trees)
– others

- Easily recognizable interaction effects

2.3. *System functioning*

2.3.1. Resource input and utilization
2.3.1.1. Quantity
- Give a general account of the resources (land, labour, capital (?) and others) that are used – their nature, quantity, utilization aspects with respect to time within a year/seasons, etc.

2.3.1.2. Pattern

- Availability and supply pattern, bottlenecks, etc.

2.3.1.3. Sources of inputs

- Source of seeds, fertilizers, etc., inputs from outside the system (e.g. seeds, fertilizer, animals), price data of inputs and source of information, power sources (animals/mechanical tractor).

2.3.2. Production

2.3.2.1. Quantity

(quantities on the basis of average farm of given size)

- Agricultural commodities, fodder and other feeds for cattle, fuelwood (firewood/charcoal), poles, timber, honey, etc.

2.3.2.2. Pattern

- Seasonality, variability (season-to-season/year-to-year), efficiency of production (input-output relationships for the scarcest resource?), production for home consumption versus market economy (export).

2.3.3. Protective and service aspects of the system

Specify any effects on:

- Soil improvement, soil productivity, soil conservation, microclimate amelioration (windbreak/shelterbelt, shade, fencing, hydrological cycle/catchment area effect, other recognizable effects on farm/area basis).

2.3.4. Socio-economic description

- Capital peaks/availability, labour peaks/availability, cash-flow (input/output), family labour utilization pattern (male/female), impact of technological inputs (improved seeds, fertilizers, etc.), special note on the specific type of land use practices adopted by women, relations between specific ethnic groups and particular agroforestry practices.

2.3.5. Overall performance assessment

At this stage, a comparative assessment may be made of the functioning of the particular system in relation to other land use systems of the locality in terms of the production and protective/service role(s). It will be of particular significance to see what would be the condition of the management unit without the agroforestry component (which would be possible by comparison with similar units without agroforestry).

2.4. *System dynamics*

2.4.1. Rate of growth/shrinkage

Indicate the expansion/shrinkage of the system over time in terms of the area covered, and the reason for that.

2.4.2. Degradation of the system
- Case-history of the breakdown; main causal factors (erosion problem, soil fertility problem, weed infestation, overgrazing/desertification, others).

2.4.3. Improvement of the system
- Significant innovations for improvement of the system over the past few years.

2.4.4. System sustainability
- Productivity pattern over time
- Impact of technological inputs on productivity
- Rate of change of land's capability to sustain production at a certain level
- Effect of the rate of production on one component on that of other component(s).

2.4.5. Special features of the system
- Highlight any outstanding features of the system/practice (e.g. specific management aspects that can cause reduction of inputs, association of particular ethnic groups/races with a system, notable success stories, etc.
- Indicate special aspects of the system/practice that warrant detailed follow-up study.

2.4.6. Data/information base
- Past/present/future research on the system/practice, information sources on the system/practice, institutions and resource persons or relevance to system, etc.

Part III

Evaluation of the system

Based on the information gathered thus far, a preliminary evaluation of the system could be attempted.

3.1. *Merits of the system*

Conspicuous advantages of the system in its productive and/or protective functions. Give comparative figures if available.

Indicate the value of the system in the specific socio-economic and ecological situations where it is currently practised.

3.2. *Weaknesses*

What are the salient points of weakness

- Climatic
- Ecological
- Biological
- Socio-economic
- Managerial
- Socio-political

What effect does each of these have on the system's performance.

3.3. *Constraints*

What are the major constraints in the operation of the system

- Inherent weaknesses mentioned above
- Input constraints
- Infrastructural problems including markets, roads, etc.

3.4. *Potentials*

Reasonable expectations on potential accomplishment under different levels of input, ecological constraints, etc.

Potentials of non-monetary inputs (timely sowing, appropriate management system, judicious plant combinations, etc.).

Potentials for improvement in the performance of the system.

Potentials for manipulating the system/components to solve specific problems and meet particular needs such as soil conservation, food production, silvopastoral production, etc.

3.5. *Extrapolability*

What is the extrapolability rating of the system if it were to be tried in other areas with similar/dissimilar conditions, and what will be the degree of success under each?

What aspects of the system needs to be modified to make it widely extrapolable?

3.6. *Research needs*

Indicate the general areas of research at the system and the component levels in order to refine the system to make it more productive, protective, widely adoptable and efficient.

Appendix 3.2

AFSI DATA COLLECTION: SECONDARY FORMAT

ODENUMBER:

NAME OF SYSTEM:

AFSI REGION
S. Asia
S. E. Asia
Mediterranean
Sahel & S. Africa
American tropics
E. C. & W. Africa

COUNTRY:

REGION:

AREA

SITE:

LATITUDE
Lower
Upper

LONGITUDE
Lower
Upper

ALTITUDE:
Lower:
Upper:

LANDFORM:
No data
Steeply sloping:
Moderately sloping:
Gently sloping:
Depositional flat
Swamps:

SOIL CLASS:
No data
Latosols
Vertisols:
Calcimorphic soils
Desert soils
Saline or alkaline soils
Gleys, alluvial or peat
Shallow or immature
Temperate types

SOIL NAME:

RAINFALL REGIME:
No data
Unimodal, high sun
Unimodal, low sun
Bimodal
Uniform:

MEAN ANNUAL RAINFALL:
Lower:
Upper:

MEAN ANNUAL TEMPERATURE

Lower: (Month)

Upper: (Month)

GENERALIZED CLIMATE:
No data:
Humid tropics (Af, Am)
Subhumid tropics (Aw, Awz, Cw, Cw2)
Semi-arid (Bshw, Bsk)
Arid (Bwh, Bwk)
Humid subtropics (Cfa)
Mediterranean (Cs, Bshs)
Temperate maritime (Cfb)
Cool or cold (D, E)

KOPPEN CLIMATE:
No data
Humid tropics, permanent
Humid tropics, monsoon
Subhumid tropics, one wet
Subhumid tropics, two wet
Semi-arid, hot
Semi-arid, warm to cold
Arid, hot
Arid, warm to cold
Humid subtr & Montane humid
Temperate maritime
High subhumid, one wet
High subhumid, two wet
Mediterranean/subtr montane
Temp. cont. tr/subtr montane

NATURAL VEGETATION TYPE:
No data
Rainforest
Tropical seasonal forest
Savanna
Thorn scrub/woodland
Grassland
Semi-desert
Desert
Temp deciduous woodland
Coniferous woodland
Montane
Swamp

POPULATION DENSITY:

LAND AVAILABILITY:
No data
Abundant
Adequate
Limited
Scarce
None

COOPERATIVES
No data
Frequent
Present
Absent

INFRASTRUCTURE:
No data
Excellent
Fair
Good
Poor

MARKETING FACILITIES:
No data
Excellent
Fair
Good
Poor

CREDIT FACILITIES:
No data
Excellent
Good
Fair
Poor

ADDITIONAL INFORMATION:

LAND USE KEYWORDS:

No data	P D
Rotational	P D
Shifting Cultivation	P D
Fallow System	P D
Ley System	P D
Forest fallow	P D
Bush fallow	P D
Savanna fallow	P D
Grass fallow	P D
Unmanaged fallow	P D
Managed fallow	P D
Planted fallow	P D
Grazing systems	P D
Natural vegetation	P D
Managed planted veg	P D
Rangelands	P D
Pastures	P D
Leys	P D
Homestead	P D
Zero grazing	P D
Ranching	P D
Nomadism	P D
Extensive	P D
Intensive	P D
Plantation	P D
Shrub crops	P D
Tree crops	P D
Field crops	P D
Smallholding	P D
Estate	P D
Forestry	P D
Plantation	P D
Farm	P D
Natural	P D
Field cropping	P D
Rainfed	P D
Irrigated	P D
Complex cropping	P D
Mixed	P D
Intercropping	P D
Other:	P D

TECHNIQUES/AF KEYWORDS:
No data
Cover trees
Shade trees
Windbreaks
Soil conservation trees
Land reclamation trees
Live fences
Live stakes
Fuelwood trees lots
Fodder trees

Techniques af keywords (cont):
Green manuring with trees
Mulching with trees
Multipurpose trees
Taungya
Permanent cover crops
Planted bunds
Improved fallow
Forest garden
Mixed garden
Home garden
Tree garden
Agrosilviculture
Agrosilvopastoralism
Silvopastoralism
Aquasilviculture
Apiculture with trees
Alley cropping
Other:

SIZE KEYWORDS:
No data
Garden/field
Smallholding
Small farm
Large farm
Estate
Ranch
Other:

SIZE MANAGEMENT UNIT:
Lower:

Upper:

Mean:

AREA OCCUPIED:

LAND TENURE:
No data
Freehold
Tenancy
Communal
State

LAND OPERATION:
No data
Land holders
Hired labour

MARKET ORIENTATION:
No data
Subsistence
Subsistence subsid comm
Commercial subsid subsit
Commercial

LABOUR INTENSITY:
No data
High
Medium
Low

INPUT INTENSITY:
No data
High
Medium
Low

CAPITAL INTENSITY:
No data
High
Medium
Low

MECHANIZATION:
No data
Hoe and spade
Plough and animals
Plough and tractor

STATUS:
No data
Research trial
Aid development
Commercial development
Established evolved

MAJOR INPUTS:

MAJOR OUTPUTS:

ADDITIONAL INFORMATION:

COMPONENT TYPES:

No data	
Natural woody vegetation	F
Forestry species	F
Tree or shrub crops	A F
Natural herb veg	A
Improved herbacious veg	
Field crops	A
Perennials	A
Semi-perennials	A
Seasonal	A
Livestock	
Grazed	A
Zero grazed	A
Warm blooded	A
Cold blooded	A

MAIN AGRO NAMES/TERMS:

MAIN FORESTRY NAMES/TERMS:

PLANT FUNCTIONS:

No data	A F
Live fence	A F
Anti-pest	A F
Soil conservation	A F
Dune fixation	A F
Windbreak	A F
N fixation	A F
Mulching	A F
Animal shade	A F
Crop shade	A F
Home shade	A F
Green manure	A F
Crop support	A F
Ritual	A F
Other:	

ANNUAL FUNCTIONS:

No data not applicable
Power
Transport
Ritual
Other:

PLANT COMPONENT PRODUCTS:

No data
Parts used:

Roots	A
Stems	A F
Woody parts	F
Leaves	A F
Flowers	A F
Fruits	A F
Seeds	A F
Bark	F
Sap latex	A F
Other:	

Types of food:

Fruits	A F
Nuts	F
Flower vegetables	A F
Green vegetables	A F
Root vegetables	A
Spices	A F
Herbs	A F
Starch	A F
Oils, fats	A F
Other:	

Types of food:

Leaves stems	A F
Flowers	A F
Fruits/seeds	A F
Roots	A
Bee forage	A F
Bark	F
Other:	

Wood products:

Fuelwood	F
Poles	F
Timber	F
Pulp	F
Building	F
Fences	F
Other:	

Other Products:

Waxes	A F
Egg oils	A F
Tannins	A F
Dyes	A F
Gums	A F
Fibres	A F
Drugs (narcotic)	A F
Medicines	A F
Beverages	A F
Latex	A F
Insect repellent	A F
Other:	

ANIMAL PRODUCTS:

No data/not applicable
Milk Honey Other:
Eggs Down
Meat Hides
Wool Manure

ADDITIONAL INFORMATION:

ARRANGEMENT OF COMPONENTS:

Woody – Herb Dominant feature: Time Space In time: No data Coincident Rotation Overlapping Concomitant Interpolated In horizontal space: Not applicable No data Mixed, dense Mixed, sparse Row/Inter-row Strip Block Boundary In vertical space: Not applicable No data One layer Two layers Three layers More than three layers	Woody – woody Dominant feature: Time Space In time: No data Coincident Rotation Overlapping Concomitant Interpolated In horizontal space: Not applicable No data Mixed, dense Mixed, sparse Row/Inter-row Strip Block Boundary In vertical space: Not applicable No data One layer Two layers Three layers More than three layers	Herb – herb Dominant feature: Time Space In time: No data Coincident Rotation Overlapping Concomitant Interpolated In horizontal space Not applicable No data Mixed, dense Mixed, sparse Row/Inter-row Strip Block Boundary In vertical space Not applicable No data One layer Two layers Three layers More than three layers	Woody – Animal Dominant feature: Time Space In time No data Coincident Rotation Overlapping Concomitant Interpolated Location of woody specie: Inside animal management unit On boundary of animal management unit Outside animal management unit Animal feed method: Grazing Browsing Grazing/Browsing Zero grazing In horizontal space: Not applicable No data Mixed, dense Mixed, sparse Row/Inter-row Strip Block In vertical space: Not applicable No data One layer Two layers Three layers More than three layers

ADDITIONAL INFORMATION:

WOODY (PERENNIAL) SPECIES

	FOOD	FODDER	WOOD	OTHER	FUNCTIONS/USES
CODE NUMBER					
FRUITS					
NUTS					
VEGETABLES					
FLOWERS					
OILS/FATS					
STARCH					
SPICES					
SEEDS					
HERBS					
LATEX					
LEAVES					
PODS/SEEDS/FRUIT					
SHOOTS					
FLOWERS					
ROOTS					
BEE FORAGE					
BARK					
FUELWOOD					
POLES					
TIMBER					
PULP					
BUILDING MATERIAL					
FENCING					
WAXES					
ESSENTIAL OILS					
TANNING					
DYES					
GUMS					
FIBRES					
DRUGS					
BEVERAGES					
WINDBREAK					
SOIL CONSERVATION					
DUNE FIXATION					
DUNE FIXATION					
LIVE FENCES					
N. FIXATION					
MULCHING					
ANIMAL SHADE					
CROP SHADE					
HOMESTEAD SHADE					
GREEN MANURE					
ANTI-PEST					

HERBACEOUS SPECIES

	FODDER	FOOD	OTHER	FUNCTIONS/USES
CODE NUMBER				
FRUITS				
VEGETABLES				
FLOWERS				
OILS/FATS				
STARCH				
SPICES				
SEEDS				
HERBS				
LEAVES				
PODS/SEEDS/FRUIT				
SHOOTS				
FLOWERS				
ROOTS				
BEE FORAGE				
ESSENTIAL OILS				
DYES				
FIBRES				
DRUGS				
BEVERAGES				
SOIL CONSERVATION				
DUNE FIXATION				
N. FIXATION				
MULCHING				
GREEN MANURE				
ANTI-PEST				
RITUALS				

ANIMAL SPECIES

CODE NUMBER	
MEAT	FOOD
MILK	
HONEY	
EGGS	
HIDES	OTHERS
DOWN	
MANURE	
POWER	SERVICES
TRANSPORT	
GRAZING	FEED TYPE
ZERO GRAZING	
BROWSING	
ZERO BROWSING	

EVALUATION:

CONSTRAINTS:

POTENTIAL:

Research needs:

Merits:

Extrapolatability:

Land Use Problems:
- No data
- Steep slopes
- Waterlogging
- Infertile soils
- Low/poor water holding capacity of soils
- Drought
- Disease
- Pests
- Frost
- Sand dune encroachment

SYSTEM HISTORY/BACKGROUND

Additional Information

Contacts:

4. Classification of agroforestry systems*

P.K.R. NAIR

1. Introduction

In order to evaluate the existing agroforestry systems and develop action plans for their improvement, it is necessary to classify these systems and thus provide a practical and realistic framework.

Most of the earlier attempts to classify AF (Comoe and Budowski 1979; Grainger 1980; Huxley 1983; King 1979; Torres 1983; Vergara 1981) were part of an exercise in concept development rather than an aid in evaluating and analysing existing AF systems. Now a substantial body of information has been gathered on the structural and functional complexities of several of such existing systems through ICRAF's global inventory of AF systems. Therefore we are better equipped than ever before to classify AF systems on the one hand, and are experiencing a greater need for classification(s) on the other.

2. Purpose and criteria of classification

Most of the existing information concerning AF systems is descriptive. The descriptions and data can be assembled in several ways to facilitate their storage, retrieval and, to some extent, comparison. However, such an assemblage of data is only an essential first step in developing a practical and realistic framework for analysis of systems and development of AF. The purpose of classification should be to provide such a framework. But, depending on the focus and emphasis of such strategies and action plans, the structure of the framework will vary. Any classification scheme should:

- Include a logical way of grouping the major factors on which production of the system will depend;
- Indicate how the system is managed (pointing out possibilities for management interventions to improve the system's efficiency);
- Offer flexibility in re-grouping the information; and
- Be easily understood and readily handled (practical).

* Adapted from Nair, P.K.R. 1985. Classification of agroforestry systems. *Agroforestry Systems* 3: 97–128.

P.K.R. Nair (ed.), Agroforestry Systems in the Tropics. 39–52.
© 1989, Kluwer Academic Publishers, Dordrecht – Printed in the Netherlands.

The complexities of these requirements suggest that a single classification scheme cannot satisfactorily accommodate all of them. A series of classifications will be needed, and each one has to be based on a definite criterion to serve a different purpose. The most commonly used criteria so far have been spatial and temporal arrangement of components, relative importance and role of components, production aims/outputs from the system, and social and economic features. While some of the classification schemes have been based on only one of these criteria (for example, role of components (King 1979); temporal arrangement of components (Vergara 1981)), some others have tried to integrate several of these criteria in hierarchical schemes in rather simple ways (Torres 1983) or more complex ones (Combe and Budowski 1979; Wiersum 1980). An assessment of the various criteria to be used in classifying AF indicates that they refer to the system's structure, function (output), socio-economic nature, or ecological (environmental) spread. These characteristics also denote the most common purposes to be served in classification schemes. Therefore most AF systems can be categorized according to the following sets of criteria:

- *Structural basis* – refers to the composition of the components, including spatial admixture of the woody component, vertical stratification of the component mix and temporal arrangement of the different components;
- *Functional basis* – refers to the major function or role of the system, mainly of the woody components (these can be productive, e.g., production of food, fodder, fuelwood, and so on, or protective, e.g., windbreak, shelterbelt, soil conservation, and so on).
- *Socio-economic basis* – refers to the level of inputs of management (low input, high input) or intensity or scale of management and commercial goals (subsistence, commercial, intermediate);
- *Ecological basis* – refers to the environmental condition and ecological suitability of systems, on the assumption that certain types of systems can be more appropriate for certain ecological conditions: there can be a set of AF systems for arid and semi-arid lands, tropical highlands, lowland humid tropics, and so on.

These broad bases of classification of AF systems are by no means independent or mutually exclusive. Indeed it is obvious that they have to be interrelated because the structural and functional bases relate to the woody components in the system whereas the socio-economic and ecological stratification refers to the organization of the systems according to certain defined conditions (socio-economic or ecological). And in any defined socio-economic or ecological situation, the systems should still have a specific structure (composition and arrangement of components) and function/role. Thus the complexity of AF classification can considerably be reduced if the structural

Table 4.1. Major approaches to classification of agroforestry systems and practices.

Categorization of systems (based on their structure and functions)			Grouping of systems (according to their spread and management)	
Structure (nature and arrangement of components, especially woody ones)		Function (role and/or output of components, especially woody ones)	Agro-ecological environmental adaptability	Socio-economic and management level
Nature of components	Arrangement of components			
Agrisilviculture (crops and trees incl. shrubs/trees and trees)	*In space* (spatial)	*Productive function*	*Systems in/for*	*Based on level of technology input*
Silvopastoral (pasture/animals and trees)	Mixed dense (e.g., homegarden)	Food	Lowland humid tropics	Low input (marginal)
Agrosilvopastoral (crops, pasture/animals, and trees)	Mixed sparce (e.g., most systems of trees in pastures)	Fodder	Highland humid tropics (above 1,200 m a.s.l., e.g., Andes, India, Malaysia)	Medium input
Others (multipurpose tree lots, apiculture with trees, aquaculture with trees, etc.)	Strip (width of strip to be more than one tree)	Fuelwood	Lowland subhumid tropics (e.g., savanna zone of Africa, Cerrado of South America)	High input
	Boundary (trees on edges of plots/fields)	Other woods	Highland subhumid tropics (tropical highlands) (e.g., in Kenya, Ethiopia)	*Based on cost/benefit relations*
	In time (temporal)	Other products		Commercial
	Coincident	*Protective function*		Intermediate
	Concomitant	Windbreak		Subsistence
	Overlapping	Shelterbelt		
	Sequential (separate)	Soil conservation		
	Interpolated	Moisture conservation		
		Soil improvement		
		Shade (for crop, animal, and man)		

and functional aspects are taken as the primary considerations in categorization of the systems and socio-economic and agro-ecological/environmental (as well as any other such physical or social) factors taken more as a basis for stratifying or *grouping* the systems for definite purposes than for *classifying* them. These approaches to classification of AF systems are summarized in Table 4.1.

3. Structural basis for classification

The structure of the system can be defined in terms of its components (constituents) and the expected role or function of each (manifested in terms of outputs). It is not only the nature (type) of components that is important, but also their arrangement.

3.1. *Based on the nature of components*

In AF land-use systems there are three basic sets of elements or components that are managed by man, namely, the tree (= woody perennial), the herb (agricultural crops including pasture species) and the animal. In order for a land-use system to be designated as an AF system, it should always have the first one, i.e., the woody perennial. In most AF systems, the second one (the herbaceous species) is also involved, the notable exceptions could be apiculture with trees and aquaculture (pisciculture) with trees. The third set of components (animals) is present in some AF systems. This leads to a simple classification of AF systems as given below and depicted in Fig. 4.1.

Agrisilvicultural crops and trees including shrubs/vines/and trees
Silvopastoral pasture/animals and trees
Agrosilvopastoral - crops, pasture/animals and trees.

There are also a few other systems, such as multipurpose woodlots (that interact economically and ecologically with other land-use production components and hence fall under the purview of AF definition), apiculture with trees and aquasilviculture. In the absence of a better term to encompass these forms of AF, they can be grouped together under "others".

This categorization of AF systems into three major types is so fundamental that any one of these can conveniently be used as a prefix to other terms emanating from other classification efforts in order to explicitly express the basic composition of constituents of any such system. For example, there can be an agrisilvicultural system for food production in the lowland humid tropics at a subsistence level of production, a commercial silvopastoral system

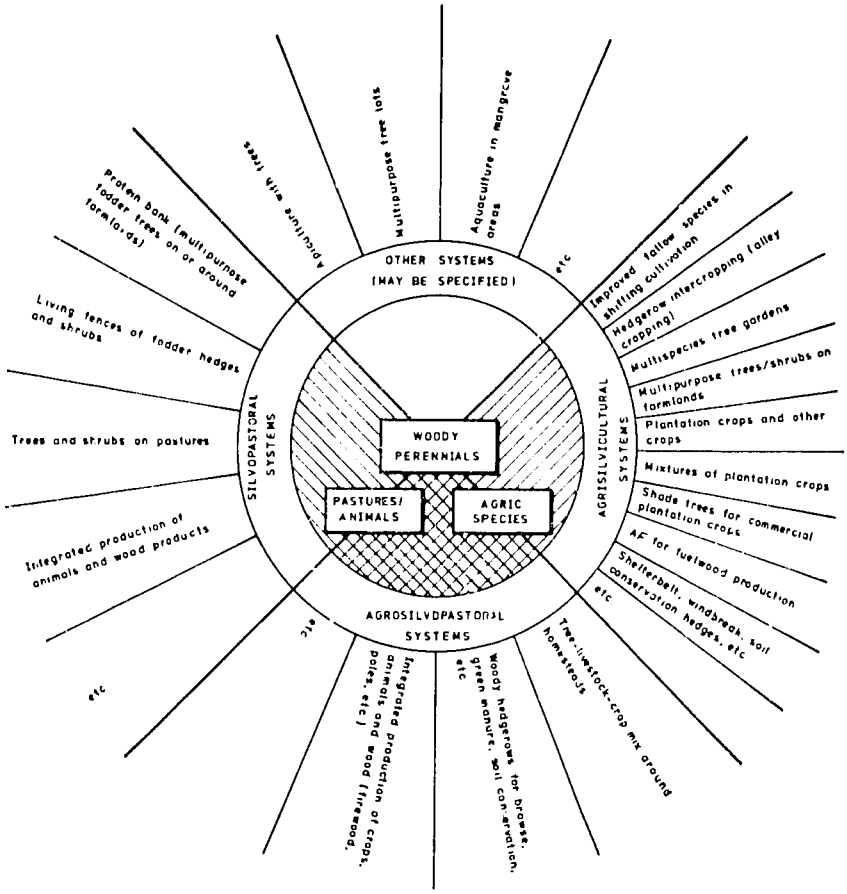

Fig. 4.1. Categorization of agroforestry systems based on the nature of components (with examples of common sub-systems/practices under each system).

for fodder and food production in lowland sub-humid (or dry) tropics, an agrosilvopastoral system for food production and soil conservation in highland humid tropics, and so on. Therefore it seems logical, compatible and pragmatic to accept the components as the basic criterion in the hierarchy of AF classification.

It may be noted that the term agrisilviculture (rather than agrosilviculture) is used to denote the combination of trees and crops, whereas agrosilvopastoral (rather than agrisilvipastoral) is used for crops + animals/pasture + trees. The intention here is to limit the use of the word agrisilviculture only to those combinations involving agricultural crops and trees. The word agrosilviculture can encompass all forms of agriculture (including animal husbandry) with trees, and thus be another word for agroforestry. That again is the reasoning behind the use of the all-inclusive "agro" prefix in agrosilvopastoral. It is worth mentioning in this context that during the process of evolution of the word "agroforestry" some people held the view that the

proper usage of the term (from the linguistic point of view) should be agriforestry and not agroforestry (Stewart 1981). But the word agroforestry has become so firmly implanted that it would now be very confusing if another word were to be popularized for the same concept. After all, one can find several other usages in technical languages that may not strictly satisfy the niceties of conventional linguistic usage.

3.2. *Based on the arrangement of components*

The arrangement of components refers to plant components of the system. Even in AF systems involving animals, the management of such animals according to a definite plan, such as, say, a rotational grazing scheme, is in consideration more of the plants than of the animals. Such plant arrangements in multispecies combinations can involve the dimensions of space and time.

Spatial arrangements of plants in AF mixtures can result in dense mixed stands (as in homegardens) or in sparse mixed stands (as in most systems of trees in pastures). Moreover, the species (or species mixes) can be in zones or strips of varying widths. There can be several forms of such zones varying from microzonal arrangements (such as alternate rows) to macrozonal ones. A commonly mentioned example of the zonal pattern is hedgerow intercropping (alley cropping) (Ssekabembe 1985; Wilson and Kang 1981). An extreme form of zonal planting is the boundary planting of trees on edges of plots and fields for a variety of purposes and outputs (fruits, fodder, fuelwood, fencing and protection, soil conservation/windbreak, and so on). It is also important to note that extreme forms of macrozonal arrangements can lead to sole cropping systems; but the interactive association of different components can be used as the criterion to decide the limits between zonal AF and sole crop (component) plots.

Temporal arrangements of plants in AF can also take various forms. An extreme example is the conventional shifting cultivation cycles involving 2–4 years of cropping and more than 15 years of fallow cycle, when a selected woody species or mixtures of species could be planted. Similarly, some silvopastoral systems may involve grass leys in rotation, with the same species of grass remaining on the land for several years. These temporal arrangements of components in AF have been described by terms such as coincident, concomitant, overlapping (of which the extreme case is relay cropping) separate, interpolated, and so on (Huxley 1983; Kronick 1984).

4. Functional classification of agroforestry systems

Two fundamental attributes of all AF systems are *production* and *sustainability*. This implies that AF systems have a productive function (producing one

or more products, usually "basic needs") as well as a service role (of protecting and maintaining the production systems).

Raintree (1984) argues that any land-use system, regardless of its degree of commercialization, can be described and evaluated in terms of the outputs of relevant basic needs such as food, energy, shelter, raw materials, cash, and so on. This is the strategy which underlines the basic-needs approach within the methodology for AF diagnosis and design development by ICRAF (Raintree 1987). According to this approach, the service roles of woody perennials are also taken as factors contributing to the production of one or more of these basic needs. For example, soil conservation affected by appropriate AF practices can be expressed in terms of its contribution to augmenting the sustainability of crop production; amelioration of microclimate through well-designed arrangements of trees and crops (e.g. shelterbelts) can be evaluated in terms of its effects on crop yields, etc.

However, this emphasis on production of outputs places undue emphasis on this attribute at the cost, if not exclusion, of the other important attribute, namely, sustainability. Although production is a very important consideration in AF, it is the sustainability aspect that makes it different from other approaches to land use. Moreover all AF systems will be producing more than one basic-need output (largely because of the multipurpose nature of the associated woody perennial component). Therefore, all AF systems have both the productive and protective roles, though to varying degrees. Depending on the relative dominance of the particular role, the system can be termed productive or protective.

Therefore it is inadequate to choose the production of a particular basic-need output as the sole criterion for classifying AF systems. However, production of an output, or for that matter any such other aspect, may be chosen as the basis for undertaking an evaluation of available AF options with a view to selecting the most appropriate ones to fulfil the stated objective.

5. Ecological and socio-economic grouping of agroforestry systems

5.1. *Ecological grouping*

Several enumerations of AF practices have been presented from various geographical regions to a large number of seminars, workshops, etc., during the late 1970s and early 1980s, as mentioned in Chapter 3. Notable among them are the group discussions held at CATIE, Turrialba, Costa Rica (de las Salas 1979) ICRAF, Nairobi (Buck 1981; Chandler and Spurgeon 1979; Hoekstra and Kuguru 1982; Huxley 1983; Nair 1987b) and IITA, Ibadan (McDonald 1982). There have also been several compilations on specific systems, as well as country/region overviews, such as the *Acacia albida* system

in West Africa (Felker 1978), the *Prosopis cineraria* system in western India (Mann and Saxena 1980), and reviews of AF in francophone Africa (FAO 1981a) and the Indian sub-continent (FAO 1981b). Also, several other reports have been published (Lundgren and Raintree 1982; Nair 1983b; 1983c; 1985a). The AF System Description Series in *Agroforestry Systems*, which is a major output from ICRAF's AF Systems Inventory Project (Nair 1987a) and forms Parts 3, 4 and 5 of this book, is the most recent and concerted effort in describing the existing AF systems.

Most of this AF systems documentation pertains to specific ecological situations from different geographical regions. It is thus easy to find several descriptions of AF systems in, say, the highland sub-humid tropics (or the tropical highlands, as they are popularly known): for example, the Chagga system on Mount Kilimanjaro in Tanzania (Fernandes *et al.* 1984), hill farming in western Nepal (Fonzen and Oberholzer 1984), multipurpose tree integration in the highlands of Rwanda (Neumann 1983), casuarina and coffee systems in Papua New Guinea (Bourke 1984). Similarly, a large number of system descriptions can be found for various other ecological regions. Recommendations on AF technologies have also been suggested for specific agro-ecological regions (for example, for hilly regions of Rwanda (Nair 1983a), and for sloping areas (Young 1984).

Descriptions of existing systems, as well as recommendations of potential AF technologies for specific agro-ecological zones, include a mixture of various forms of AF (in terms of the nature as well as arrangement of components). Thus there can be agrisilvicultural, silvopastoral or agro-silvopastoral systems in any of the ecological regions. For example, Young (1984) analysed the AF potential for sloping lands using the primary data collected by ICRAF's AF Systems Inventory Project and others for eight systems in sloping lands in various parts of the world, and showed that all the three basic categories of AF (agrisilvicultural, silvopastoral and agrosilvopastoral) can be seen in this particular land form. Similarly, Nair (1985b) examined the AF options in the context of land clearing in the humid tropics. Thus most AF categories can be found in all agro-ecological zones.

In summary, agro-ecological zonation alone cannot be taken as a satisfactory basis for classification of AF systems. Several AF systems and practices (existing as well as potential) are relevant to any major agro-ecological zone; depending on the special conditions of any zone, the emphasis of the system/practice will also vary. For example, in the tropical highlands, one of the main considerations would be the protective role (soil-conservation potential) of AF, whereas in sparsely-populated semi-arid savannas, silvopastoral systems for production of livestock (and fuelwood) would be of priority consideration.

5.2. *Socio-economic grouping*

Socio-economic criteria such as scale of production and level of technology input and management have also been used as criteria for classifying AF systems. Lundgren (1982) thus groups systems into commercial, intermediate and subsistence systems.

The term commercial is used where the production of the output, usually a single commodity, for sale is the major aim of the system; scale of operations is often medium to large and land ownership may be government, corporate or private; labour is normally paid or otherwise contracted. Examples include commercial production of agricultural plantation crops such as rubber, oil palm and coconut, with permanent underplantings of food crops, other crops, or pasture/animals; commercial production of shade-tolerating plantation crops like coffee, tea, and cacao under overstorey shade trees; rotational timber/food crops systems in which a short phase of food-crop production is used as a silvicultural method to ensure establishment of the timber species (various forms of taungya); commercial grazing and ranching under large-scale timber and pulp plantations; etc.

"Intermediate" AF systems are those that are intermediate between commercial and subsistence scales of production and management: production of perennial cash crops and subsistence crops undertaken on medium-to-small-sized farms where the cash crops cater for the cash needs, and the food crops meet the family's food needs. Usually farmers who either own the land, or have long-term tenancy rights to land, reside and work themselves on the land, supplemented by paid temporary labour. The main distinguishing features of the intermediate system from those of the commercial system, at one end, and the subsistence system, on the other, are holding size and level of economic prosperity. Several AF systems in many parts of the world can be grouped as intermediate systems, especially those based on plantation crops such as coffee, cacao and coconut. Similarly, there are several intermediate AF systems based on a large number of fruit trees, especially in the Asia-Pacific region (Nair 1985a), and short-rotation timber species such as *Albizia falcataria* in the Philippines (Pollisco 1979) and Indonesia (Nair 1985b).

Subsistence AF systems are those where the use of land is directed toward satisfying basic needs and is managed mostly by the owner/occupant and his family. Cash crops, including sale of surplus production of commodities, may well be a part of these systems but are only supplementary. Most of the AF systems practised in various parts of the developing countries come under the subsistence category. All forms of traditional shifting cultivation found throughout the tropics are the most widespread example. However, not all the forms of subsistence AF systems are as "undesirable" or resource depleting as traditional shifting cultivation. For example, the integrated, multi-species

homegarden system found in almost all thickly populated areas is a "progressive" AF system (Wiersum 1980; Michon *et al.* 1986). Similarly, several commendable systems of a subsistence nature can be found in many other regions; for example, in Latin America (Wilken 1977), arid West Africa (von Maydell 1979, 1987; Le Houérou 1987), humid West Africa (Getahun *et al.* 1982) and India (ICAR 1979).

Grouping of AF systems according to these socio-economic and management criteria is yet another way of stratifying the systems for a purpose-oriented action plan. Such an approach will be useful in development efforts, for example. However, there are some drawbacks if these criteria are accepted as the primary basis for classifying the systems. First, the criteria for defining the various classes are not easily quantifiable; the standards set for such a differentiation will reflect the general socio-economic situation of the locality. What is considered as "subsistence" level in one set of situations may well fall under "intermediate" or even a higher category in another set of situations. Moreover, these class boundaries will also change with time. A good example is the gum-arabic production systems of the Sudan. It used to be a flourishing "intermediate" system consisting of a planned rotation of *Acacia senegal* for gum production for 7–12 years. *Acacia senegal* also provided fodder and firewood and improved soil fertility (Seif-el-Din 1981). But with the advent of artificial substitutes for gum arabic, the *Acacia senegal* - millet system has now degenerated into a subsistence system.

Therefore these socio-economic factors that are likely to change with time and management conditions cannot be rigidly adopted as a satisfactory basis for an objective classification scheme, but they can be employed as a basis for grouping the systems for a defined objective or action plan.

6. A framework for classification of agroforestry systems

The foregoing analysis reveals the following:

- The commonly used criteria for classifying AF systems and practices are:

  Structure of the system (nature and arrangement of components);
  Function of the system (role and output of components);
  Agro-ecological zones where the system exists or is adoptable; and
  Socio-economic scales and management levels of the system.

- Each of these criteria has merits and applicability in specific situations, but they have limitations also so that no single classification scheme can be accepted as a universally applicable one. Therefore, classification of AF systems will have to be purpose-oriented.

- The complexity of the problem can be reduced if the structural and functional aspects of the system are taken as the criteria for categorizing the systems and agro-ecological and socio-economic aspects as the basis for grouping them.
- Since there are only three basic sets of components that are managed by man in all agroforestry systems (woody perennials, herbaceous plants and animals), a logical first step to classifying AF is based on the nature of these components, namely:

  - Agrisilvicultural
  - Silvopastoral, and
  - Agrosilvopastoral

  (There are also a few other specialized systems.)

- Having done such a preliminary categorization, the systems can subsequently be grouped according to any of the purpose-oriented criteria

Table 4.2. Framework for a purpose-oriented classification of agroforestry systems.*

First step	Subsequent step(s)	
Classification based on the nature of components	Criteria	Major areas of application
Agrisilvicultural Silvopastoral Agrosilvopastoral	Arrangement of components - In time - In space	Research on plant management for optimizing interactions
Other (specify)	Function/role of components - Productive - Protective (service)	Development projects for exploiting agroforestry potential
	Agro-ecological zones and other specified land forms	Land-use planning, regional development
	Socio-economic aspects	R & D programmes, socio-economic analysis of agroforestry potential, resource-utilization plan

* See Table 4.1 for major approaches in classification.

mentioned above. Each of the resulting groups can have any one of the above three categories as a prefix, for example:

- Silvopastoral system for cattle production in tropical savannas;
- Agrisilvicultural system for soil conservation and food production in tropical highlands.

A framework for classification of AF systems based on these considerations is given in Table 4.2.

At first, the systems can be designated according to the nature of the components, and then, for each category, information can be given on the other major characteristics that can be used as the criteria for grouping them subsequently for any specified purpose. This appears to be a logical, simple, pragmatic and purpose-oriented approach to classification of AF systems, and this approach has been adopted for grouping the existing systems, as discussed in the following chapter.

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5. Agroforestry systems, practices and technologies

P.K.R. NAIR

The words "system", "sub-system", "practice" and "technology" are very commonly used in AF literature. In systems-analysis language, a *system* refers to a group of physical components, i.e., an assemblage of objects, connected or related in such a manner as to form and/or act as an entire unit (Arnold and de Wit 1976; de Wit and Goudrian 1974). In land-use terms, a system refers to a type of land use specific to an area and described according to its bio-technical and socio-economic aspects: for example, an agricultural system or a forestry systems denotes a type of agriculture or forestry land use of the locality, described in terms of its main components, level of management, nature of output, and so on. The broad terms used to describe specific systems are usually clear enough to portray the basic nature of the systems: for example, rice production systems, subsistence agricultural systems, plantation-crop systems, mixed cropping systems, maize-wheat rotation system, livestock production system, commercial timber production system, and so on. And, of course, each one of these has various sub-divisions and forms too.

These common land-use systems of agriculture and forestry are, however, mostly oriented to the production of a specific commodity (or groups of similiar commodities) so that, in land-use literature, commodity orientation has evolved as the first consideration of the system nomenclature. The complex and multiple output nature of AF puts some restrictions on demarcation of specific systems in this way. Instead, the term agroforestry system as used in the AF literature corresponds to specific or generalized AF land utilization types (Young 1984), the basis for defining and demarcating the various such systems being not only biological or technical, but also economic or social. In a more sociological context, Raintree (1987) explains the concept of land-management systems for the "diagnostic and design (D&D)" purpose as that part of the man-environment complex or "human ecosystem" where the organizing influence of the manager (the man) is felt most clearly and directly; in other words, a relevant decision-making unit within a local human ecosystem. Obviously this is a variable-scale concept because the extent of the decision-making unit can vary from the family farm to broader geographical units. It can therefore be surmised that from the point of view of distinguishing and classifying AF systems, an AF system can be considered as a type of AF land use that is specific to a locality and described according to its biological composition and arrangement, level of technical management, or socio-economic features.

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Table 5.1. Some examples of prominent agroforestry systems and practices in the tropics and

SYSTEMS		EXAMPLES FOR DIFFERENT	
Major systems	Sub-systems practices	South Pacific	South-east Asia
AGRISILVICULTURAL SYSTEMS	Improved "fallow" (in shifting cultivation areas)		Forest villages of Thailand; various fruit trees and plantation crops used as "fallow" species in Indonesia
	The taungya system	(e.g. taro with *Cedrella* and *Anthocephalus* tree)	Widely practised: forest villages of Thailand is an improved form
	Tree gardens	Involving fruit trees	Dominated by fruit trees
	Hedgerow intercropping (alley cropping)		Extensive use of *Sesbania grandiflora*, *Leucaena leucocephala* and *Calliandra callothyrsus*
	Multipurpose trees and shrubs on farmlands	Mainly fuit or nut trees (e.g. *Canarium*, *Pometia*, *Barrington*, *Pandanus*, *Artocarpus altilis*)	Dominated by fruit trees; also *Acacia mearnsii*-cropping system, Indonesia
	Crop combination with plantation crops	Plantation crops and other multipurpose trees, e.g. *Casuarina* and coffee in the highlands of PNG; also *Gliricidia* and *Leucaena* with cacao	Plantation crops + fruit trees, smallholder systems of crop combinations with plantation crops; plantation crops with spice trees
	AF fuelwood production	Multipurpose fuelwood trees around settlements	Several examples in different ecological regions
	Shelterbelts, windbreaks, soil conservation hedges	*Casuarina oligodon* in the highlands as shelterbelts and soil improver	Terrace stabilization in steep slopes
SILVOPASTORAL SYSTEMS	Protein bank (cut-and-carry fodder production)	Rare	Very common, especially in highlands
	Living fence of fodder trees and hedges	Occasional	*Leucaena*, *Calliandra*, etc. used extensively
	Trees and shrubs on pastures	Cattle under coconuts, pines and *Eucalyptus deglupta*	Grazing under coconuts and other plantations
AGROSILVOPASTORAL SYSTEMS	Woody hedges for browse, mulch, green manure, soil conservation, etc.	Various forms, *Casuarina oligodon* widely used to provide mulch and compost	Various forms
	Homegardens (involving a large number of herbaceous and woody plants with or without animals)	Several types of homegardens and kitchen gardens	Very common; Java homegardens often quoted as good examples; involving several fruit trees
OTHER SYSTEMS	Agro-silvo-fishery (aquaforestry)		Silviculture in mangrove areas; trees on bunds of fish-breeding ponds
	Various forms of shifting cultivation	Common	e.g. swidden farming
	Apiculture with trees	Common	Common

sub-tropics.

GEOGRAPHIC REGIONS				
South Asia	Middle East and Mediterranean	East and Central Africa	West Africa	American tropics
Improvement to shifting cultivation; several approaches, e.g., in the north-eastern parts of India		Improvements to shifting cultivation, e.g. gum gardens of the Sudan	*Acioa barterii*, *Anthonontha macrophylla*, *Gliricidia sepium*, etc., tried as 'fallow' species	Several forms
Several forms, several names		The 'shamba' system	Several forms	Several forms
In all ecological regions	The Dehesa system; 'Parc arboreé'			e.g., "Paraiso woodlot" of Paraguay
Several experimental approaches, e.g., conservation farming in Sri Lanka		The corridor system of Zaire	Experimental systems on alley cropping *with leucaena* and other woody perennial species	Experimental
Several forms both in low- and highlands, e.g., hill farming in Nepal, *Khejri*-based system in the dry parts of India	The oasis system; crop combinations with the Careb tree; the Dehesa system; Irrigated systems; olive trees + cereals	Various forms; The Chagga system of Tanzanian highlands; the Nyabisindu system of Rwanda	*Acacia albida*-based food production systems in dry areas *Butyrospermum* + *Parida* systems; "Parc arborée"	Various forms in all ecological regions
Integrated production systems in smallholdings, shade trees in plantations; other crop mixtures including various tree spices	Irrigated systems; olive trees + cereals	Integrated production; shade trees in commercial plantations mixed systems in the highlands	Plantation crop mixtures; production smallholder systems	Plantation crop mixtures; shade trees in commercial plantations; mixed in smallholdings; spice trees; babassu palm-based systems
Various forms including some forms of social forestry		Various forms	Common in the dry regions	Several forms in the dry regions
Use of *Casuarina* spp as shelterbelts; several windbreaks	Tree spices for erosion control	The Nyabisindu system of Rwanda	Various forms	Live fences, windbreaks especially in highlands
Multipurpose fodder trees on or around farmlands especially in highlands		Very common	Very common	Very common
Sesbania, *Euphorbia* *Syzygium* etc., common		Very common in all ecological regions		Very common in the highlands
Several tree species being used very widely	Very common in the dry regions; the Dehesa system	The *Acacia*-dominated system in the arid parts of Kenya, Somalia and Ethiopia	Cattle under oil palm; cattle and sheep under coconut	Common in humid as well as dry regions, e.g., under plantation crops in Brazil
Various forms, especially in lowlands		Common; variants of the shamba system	Very common	Especially in hilly regions
Common in all ecological regions; usually involving fruit trees	The oasis system	Various forms (the Chagga homegardens; the Nyabisindu system)	Compound farms of humid lowlands	Very common in the thickly populated areas
Occasional				
Very common; various names		Very common	Very common in the lowlands	Very common in all ecological regions
Common	Common	Common	Common	

Table 5.2. Major agroforestry practices.

Agroforestry practice	Brief description (of arrangement of components)	Major groups of components (w = woody h = herbaceous f = fodder for grazing a = animals)	*Main types of component interactions in space(s) time (t)	Primary role of woody component Prt = protective Prd = productive	Agro-ecological adaptability
A. Agrisilvicultural systems (crops – including shrub vine tree crops – and trees)					
1. Improved fallow	Woody species planted and left to grow during the "fallow phase"	w: fast-growing preferably leguminous h: common agricultural crops	t: sequential (in rotational cycles)	Prt: soil fertility Prd: wood products	In shifting cultivation areas
2. Taungya	Combined stand of woody and agricultural species during early stages of establishment of plantations	w: usually plantation forestry spp. h: common agricultural crops	s: concomitant t: sequential (in rotational cycles)	Prd: additional income from agricultural crops; also management care for plantation species	In all ecological regions (where taungya is practised); several improvements possible
3. Alley cropping (hedgerow intercropping)	Woody species in hedges; agricultural species in alleys in between hedges; microzonal or strip arrangement	w: fast-growing, leguminous, that coppice vigorously h: common agricultural crops	s: zonal (strip) t: concomitant to intermittent	Prt: soil improvement, and or soil conservation Prd: additional products from hedges	Sub-humid to humid areas with high human population pressure and fragile (productive but easily degradable) soils
4. Multilayer tree gardens	Multispecies, multilayer, dense plant associations with no organized planting arrangements	w: different woody components of varying form and growth habits h: usually absent; shade tolerant ones sometimes present	s: mixed dense t: coincident	Prd: various types of outputs Prt: soil conservation and protection; efficient nutrient cycling	Areas with fertile soils, good availability of labour, and high human population pressure

5. Multipurpose trees on crop lands	Trees scattered haphazardly or according to some systematic patterns on bunds, terraces or plot field boundaries	w: multipurpose trees and other fruit trees h: common agricultural crops	s: mixed sparse t: interpolated	Prd: production of various tree products Prt: fencing, social values, plot demarcation	In all ecological regions esp. in subsistence farming; also commonly integrated with animals
6. Plantation crop combinations	1. Integrated multistorey (mixed, dense) mixtures of plantation crops 2. Mixtures of plantation crops in alternate or other regular arrangement 3. Shade trees for plantation crops; shade trees scattered 4. Intercropping with agricultural crops	w: plantation crops like coffee, cacao, coconut, etc., fruit trees (esp. in 1); fuelwood fodder spp. esp. in 3. h: usually present in 4, and to some extent in 1; shade-tolerant species	s: mixed dense (1, 2, 4) or mixed sparse (3) t: 1. Interpolated 2. Coincident or overlapping 3. Coincident 4. Intermittent or concomitant	Prd: production of a large number of products Prt: soil surface protection; shade and windbreak	In humid lowlands or tropical humid/ sub-humid highlands (depending on the adaptability of the plantation crops concerned); usually in smallholder subsistence system
7. Homegardens	Intimate, multistorey combination of various trees and crops around homesteads	w: fruit trees predominate; also other woody species; vines, etc.	s: mixed dense t: coincident to interpolated h: shade-tolerant crops	Prd: production of various products Prt: soil surface protection	In all ecological regions, especially in areas high population density
8. Trees in soil conservation and reclamation	Trees on bunds, terraces, raisers, etc. with or without grass strips; trees for soil reclamation	w: multipurpose and/or fruit trees h: common agricultural species	s: zonal (strip) t: intermittent	Prt: soil conservation Prd: various tree products	In sloping areas, especially in highlands, reclamation of degraded, acid, alkali soils, and sanddune stabilization

Table 5.2. (continued)

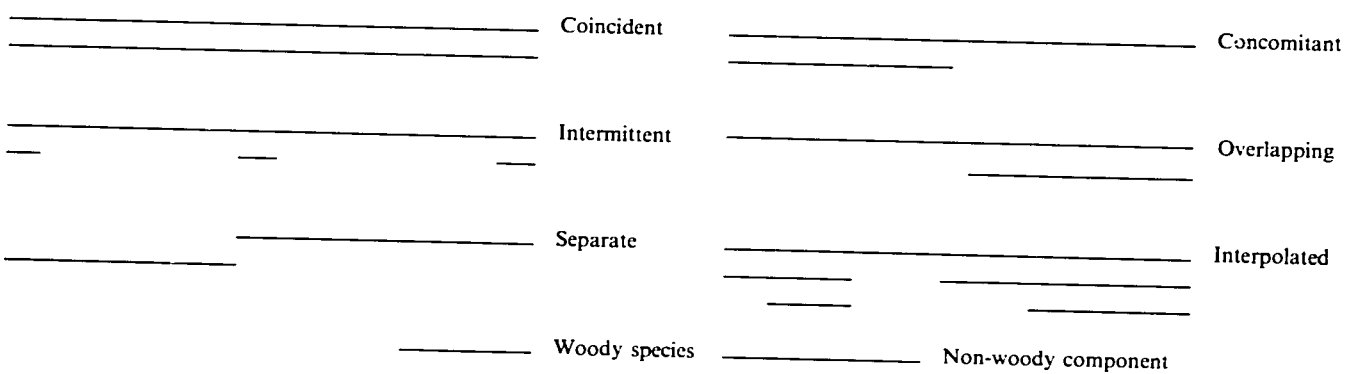
Agroforestry practice	Brief description (of arrangement of components)	Major groups of components (w = woody h = herbaceous f = fodder for grazing a = animals)	*Main types of component interactions in space(s) time (t)	Primary role of woody component Prt = protective Prd = productive	Agro-ecological adaptability
9. Shelterbelts and windbreaks, live hedges	Trees around farmlands/plots	w: combination of tall-growing spreading types h: agricultural crops of the locality	s: zonal (strip boundary) t: coincident, interpolated	Prt: shelterbelts windbreak; fencing Prd: usually firewood	In wind-prone areas
10. Fuelwood production	Interplanting firewood species on or around agricultural lands	w: firewood species h: agricultural crops of the locality	s: zonal (strip boundary) t: coincident	Prd: firewood Prt: fencing; shelterbelts; boundary demarcation	In all ecological regions
B. Silvopastoral systems (trees + pasture and/or animals)					
11. Trees on rangeland or pastures	Trees scattered irregularly or arranged according to some systematic pattern	w: multipurpose; usually of fodder value f: present a: present	s: mixed sparse t: coincident	Prd: trees as fodder Prt: shade; environmental protection	Extensive grazing areas
12. Protein banks	Production of protein-rich tree fodder on farm rangelands for cut-and-carry fodder production	w: leguminous fodder trees h: present f: present	s: zonal t: coincident or interpolated	Prd: fodder production Prt: soil and environmental protection depending on arrangement	Usually in areas with high man:land ratio

13. Plantation crops with pastures and animals	Example: cattle under coconuts in south-east Asia and the south Pacific	w: plantation crops f: present a: present	s: mixed sparse t: intermittent	Prt: shade and protection to fodder and animals Prd: (plantation crop products)	In areas with less pressure on plantation crop lands
C. Agrosilvopastoral systems (tree + crops + pasture/animals)					
14. Homegardens involving animals	Intimate, multistorey combination of various trees and crops, and animals, around homesteads	w: fruit trees predominate; also other woody species a: present	s: mixed dense t: interpolated coincident	Prd: various products Prt: soil surface protection; organic recycling	In all ecological regions with high density of human population
15. Multipurpose woody hedgerows	Woody hedges for browse, mulch, green manure, soil conservation, etc.	w: fast-growing and coppicing fodder shrubs and trees h: (similar to alley cropping and soil conservation)	s: zonal (strip or boundary) t: intermittent to coincident	Prt: soil conservation Prd: various products, mainly fodder	Humid to subhumid areas with hilly and sloping terrain
D. Others					
16. Apiculture with trees	Trees for honey production	w: honey producing trees (other components may be present)	s: boundary, mixed, sparse (or any other) t: (variable)	Prd: honey production Prt: location-specific	Depending on the feasibility of apiculture
17. Aquaforestry	Trees lining fish ponds, tree leaves being used as "forage" for fish	w: trees and shrubs preferred by fish (other components may be present)	s: boundary planting t: coincident to intermittent	Prd: fish production Prt: bund stabilization around fish ponds	Lowlands

Table 5.2. (continued)

Agroforestry practice	Brief description (of arrangement of components)	Major groups of components (w = woody h = herbaceous f = fodder for grazing a = animals)	*Main types of component interactions in space(s) time (t)	Primary role of woody component Prt = protective Prd = productive	Agro-ecological adaptability
18. Multipurpose woodlots	For various purposes (wood, fodder, soil protection, soil reclamation, etc.)	w: multipurpose species; special location-specific species (other components may be present)	s: zonal or mixed t: separate or overlapping	Prt: various protective Prd: various	Various

* Temporal arrangements of components in agroforestry systems



The major field examples of agroforestry systems from different geographical regions, grouped together according to the framework proposed for classification in Chapter 4, are presented as Table 5.1.

More detailed information on the different types of systems in various ecological regions, and the common woody species involved in each, is given as Appendix I to Chapter 6.

The other commonly used expression in AF literature is *sub-system*. Semantically it indicates a lower-order hierarchy of the system. A system can well be conceived to be composed of various sub-systems, or compartments, each with definable boundaries, though seldom existing independently; it is in this way that the term is used in a physical sense in systems-analysis language. But in AF literature the sub-system refers to a part of the system with a more restricted role, content and complexity than the system itself. Depending on the criteria used for defining or designating the system (biological, socio-economic, and so on), the types of sub-systems can also vary. For example, an agrisilvicultural system can have several types of sub-systems according to the type and arrangement of its constituent components. But another way of looking at it is based on the system's output, that is, to consider a system as being composed of several sub-systems, each producing a defined "basic need" as its major output, so that there can be a food sub-system, an energy sub-system, a shelter sub-system, a cash sub-system, and so on (Raintree 1987).

An agroforestry *practice* usually denotes a specific land management operation of an agroforestry nature on a farm or other management unit, and consists usually of arrangements of AF components. Several such practices will be involved in the constitution and maintenance of an AF system. Commonly these practices include the arrangements of components in space and time *vis-à-vis* the major function of the tree component. Moreover, although several AF systems have been recorded from different parts of the world, the distinctive AF practices that constitute these systems in various eco-regions are only a few. Alley cropping (hedgerow intercropping), boundary planting of trees, trees and shrubs as shelterbelts and windbreaks, use of woody perennials in soil conservation, tree gardens, woodlots on agricultural lands, etc. are commonly found AF practices in most AF systems. These most commonly found AF practices and their essential characteristics are listed in Table 5.2. Any of these *practices* becomes an AF *system* when it is developed or spread to such an extent in a specific area as to form a definite land-utilization type in that area.

One essential point to note here is that an AF practice can exist even in a non-agroforestry land-use system. An example is the practice of growing rows of *Sesbania grandiflora* on the bunds of rice paddies in Java, Indonesia. This woody species is harvested for its leaves as green manure, its flowers are eaten as a vegetable, it provides firewood and it adds to the fertility of the soil

underneath through biological fixation of atmospheric nitrogen. Thus the woody species interacts ecologically and economically with the crop (rice) production system; in other words, it is an AF practice in an agricultural production system.

Hierarchically, the system, the sub-system and the practice form different levels of organization of the components, i.e., a system consists of several sub-systems and each sub-system consists of several practices. Depending on the degree of "evolution" and the level of physical spread, these terms also represent different extents to which they are adopted in a given locality, a system being widely practised to form a land-utilization type of the locality, a practice being a management operation involving the components within a system, and a sub-system falling in between. However, the words are used rather promiscuously, and even synonymously, in common AF usage, so that it becomes difficult to differentiate them from one another.

Another term that is commonly used in all land-use systems, including agroforestry, is "technology", and it is usually used in combination with a particular production system or land-use system as the prefix; thus, agricultural technology, wood-production technology, agroforestry technology, and so on. The word or suffix "technology" in this sense indicates an innovation or improvement, usually through scientific intervention, that can be applied with advantage in the management of the system or practice concerned. The inputs that are used for developing such technologies can sometimes be the most significant aspects, and these are called input technologies; e.g., improved varieties of plants, agrochemicals, and so on. Most of the promising agroforestry technologies are also known by the same names as AF practices (Table 5.2), because whatever little scientific interventions that have been made were for improving existing AF practices rather than devising totally new ones. Thus, boundary planting of multipurpose trees, which is an existing agroforestry practice in some regions, can be proposed, with appropriate modifications, as a potentially adoptable new technology for other areas.

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6. Ecological spread of major agroforestry systems*

P.K.R. NAIR

1. Ecological zones of agroforestry significance in the tropics and subtropics

The major physical parameters that determine the ecology of a location in the tropics are rainfall (quantity and distribution) and temperature. Altitude also is important because of its influence not only on temperature, but also on land relief characteristics. The FAO Agro-Ecological Zones Inventory divides the tropics into "warm", "moderately cool", "cool" and "cold" zones depending on the climatic (mainly temperature) regime during the "growing period". These growing periods refer to a few selected agricultural crops that are seasonal and therefore do not necessarily reflect the growing periods of perennial species (although it can be argued that the agricultural growing period also represents the peak growing seasons of the perennial species in most cases).

From the agroforestry point of view, the major ecological regions recognized in the FAO State of Food and Agriculture Reports (SOFA) are more relevant: these are temperate, mediterranean, arid and semi-arid, subhumid tropical (lowland), humid tropical (lowland) and highland. These classes, except the first (and possibly the second), cover the tropical and subtropical lands where agroforestry systems of the types that are discussed in this book exist or have a potential. These major ecological regions of the tropics and subtropics are shown in Fig. 6.1, and their main characteristics (mainly adapted from Young 1986), are summarized in Table 6.1.

2. Agroforestry systems in lowland humid and subhumid tropics

Characterized by hot, humid climates for all or most of the year, and an evergreen or semi-evergreen vegetation, the lowland humid and subhumid tropical region (but usually referred to as humid tropics) is by far the most important ecological region in terms of the total human population it supports, and area and diversity of agroforestry and other land-use systems. Because of the climatic conditions that favour rapid growth of a large number of plant species, various types of agroforestry plant associations can be found

* Based on Nair, P.K.R. (1987). Agroforestry systems in major ecological zones of the tropics and subtropics. ICRAF Working Paper No. 47. ICRAF, Nairobi.

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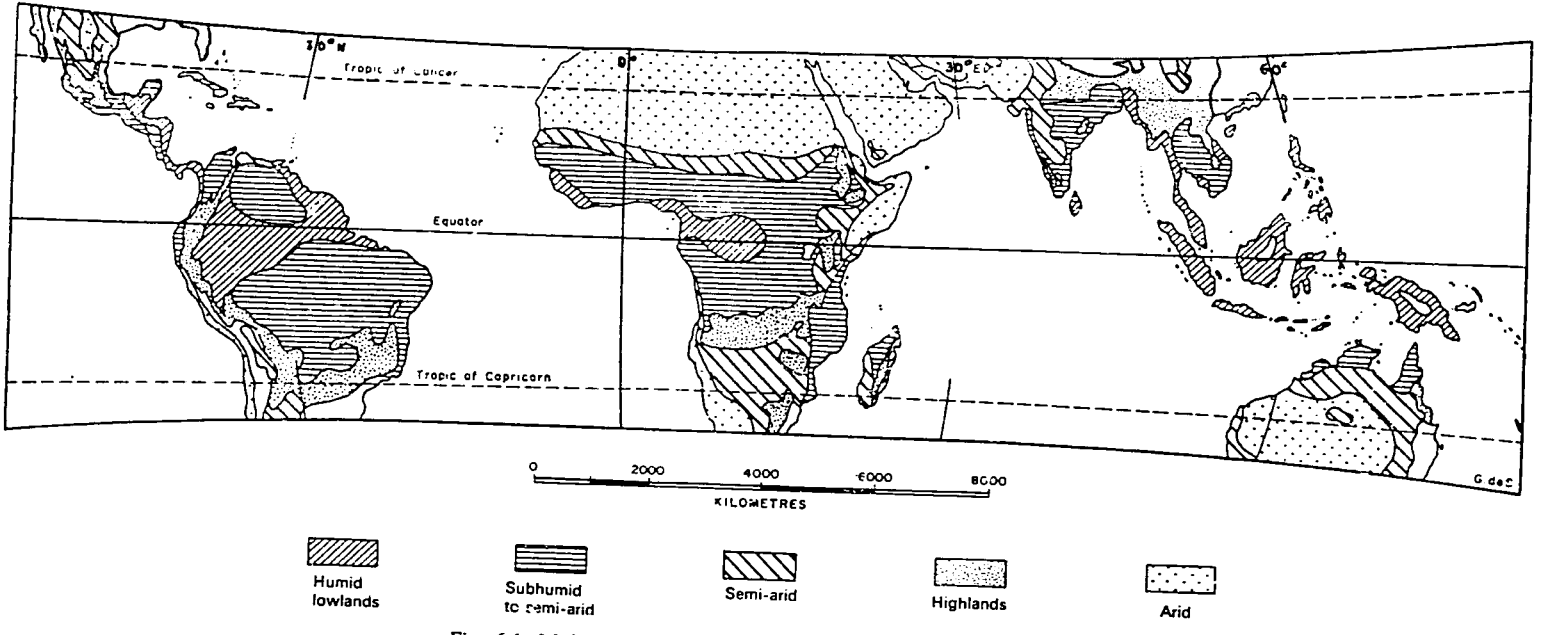


Fig. 5.1. Major ecological regions of the tropics and subtropics.

Table 6.1. Main characteristics of the major ecological regions of agroforestry importance in the tropics and subtropics*

Characteristics	Humid subhumid lowlands	Dry regions (semi-arid and arid)	Highlands
Climate	Hot, humid for all or most of the year, rainfall > 1000 mm; sometimes one or more extended dry periods per year; Koeppen Af, Am and some Aw, esp. Aw"	Hot, one or two wet seasons and at least one long dry period; rainfall 1000 mm; Koeppen Aw" (some), Aw', and B climates	Cool temperatures, subhumid or humid (arid highlands are of low AF potential); altitude over 1000 m; Koeppen Ca, Cw (agricultural growing period over 120 days)
Vegetation and soils	Evergreen or semi-evergreen vegetation; Ultisols (Acrisols) and Oxisols (Ferralsols) and other acid, low-base tropical soils	Savannas with low or medium-high trees and bushes (Aw); thorn scrub and steppe grasslands (BS), Vertisols, Alfisols (Luvisols, Nitosols) and Entisols	Evergreen to semi-evergreen vegetation depending on rainfall. Oxisols (Humic Ferralsols) and Ultisols (Humic Acrisols) Andosols (volcanic soils)
Major geographical spread (of areas with AF importance)	All tropical continents, especially south-east and south Asia, west Africa and central and south America; about 35% of tropical land	Savanna and sub-Saharan zones of Africa, Cerrado of South America, semi-arid and arid parts of Indian subcontinent approx. 45% of total tropical land	Asia (Himalayan region, some parts of southern India and S.E. Asia), east and central African highlands, Andes; about 20% of tropical land
Main land-use systems	Commercial forestry, agricultural tree crop plantations, rice-paddies (esp. Asia), ranching (S. America), shifting cultivation, arable cropping	Arable farming, extensive ranching or nomadic pastoralism, perennial crop husbandry towards the more humid areas, forestry	Arable farming, plantation agriculture and forestry, ranching (in south and central America), shifting cultivation
Main land-use and ecological problems	Excessive deforestation (and consequent shortening of fallows, etc.) overgrazing, soil acidity and consequent problems, low soil fertility, high rainfall erosivity	Drought (in areas with less rainfall), soil fertility decline caused by over-cultivation, over-grazing, degradation of deciduous woodland, fuelwood/fodder shortage	Soil erosion; shortening of fallows; over-grazing, deforestation and ecosystem degradation; fodder/fuel shortage
Major agroforestry emphasis	Improved fallows, soil fertility improvement and conservation, food production	Fuelwood/fodder production, soil-fertility improvement, windbreaks and shelterbelts, food production	Soil conservation, fodder/fuel production, watershed management, ecosystem stabilization and protection of rare species

* Adapted from Young (1986) in consultation with A. Young.

in areas with high human population densities. Various forms of homegardens, plantation-crop combinations, and multilayer tree gardens are common in such regions. In areas with a low population density, such as the low selvas of Latin America, trees on rangelands and pastures, other silvopastoral systems, improved fallow in shifting cultivation areas, multipurpose tree woodlots, etc. are the common AF systems. Examples of AF systems in the humid tropical lowlands about which ICRAF has data in the computerized AFSI database are included in Appendix 6.1.

The lowland humid tropics also include areas under natural rain forests. In such areas, cutting of rain forest at rates much faster than natural or managed regeneration is a common problem. This causes shortening of fallow periods in shifting-cultivation cycles and resultant loss of soil productivity and accelerated soil erosion. The potential of appropriate agroforestry systems to combat these problems needs to be exploited in future land-use strategies in this zone.

3. Agroforestry systems in semi-arid and arid tropics

Extending over the savanna and Sudano-Sahelian zone of Africa, the cerrado of South America and large areas of the Indian subcontinent, the semi-arid and arid tropics are characterized by one or two wet seasons (*Koeppen Aw* or *Aw'*, respectively) and at least one long dry season. Drought is a hazard in the drier parts of the zone.

The main agroforestry systems in this zone also depend on the human population pressure; homegardens and multilayer tree gardens are common in the wetter areas with high population pressure. But generally speaking, the most predominant AF systems in this zone are:

- Various forms of silvopastoral systems,
- Windbreaks and shelterbelts, and
- Multipurpose trees on crop lands, notably *Acacia albida*-based systems in Africa and *Prosopis*-based agrisilvicultural systems in the Indian sub-continent (see Appendix 6.1).

Fuelwood shortage is a major problem in most parts of the semi-arid and arid tropics. Agroforestry potentials in fuelwood production are well documented (e.g., Nair 1987). Similarly, desertification and fodder shortage, which are the other major ecological problems in this zone, could be tackled to some extent through the agroforestry approach.

4. Agroforestry systems in tropical highlands

Approximately 20% of the tropical lands are at elevations from 900 to 1,800 m, in about half of the Andean highlands of Central and South America, parts

of Venezuela and Brazil, the mountain regions of the Caribbean, many parts of East and Central Africa, the highlands of Cameroon, same parts of the Deccan Plateau of India and some parts of the south-east Asia mainland. The altitude exceeds 1,800 m in about 3% of the tropical area in the Andes, the Ethiopian and Kenyan highlands, northern Burma and parts of PNG. In the subtropical regions, the most important highlands are in the Himalayan region.

The areas in these highland tropics with significant agroforestry potential are humid or subhumid; those with dry climates have very low potential. Land-use problems in the highlands are similar to those in humid or dry lowlands, depending on the climate, with the addition that sloping lands and steep terrain make soil erosion a major concern. Moreover, the annual temperatures are low in the highlands (for every 100 m increase in elevation in the tropics, there is a decline of 0.6°C in the mean annual temperature), and this affects the growth of certain lowland tropical species.

The main AF systems in the tropical highlands are:

- Production systems involving plantation crops such as coffee and tea in commercial as well as smallholder systems;
- Use of woody perennials in soil conservation and soil-fertility maintenance;
- Improved fallows; and
- Silvopastoral combinations (see Appendix 6.1).

5. Agro-ecological analysis of existing agroforestry systems

The existence of an AF system/practice in a particular area is determined not only by environmental and agro-ecological factors, but also by socio-economic considerations. In different areas with identical agroclimatic conditions, factors such as human population pressure, availability of labour and other production resources, proximity and accessibility to market sources, etc., are the main determinants of the types and forms of agroforestry systems. Even in the case of systems that are widespread in most ecological and geographical regions, such as shifting cultivation and taungya, these systems have very many variants that are specific to certain defined situations. As a general rule, it can be said that while the ecological factors determine the major type of AF system in a given locality, the complexity of the system and the degree of intensity of its management increase in direct proportion to the population intensity and land productivity of the area. A typical example is the spread of multispecies, multistoreyed homegarden systems. Though found mostly in humid lowlands, homegardens are common in pockets of high population density in other ecological regions also. Analysing the structural and functional aspects of ten selected homegarden systems from different ecological

regions, Fernandes and Nair (1986) found that although the average size of each homegarden unit is less than 0.5 ha, the units are composed of a large number of woody and herbaceous species carefully structured to form 3-5 vertical canopy strata and each component having a specific place as well as function in the multispecies complex.

There are some functional aspects of specific AF practices that are emphasized or necessitated in specific agro-ecological situations. For example, the functional emphasis of AF systems in sloping lands is erosion control and soil conservation; in wind-prone areas, woody species are successfully used as shelterbelts and windbreaks; the emphasis is on fuelwood production in areas with fuelwood shortage; there are also specific agroforestry approaches for the reclamation of degraded lands and other waste lands (such as highly eroded lands, areas with high levels of salinity/alkalinity, etc.).

The ecological potential of an area is undoubtedly the prime factor that decides the adoption and spread of specific AF systems in different parts of the world. The preponderance of homegardens and other multispecies mixes in fertile lowlands and high potential areas at one end of the ecological scale and extensive silvopastoralism at the other end, with various systems in between, gives a spectrum of agro-ecological adaptability and spread of various AF systems. This is schematically presented in Fig. 6.2.

Figure 6.2 represents a very rough approximation of the general pattern of the major agroforestry systems in different ecological regions. It does not include all AF systems, nor does it fully portray the relative spread (in terms of areas involved) or the level of management of the various systems. A further step in this direction is to indicate the major known areas of concentration of important agroforestry systems in the tropics and subtropics, i.e., something like a "map of the agroforestry situation in the tropics and subtropics". This is attempted in Fig. 6.3.

The "map" represents areas with a relative abundance of specified agroforestry systems, but does not identify localized systems or systems whose presence is relatively less significant in an area. For example, as mentioned earlier, "multipurpose trees on farmlands" can be found in almost all ecological and geographical regions. But there are only a few such systems that make them distinctly unique agroforestry systems. Examples include the arid-zone systems involving *Acacia albida* (Miehe 1986; Poschen 1986) and *Prosopis* (Shankarnarayan *et al.* 1987). Thus, only some such "multipurpose trees on farmlands" systems have been studied and/or described in some detail, and thus gone into ICRAF's AFSI data records. The mention of the existence of any of these systems in Fig. 6.3, therefore, is mainly an indication that AFSI records are available on it. Indeed, innumerable location-specific agroforestry systems and practices do exist all over the tropics and subtropics and many of them are important in various ways. But, often many of them are not important enough in the overall economy and land-use pattern of the area

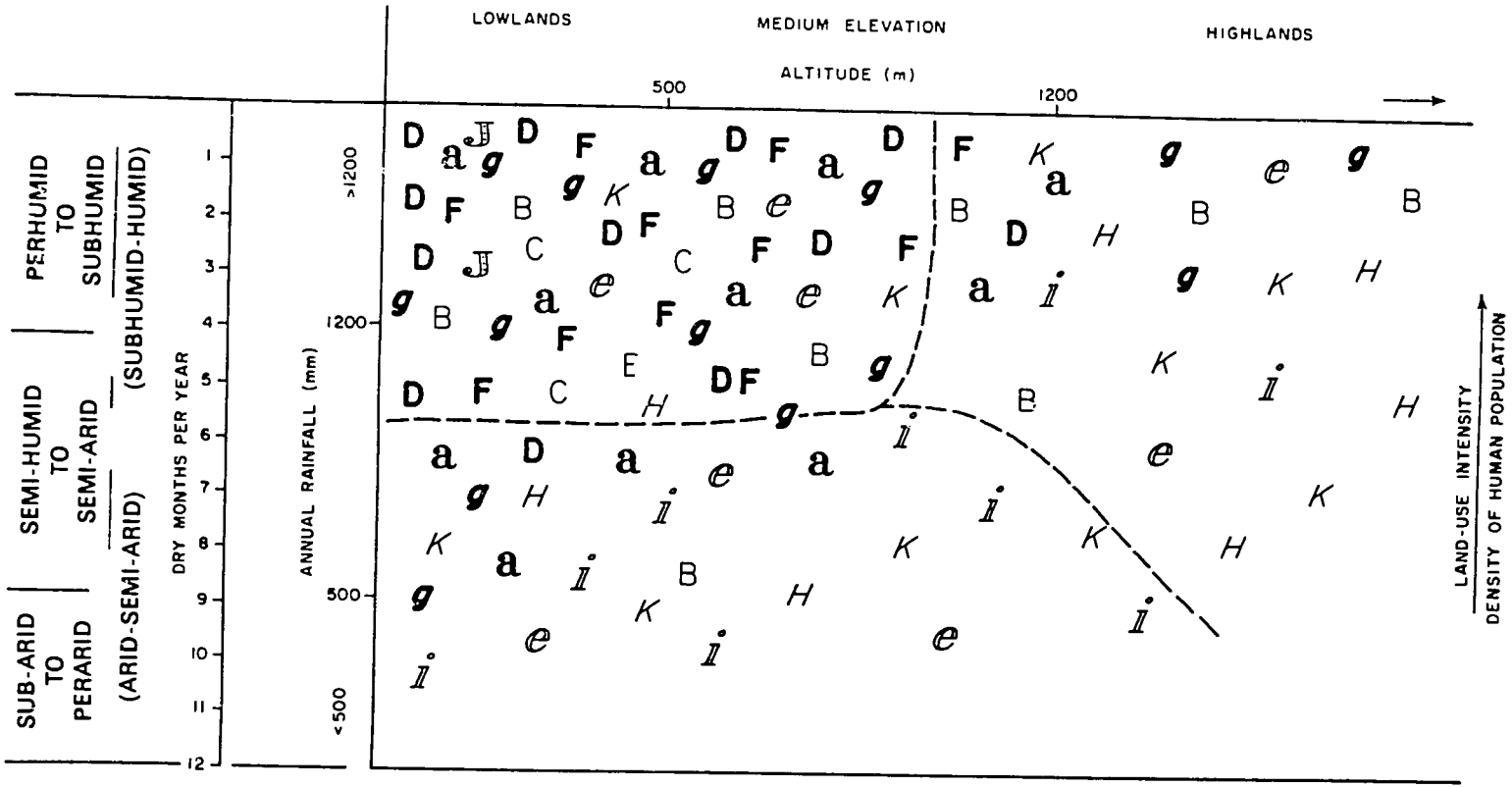
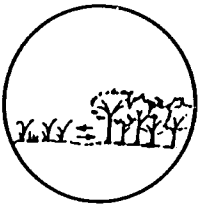
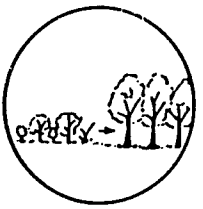


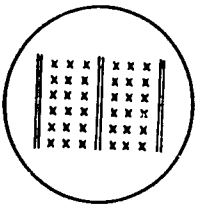
Fig. 6.2. Ecological spread of major agroforestry systems (see legend for systems on p. 70)



a
Improved fallows in shifting cultivation

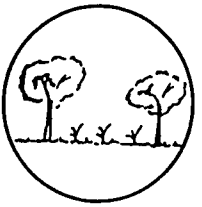


B
Improvement to taungya

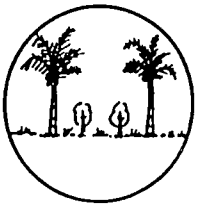


C
Alley cropping

D
Multilayer tree gardens

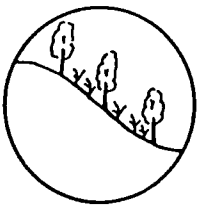


e
Multipurpose trees on croplands

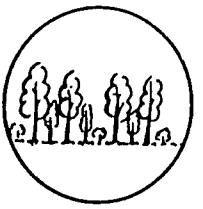


F
Plantation crop combinations

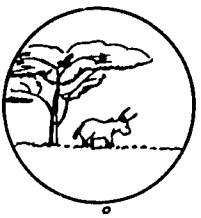
g
Homegardens



H
Tree hedges for soil conservation

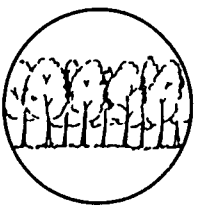


H
Windbreaks/ shelterbelts



I
Trees on pastures/ rangelands

J
Trees in pisciculture



K
MPT woodlots for fodder/fuel

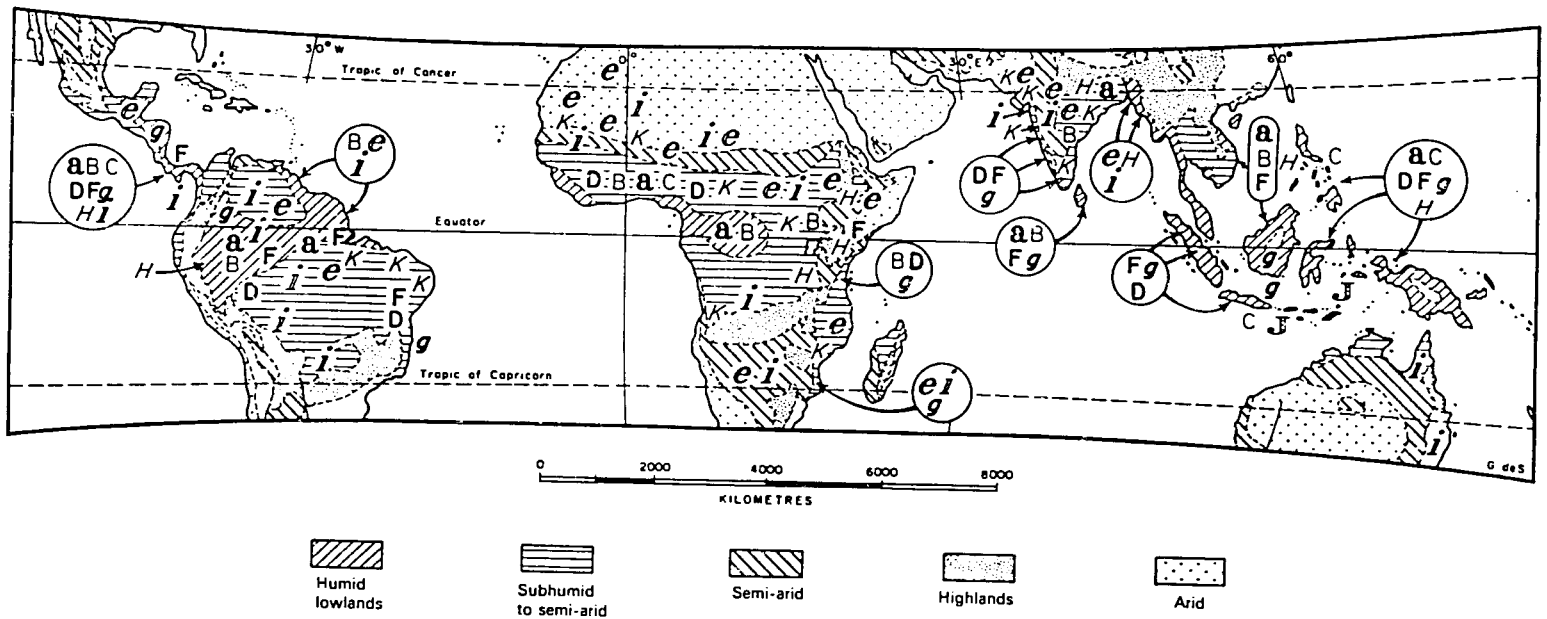


Fig. 6.3. Major agroforestry systems in different ecological regions of the tropics and subtropics (see legend for system names on p. 70).

where they exist to merit special mention on such a highly condensed and abstract global map.

This "map" (Fig. 6.3) is an improvement over Fig. 6.2 in that geographical spread of the systems is shown in relation to the ecological conditions in different places. One significant feature that emerges from this is that, irrespective of the socio-cultural differences in different geographical regions, the major types of agroforestry systems are structurally similar in areas with identical ecological characteristics. The level of intensity at which these different systems are managed will, obviously, be different in various situations.

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Appendix 6.1

MAJOR AGROFORESTRY SYSTEMS AND PRACTICES IN DIFFERENT ECOLOGICAL ZONES OF THE TROPICS AND SUBTROPICS*

System/practice	Major output/ function	Country/region	Socio-economic scale of production	Major woody species involved	Remarks
1. *Humid/sub-humid lowlands*					
1.1. *Agrisilvicultural systems*					
1. Improved "fallow" (in shifting cultivation areas)	Food and wood production; soil-fertility improvement	Indonesia	Subsistence	*Aleurites molucana* *Erythrina* spp. *Styrax* spp.	
		Nigeria	Subsistence	*Acioa barterii* *Anthonotha macrophylla* *Gliricidia sepium*	
		Also being tried in many other places		Various fruit trees also being tried	"Forest villages of Thailand"; Boonkird *et al.* 1984 (Ch.14)
2. Hedgerow inter-cropping (alley cropping)	Production of food and firewood; soil-fertility improvement and soil conservation	S.E. Asia Nigeria Now being tried in very many places, mostly on experimental basis	Subsistence (experimental)	*Calliandra callothyrsus* *Leucaena leucocephala* and several other species	Allen 1985 (Ch.18)

3. Multispecies mixes (tree gardens)	Production of food, fodder and wood products for home consumption and sale for cash	Nigeria	Subsistence	*Daniellia oliveri* *Gliricidia sepium* *Parkia clappertoniana* *Pterocarpus africana*	"Compound gardens of Nigeria"; Okafor and Fernandes 1987 (Ch. 25)
		Pacific islands	Subsistence	*Inocarpus edulis* *Morus nigra* *Spondias dulce*	
		India Sri Lanka	Subsistence Intermediate	*Areca catechu* *Artocarpus* spp. *Cocos nucifera* *Mangifera indica* *Zyzygium aromaticum*	"Homestead agroforestry in Kerala, India"; Nair and Sreedharan 1986 (Ch. 10)
		Paraguay	Subsistence, Intermediate	*Melia azedarach* *Leucaena leucocephala*	
		S.E. Asia	Subsistence Intermediate	*Albizia falcataria* *Artocarpus* spp. *Bambusa* spp. *Cinnamomum aromaticum* *Durio zibethinus* *Nephelium lappacium*	"Multistoreyed garden system of Sumatra"; Michon *et al.* 1986 (Ch. 16)

System/practice	Major output/function	Country/region	Socio-economic scale of production	Major woody species involved	Remarks
4. Multipurpose trees/shrubs on farmlands	Production of food, fuelwood, other wood products; sustainability of production; soil conservation	Brazil	Intermediate Subsistence	*Cassia excelsa* *L. leucocephala* *Mimosa scabrella*	
		India	Subsistence Intermediate	*Derris indica* *Emblica officinalis* *Moringa oleifera* *Tamarindus indica*	Jambulingam and Fernandes 1986 (Ch. 9)
		Kenya	Subsistence	*Anacardium occidentale* *Ceiba pentandra* *Mangifera indica* *Manilkara achras*	
		S.E. Asia	Subsistence Intermediate Commercial	*Acacia mangium* *Artocarpus* spp. *Durio zibethinus* *Gliricidia sepium* *Sesbania grandiflora*	Nair and Sreedharan 1986 (Ch. 10)
5. Crop combinations with plantation crops				Plantation crops involved *Anacardium occidentale* *Camellia sinensis* *Cocos nucifera* *Coffea arabica* *Elaeis guineensis* *Hevea brasiliensis* *Piper nigrum* *Theobroma cacao*	Leuschner and Khalique 1987 (Ch. 13)

(i) Integrated production of plantation crops and other crops	Production of plantation crops for sale (cash)				
	Production of subsidiary (food) crops: sustainability				
(ii) Mixtures of plantation crops		Brazil	Commercial to subsistence	*Bertholletia excelsa* *Copernicia prunifera* *Cordia alliodora* *Inga* spp. *Orbignya* spp. *Samanea saman*	Alvim and Nair 1986 (Ch. 30) Johnson and Nair 1984 (Ch. 28) May *et al.* 1985 (Ch. 29)
(iii) Shade trees for commercial plantation crops		Costa Rica	Commercial to subsistence	*Cordia alliodora* *Erythrina poeppigiana* *Gliricidia sepium* *Inga* spp.	
		India Sri Lanka	Subsistence to commercial	*Albizia* spp *Cassia* spp. *Erythrina* spp. *Grevillea robusta*	Liyanage *et al.* 1984 (Ch. 11)
		S.E. Asia	Commercial to subsistence	Various fruit trees	
		West Indies	Subsistence Intermediate	*Inga vera* Various spice trees	

System/practice	Major output/ function	Country/region	Socio-economic scale of production	Major woody species involved	Remarks
		Western Samoa	Subsistence	*Erythrina variegata* *Gliricidia sepium* *Leucaena leucocephala*	
6. AF for fuelwood production (interplanting firewood species on or around field/farms)	Production of fuelwood; production of other products like food, poles, fodder	India	Subsistence	*Albizia* spp. *Cassia siamea* *Casuarina* spp. *Derris indica* *Emblica officinalis*	Nair (1987) Jambulingam and Fernandes 1986 (Ch. 9)
	Fencing, shade, shelterbelts, etc.	Indonesia	Subsistence	*Albizia falcataria* *Calliandra callothyrsus* *Sesbania grandiflora* *Trema orientalis*	
7. Shelterbelts, windbreaks, soil-conservation hedges	Protective roles (shelterbelt windbreak, etc.) Soil conservation; Production of food, fuelwood	India	Subsistence Intermediate	*Casuarina equisetifolia* *Syzygium cuminii*	
		Indonesia and other parts of S.E. Asia	Subsistence Intermediate	*Gliricidia sepium* *Leucaena leucocephala* *Sesbania grandiflora*	

1.2. *Silvopastoral systems (humid/subhumid lowlands)*

1. Protein bank; multipurpose trees on or around farmlands	Production of fodder/livestock and food crops	India Nepal Sri Lanka	Mostly subsistence	*Artocarpus* spp. *Anogeissus latifolia* *Bombax malabaricum* *Cordia dichotoma* *Dalbergia jambolana* *Samanea* spp. *Zizyphus jujuba*	
2. Living fences of fodder trees and shrubs	Service function (fences); production of tree products	Costa Rica		*Diphysa robinoides* *Gliricidia sepium*	
		Ethiopia	Subsistence	*Erythrina abyssinica*	
		S.E. Asia	Subsistence	*Sesbania grandiflora*	
3. Trees and shrubs on pastures	Production of pasture livestock and wood	Brazil	Mostly subsistence	*Acacia* spp. *Anacardium occidentale* *Cedrela odorata* *Cordia alliodora* Various palms	Johnson and Nair 1984 (Ch. 28)
		Costa Rica	Subsistence	*Enterolobium cyclocarpum* *Erythrina poeppigiana* *Samanea* spp.	Escalante 1985 (Ch. 31)
		India	Subsistence to intermediate	*Derris indica* *Emblica officinalis* *Psidium guajava* *Tamarindus indica*	

System/practice	Major output/ function	Country/region	Socio-economic scale of production	Major woody species involved	Remarks
1.3. *Agrosilvopastoral systems (most ecological zones)*					
1. Homegardens: tree-crop-livestock mix around homestead (these dense associations are found in almost all ecological regions and countries; only some examples are given)	Production of food/fodder fuelwood, etc. for home consumption, and, sometimes, for sale (cash)	South and S.E. Asia	Subsistence to intermediate		"Kandyan gardens of Sri Lanka"; Jacob and Alles 1987 (Ch. 12)
		Nigeria	Mostly subsistence		
		Latin American countries	Mostly subsistence		
		Tanzania (highlands)	Subsistence to intermediate		"Chagga homegardens"; Fernandes *et al.* 1984 (Ch. 12)
2. Woody hedgerows for browse, mulch, green manure and soil conservation	Production of food/fodder/ fuelwood; soil conservation	Indian sub-continent	Mostly subsistence	*Erythrina* spp. *Leucaena leucocephala* *Sesbania* spp.	"Homestead agroforestry in Bangladesh"; Leuschner and Khalique 1987 (Ch. 13)
		S.E. Asia			
2. *(Dry) semi-arid and arid regions*					
2.1. *Agrisilvicultural systems*					
1. Multipurpose trees and shrubs on farmlands	Same as in lowlands	Brazil	Subsistence	*Caesalpinia ferrea* *Prosopis juliflora* *Zizyphus joazeiro*	

In many places, strips of trees are planted along the edges of contour terraces		Central African Republic	Subsistence	*Adansonia digitata* *Balanites aegyptiaca* *Borassus aethiopium*	von Maydell 1987; Le Houérou 1987
		India	Subsistence	*Cajanus cajan* *Derris indica* *Prosopis cineraria* *Tamarindus indica*	Shankarnarayan *et al.* 1987 (Ch. 8)
		Kenya	Subsistence	*Acacia* spp. *Balanites aegyptiaca* *Cajanus cajan*	
		Sudan and Sahelian countries	Subsistence	*Acacia albida*	Poschen 1986 (Ch. 23) Miehe 1986 (Ch. 22)
		Tanzania	Subsistence	*Acacia* spp. *Combretum* spp.	
2. AF fuelwood production	Fuelwood	Chile	Subsistence	*Prosopis tamarugo*	
		India	Subsistence	*Albizia lebbek* *Cassia siamea* *Prosopis* spp.	
		Sahel	Subsistence	*Acacia albida* *A. senegal* *A. tortilis*	

System/practice	Major output/ function	Country/region	Socio-economic scale of production	Major woody species involved	Remarks
3. Shelterbelts and wind-breaks	Protection of agricultural fields from winds; production of fuelwood	India Pakistan	Subsistence, Intermediate	*Azadirachta indica* *Cajanus cajan* *Cassia siamea* *Eucalyptus* spp. *Pithecellobium dulce* *Populus* spp.	Shankarnarayan *et al.* 1987 (Ch. 8)
2.2. *Silvopastoral systems (dry regions)*					
1. Protein bank	Same as in other regions	India	Subsistence	*Acacia nilotica* *Ailanthus excelsa* *Opuntia ficus* *Prosopis* spp. *Rhus sinuata*	Jambulingam and Fernandes 1986 (Ch. 9)
2. Living fences	Same as in other regions	East Africa	Subsistence	*Acacia* spp. *Commiphora africana* *Euphorbia tirucalli* *Zizyphus mucronata*	
3. Trees and shrubs on pastures	Same as in other regions	India	Subsistence	*Acacia* spp. *Prosopis* spp. *Tamarindus indica*	
		Middle East and Mediterranean	Commercial	*Acacia* spp. *Ceratonia siliqua* *Haloxylon* spp. *Prosopis cineraria* *Tamarix aphylla*	

3. *Tropical highlands*

3.1. *Agrisilvicultural systems*

1. Multipurpose trees and shrubs on farmlands	Food production; soil conservation	India	Subsistence	*Albizia* spp. *Bauhinia variegata* *Dalbergia sissoo*	"Hill farming in Nepal"; Fonzen and Oberholzer 1984 (Ch. 7)
		Kenya	Subsistence	*Ceiba pentandra* *Eriobotrya japonica* *Grevillea robusta*	
		Nepal	Subsistence	*Bauhinia* spp. *Erythrina* spp. *Ficus* spp. *Litsea polyntha*	
		Paraguay	Subsistence	*Melia azedarach*	"Gigante woodlots"; Evans and Rombold 1984 (Ch. 27)
		Tanzania	Subsistence	*Albizia* spp. *Cordia africana* *Croton macrostachys* *Trema guineensis*	
2. Crop combinations with plantation crops		Brazil	Subsistence Intermediate	*Alnus acuminata* *Enterolobium contorsiliquum* *Erythrina velutina*	
		Costa Rica	Subsistence, Intermediate	*Alnus acuminata* *Erythrina poeppigiana* *Inga* spp.	
		India	Subsistence	*Albizia* spp. *Grevillea robusta*	Bourke 1984 (Ch. 17)
		Sri Lanka			
		Kenya	Subsistence	*Grevillea robusta*	
		Papua New Guinea	Subsistence, Intermediate	*Casuarina olygodon*	
		Rwanda	Subsistence	*Albizia* spp.	
		Tanzania	Subsistence	*Cordia africana* *Grevillea robusta* *Trema guineensis*	

System/practice	Major output/ function	Country/region	Socio-economic scale of production	Major woody species involved	Remarks
3. AF fuelwood production	(Same as lowlands) Nepal	India	Subsistence	*Albizia stipulata* *Bauhinia* spp. *Grewia* spp.	
4. Shelterbelts; windbreaks; soil conservation; hedges		(same as in lowlands)			
3.2. *Silvopastoral systems (tropical highlands)*					
1. Protein Bank	Production of fodder/animals and fuelwood; soil conservation	Indian sub-continent	Mostly subsistence	*Albizia stipulata* *Bauhinia* spp. *Ficus* spp. *Grewia oppositifolia*	
		Morus alba			
2. Living fences	Service roles	Costa Rica	Commercial to subsistence	*Gliricidia sepium*	
		Ethiopia	Commercial to subsistence	*Erythrina abyssinica*	
		East Africa	Commercial to subsistence	*Dovyalis caffra* *Euphorbia tirucalli* *Iboza multiflora*	
3. Trees and shrubs on pastures	Fodder/animal production; food production	Brazil	Mostly subsistence	*Desmanthus varigatus* *Desmodium discolor*	
		Costa Rica	Mostly subsistence	*Alnus acuminata*	
		Indian sub-continent	Mostly subsistence	*Albizia stipulata* *Alnus nepalensis* *Grewia* spp. *Robinia pseudoacacia*	

Part 3

Agroforestry systems in Asia-Pacific

7. Use of multipurpose trees in hill farming systems in western Nepal*

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Abstract. A large number of multipurpose trees and shrubs are deliberately retained or incorporated on farms in the subsistence farming systems on the steep slopes in parts of Nepal. Woody perennials are maintained in contour strips across the slopes and around the fields. The contribution of these trees is the production of fodder and firewood and their protective function in reducing the erosion hazards and thereby making crop production possible on steep slopes where profitable cropping would otherwise be extremely difficult. Based on a case study in two villages of the Western Development Region, this paper presents some data on basic farm-management aspects, production of crops and other components of the system. The performance of the system is assessed and its merits and weaknesses highlighted.

Although the hill-farming system extends over a wide area and accounts for a large proportion of Nepal's population, it has not received any research attention nor benefited from any scientific innovations. The possibilities for improvement in terms of component technologies as well as farming systems, including the incorporation of local medicinal plants, are indicated.

1. Introduction

Nepal, located on the southern slopes of the Himalayas, extends from the Gangetic plain in the south and occupies one-third of the entire length of the Himalayan range. The country has a rectangular shape, approximately 830 km long (east–west) and 200 km broad (north–south), and has a total land area of 147,141 km^2. Within this short distance are remarkable altitudinal variations ranging from a mere 150 m a.s.l. in the southern foothills to well over 8,000 m a.s.l. at the northern crest line. The heavy rainfall of a monsoon-type climate clearly differentiates the forested east Himalayan region from the relatively dry western part. More than 15 million people of different ethnic origins live in this Hindu kingdom.

Nepal is divided into five administrative units or Development Regions, namely, Far Western, Mid Western, Western, Central and Eastern Region.

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This paper is based on a survey of existing agroforestry systems in the hills of the Western Development Region. However, among the different Development Regions, there are many similarities in terms of land-use patterns and socio-economic characteristics, the site-specific variations being brought about by local factors such as aspect of slope (north- or south-facing), foothill (deep soil) vs. hilltop (shallow, poor soil), altitude, etc. Therefore the systems/practices described here can be taken as fairly representative for over 50% of Nepal.

2. General description of the area

The Western Region extends from the Terai lowland (150 m) to the Himalayas (Annapurna, Dhaulagiri – 8,172 m). The system described here is found in the 500–2,500 m altitude range. The climate is warm to temperate with heavy monsoon rains between June and September when 80–90% of the annual rainfall is received. The total quantity of rain varies widely depending on altitude and topography, and ranges from 1,000 to 2,000 mm per annum in areas of about 1,000 m altitude.

The soils, developed from a complex jumble of phyllites, schists, quartzites, granites and limestones, are generally poor for agriculture. They are severely weathered, contain only little organic matter and have a very low capacity to retain moisture and nutrients. In addition, they are prone to serious erosion hazards if not managed carefully: an annual soil loss of more than 12 t ha^{-1} equivalent to 0.8 mm of the topsoil, has been estimated (Tinau Watershed Project 1980).

Climax vegetation also varies according to altitude and topography: in the lower sites (less than 1,000 m) mixed, evergreen broad-leaved forests of the *Shorea robusta*-type prevail; at higher elevations, broad-leaved or pure coniferous forests are found with *Pinus roxburghii* as the predominant species. Figure 7.1 shows the relationship between altitude, ecology and land-use patterns. In general, the steeper the slopes the greater the proportion of forest preserved; the higher the rainfall the greater the agricultural activity. Data on land-use patterns for Palpa District of Western Region are as follows:

- Irrigated (*bari*) land – 6.2%
- Non-irrigated (*khet*) land – 26.0%
- Grassland – 3.2%
- Forest – 37.7%
- Scrub and bush – 24.4%
- Other forms of land use – 2.5%.

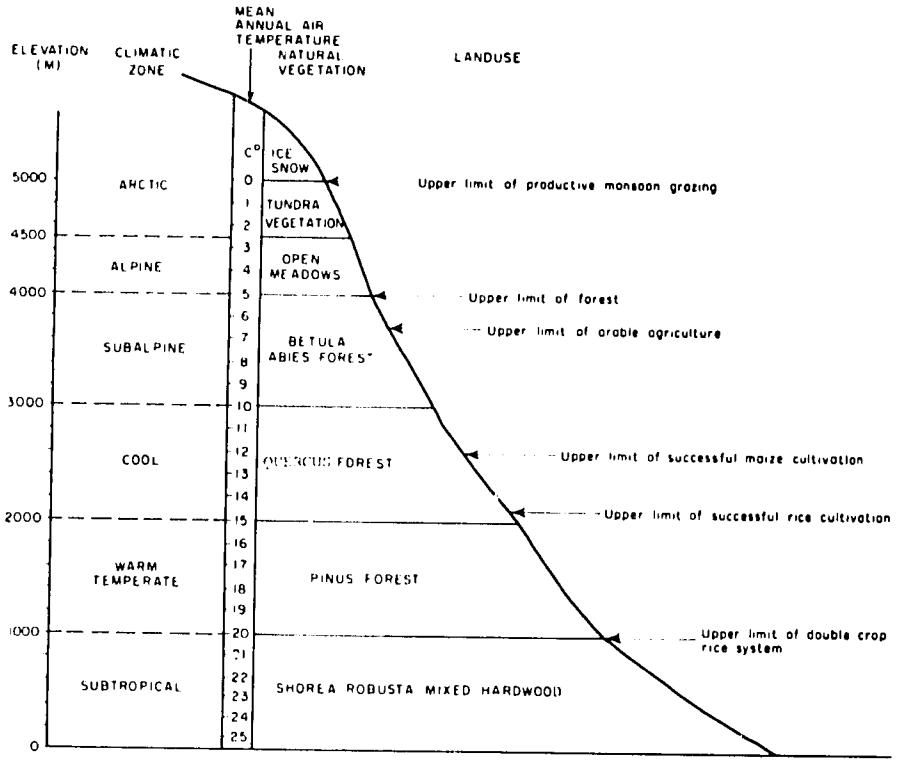

Fig. 7.1. Interrelationships between altitude, mean annual temperature and land-use limits in Western Development Region, Nepal.

An eye-catching characteristic of the foothills and gentle slopes is the terraces dug with great difficulty by the farming families. Slopes too steep for terraces show a dense network of tree strips with sloping fields in between.

Communal grazing land is also found on land of low productivity but close to villages. Very steep slopes, hilltops and areas away from settlements are covered with forest, most of which has been badly denuded. Figure 7.2 gives a general view of the landscape.

Despite these relatively inhospitable conditions, the area is densely populated, with more than 100 persons per km^2 and an annual population growth rate of more than 2.5%. Ninety-three percent of the people have to make their livelihood from agriculture and related activities.

The agroforestry practices that are commonly found in the area are the use of shrubs for live fences around farmlands, pasture (grazing) in forest areas and the use of strips of multipurpose trees and shrubs around sloping fields (those with 40–70% slope). This practice of incorporating multipurpose trees and shrubs is the subject of further description in this paper. The data presented here are based on a case study conducted by E. Oberholzer in two representative villages in Palpa District.

Fig. 7.2. Photograph giving a general view of the landscape of the study area.

3. Structure of the system

The main components of this land-use system are field crops, trees/shrubs and animals.

3.1. *Crops*

The major crops are maize (*Zea mays*), various pulses (*Phaseolus* spp., *Vigna unguiculata*, *Glycine max*, etc.), finger millet (*Eleusine coracana*), vegetables, rape (*Brassica napus*), wheat (*Triticum aestivum*), barley (*Hordeum* sp.), and buckwheat (*Polygonum* sp.). Around the houses, various vegetables and bananas are grown, mainly for household consumption.

3.2. *Trees shrubs*

Several trees and shrubs can be found on the farmlands (terraces). Most of them were not planted but deliberately preserved retained when the terraces were built. The species found most commonly on farmlands are listed in Table 7.1, the first ten species constituting roughly two-thirds of all such woody perennials. Evidently these are the species that are preferred by the farmers for their multiple outputs (fodder, fuel, fruits, timber, fence posts, etc.).

Table 7.1. Perennial plants in contour strips on farmlands Western Nepal in order of prevalence.

Local name	Botanical name	Type	Main use
Kutmero	*Litsea polyantha*	Tree	Fodder, fuel (timber)
Dabdabe	*Garuga pinnata*	Tree	Fodder, fuel (timber)
Keraa (banana)	*Musa* spp.	Tree	Fruit, mulch
Berulo	*Ficus clavata*	Shrub	Fodder
Chilaune	*Schima wallichii*	Tree	Fodder, fuel, timber
Kanyu	*Ficus semicordata*	Tree	Fodder, fuel
Assuro	*Adhatoda vasica*	Shrub	Live fence, erosion control
Sal	*Shorea robusta*	Tree	Timber, fodder, fuel
Gidari	*Premna* spp.	Small tree	Fodder
Badahai	*Artocarpus lakoocha*	Tree	Fodder, fruit, fuel
Bans	*Dendrocalamus strictus*	Tree	Fodder, fuel, timber
	Arundinaria spp.	Tree	Fodder, fuel, timber
	Bambusa spp.	Tree	Fodder, fuel, timber
Forso	*Grewia* spp.	Tree	Fodder, fuel
Thotne	*Ficus hispida*	Tree	Fodder, fuel
Bilaune	*Maesa chisia*	Tree	Fodder, fuel
Khirro	*Wrightia antidysenterica*	Small tree	Live fence
Mayel	*Pyrus pashia*	Small tree	Fuel, timber, live fence
Koiralo	*Bauhinia variegata*	Tree	Fodder, fuel, fruit
Aap (mango)	*Mangifera indica*	Tree	Fruit, fuel
Boklimho	*Rhus javanica*	Tree	Fodder, fuel
Belaunti (amba)	*Psidium guajava*	Tree	Fruit, fuel
Arhu	*Prunus persica*	Tree	Fodder, fuel
Rohini	*Mallotus phillippinensis*	Tree	Fodder, fuel
Simal	*Salmalia malabarica*	Tree	Fuel, timber, spice
Kaulo	*Machilus gamblei*	Tree	Fodder, fuel
Dhalai	*Castanop[illegible]dica*	Tree	Fodder, fuel, timber
Gaelo	*Callicarpa arborea*	Tree	Fodder, fuel
Kiloa	*Tinospora malabarica*	Small tree	Fuel
Dalchini	*Cinnamomum* spp.	Tree	Spice, fuel
Anghero	*Pavetta indica*	Small tree	Fuel
Paingyo	*Prunus cerastoides*	Tree	Fodder, fuel, timber
Amilo	*Berchemia floribunda*	Tree	Fruit, fuel
Khamari	*Gmelina arborea*	Small tree	Fodder, fuel
Kimbu	*Morus alba*	Tree	Fodder, fruit, fuel
Bakaino	*Melia azedarach*	Tree	Fuel, fodder
Kabro	*Ficus lacor*	Tree	Fodder, fuel
Darim	*Punica granatum*	Tree	Fodder, fuel
Gajyo	*Bridelia retusa*	Tree	Fodder, fuel
Amaro	*Antidesma diandrum*	Shrub	Fuel
Jamun	*Syzigium* spp.	Tree	Fodder, fuel
Lankuri	*Fraxinus floribunda*	Tree	Fuel, timber
Ankhatarywa	*Trichilia connaroides*	Tree	Fodder, fuel
Chuletro	*Brassaiopsis hainla*	Tree	Fodder, fuel
Naspati	*Pyrus serotina*	Tree	Fruit, fodder, fuel
Barahmas	*Nerium odorum*	Small Tree	Fuel, sacrificial value
Bharlo	*Bauhinia vahlii*	Tree	Fodder, fuel
Khari	*Celtis australis*	Tree	Fodder, fuel, timber
Aaru bakhadaa	*Prunus domestica*	Tree	Fruit, fuel
Balayo	*Rhus succedanea*	Tree	Fodder, fuel
Phaledo	*Erythrina variegata*	Tree	Fodder, fuel
Chiuri	*Bassia butyracea*	Tree	Fodder, fruit
Nemaro	*Ficus roxburghii*	Tree	Fodder, fuel
Bohori	*Ziziphus jujuba*	Tree	Fodder, fruit
Kafal	*Morus indica*	Small tree	Fruit, fuel

In addition to these trees and shrubs, public (communal/government) forests and grassland in the vicinity provide 30% of the fodder requirements and 70% of the firewood needs of the villagers.

3.3. *Animals*

Table 7.2 indicates the average number of livestock per household.

Table 7.2. Average number of livestock per household.

Animals	No	Uses*
Cows	1.4	Manure, milk, religious needs
Oxen	1.3	Draught, manure
She-buffaloes	1.3	Milk, manure
He-buffaloes	0.1	Draught, manure, meat
Goats	2.6	Meat, manure
Pigs	1.6	Meat
Poultry	5.8	Eggs, meat

* In addition to these uses, the animals are also sold in times of financial need.

3.4. *Arrangement of components*

The cropping systems are different in the non-irrigated (*bari*) and irrigated (*khet*) lands. The cultivation on the sloping *bari* land is very labour intensive. Maize is the most common summer crop, and it is grown as a sole crop or in mixed/relay cropping sequences. On the irrigated (*khet*) lands, one crop of rice

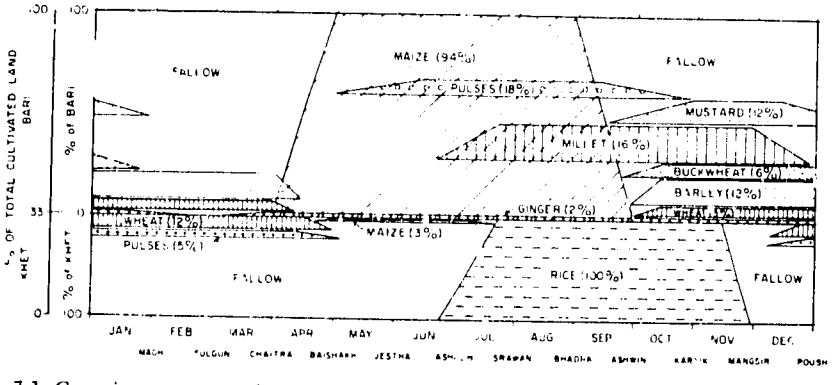

Fig. 7.3. Cropping pattern and cropping intensity on *bari* (non-irrigated) and *khet* (irrigated) lands in Western Nepal.

Fig. 7.4. Photograph showing the arrangement of multipurpose tree strips.

is cultivated as a sole crop. After the harvest of rice, *khet* is fallow for the rest of the year. Figure 7.3 shows the cropping pattern and cropping intensity of the *bari* lands of the Tinau Watershed Project area.

Trees and shrubs are grown usually in strips 1.5–6 m wide along the boundaries of the fields, and the strips are spaced 25–30 m apart. Thus there are about 400 running metres of tree strips of varying width per hectare, covering roughly 10% of the land area (Fig. 7.4).

3.5. *Interactions between components*

The intimate association between the components of the system results in interactions, both positive and negative, in both space and time. The direct interactions involve those between tree strips and field crops (soil conservation, shading by trees on adjacent rows of crops), fodder trees and animals, cattle (manure) and crops, etc. One of the main competitive interactions is the use of grass for thatching and for cattle feed. Then there are cyclic interactions involving the use of crop residues for soil protection and fertility build-up. But the most significant interaction effect between trees and crops in the system is that the whole system of farming on these hills with slopes up to 40% works only due to the existence of contour strips of trees and shrubs. These not only protect the soil from erosion, but also provide much-needed fodder, firewood

and fence posts and other types of farm timber. The farmers are very aware and appreciative of these positive interaction effects of the woody perennial strips so that they reconcile to the negative interaction effects (shading and consequently lower yields of crops near the trees, damage to young crops by dripping of large drops of rain from the overhanging trees, etc.).

4. System functioning and dynamics

4.1. *Socio-economic aspects*

Some of the basic farm management data are given below.

Average number of members per farm household:	6.4 (2–10), of which 2.8 below 15 years
Land available per household	
– Private agricultural land: crops	0.60 ha
grass	0.15 ha
– Private tree strips	0.09 ha
– Common grazing land	0.15 ha
– Forests (communal, governmental)	0.55 ha
Yearly labour input per household	900 man days
– For agriculture	450 man days
– For animals	150 man days
– For water and firewood collection, food preparation (unknown but steadily increasing), estimate	300 man days
Manure produced by stall-fed animals	Equivalent of 35 kg N ha^{-1} yr^{-1} distributed in fields
No chemical fertilizer	
No other external inputs	

Usually all farm production is for home consumption only. Market facilities are poor; the quality of the produce is also poor compared to that of the products from the *terai* flatlands. Therefore, there is only a little sale of produce in nearby towns.

Usually all able-bodied persons work on the household farm, especially at times of peak labour requirement such as the sowing season. Moreover, it is also a common practice for the neighbouring families to give mutual help in farm operations. All work requiring hard physical labour is done by men. During winter, when there are practically no agricultural operations on the farm, there is considerable unemployment when some men look for off-the-farm jobs.

About 10% of the households earn money from non-farming occupations such as carpentry, tailoring, handicrafts, etc.

4.2. *Production*

Agricultural crops

The average yields of agricultural crops on the sloping *bari* land are:

– Maize	899 kg/ha
– Wheat	637 kg/ha
– Millet	206 kg/ha
– Rapeseed	186 kg/ha

At an average of 6.4 members per family, these figures amount to an annual average of 90.9 kg of cereal grain produced per capita. The average consumption of cereals per capita is 130 kg/yr^{-1}, thus there is a deficit of about 40 kg cereal grain per capita annually. This deficit is covered mainly by rice produced in the plains and foothills, which is purchased by cash obtained from the sale of animals or accrued by way of wages when the farmer works elsewhere as a paid worker.

Fodder

Table 7.3 indicates the fodder supply and demand position in the two villages of the study area. The table indicates that the total production is less than the total demand. The deficit is met mainly by collecting fodder from distant areas. But it is also common for the animals to be underfed during the dry season.

Firewood

Each family farm has about 300 running metres of tree strips with 300–400 trees in them. According to the farmers interviewed, these trees provide firewood for the family for about four months of the year. This figure is

Table 7.3. Annual production and demand for fodder in the two villages of the study area.

	Village 1		Village 2	
	Tons TDN*	% of total demand	Tons TDN	% of total demand
Production				
Agricultural by-products				
- wheat, - maize, - millet, - other	28.8	14	13.2	7
Privately owned trees (contour strips)	85.9	41	101.6	58
Private grassland	3.0	1	4.2	2
Forests (government, communal)	49.6	23	43.6	25
Common grazing land	5.7	3	6.3	4
Total	173.0	82	168.9	96
Total demand	211.4	100	176.7	100
Total deficit	38.4	18	7.1	4

Source: Pandey 1982.

Basis of calculations

BLU - Big Livestock Unit of 300-400 kg liveweight
1 cattle - 0.80645 BLU
1 buffalo - 0.86666 BLU
1 goat/sheep - 0.06 BLU
For Nepal, an annual fodder demand of 2 t dry matter/BLU equivalent to 1 t TDN/BLU is estimated.
*TDN = total digestible nutrients.

reasonable if we assume a mean annual consumption of 0.7 m^3 of firewood per head, and an average extraction rate of 18.9 m^3 ha^{-1} yr^{-1}. For the rest of the year, firewood is collected from the public forests around. However, since the growth rate in the public forests is very low (about 3 m^3 ha^{-1} yr^{-1}), these public forests are subjected to rapid degradation and over-exploitation, as can be seen from their depleted appearance all over the country.

Other farm products

The few poles and timber needed to build and maintain houses and for other farm uses are easily obtained from the trees on the contour strips. Some 10% of the families keep honey bees in log hives producing small amounts of honey and wax, which are used for household consumption only.

4.3. *System dynamics*

From the foregoing description, it is evident that this is a purely subsistence system in which practically no improvement has been made over the past several decades. It is likely to break down fast because of pressures of population increase and a myriad of consequent problems -- such as fragmentation of holdings, extending farming to marginal areas and forests, causing more soil erosion and greater firewood shortage, overgrazing of pastures, decline in soil fertility and crop-production level, and so on. In short, the weight of all these factors is destroying the very basis of the improvement in land use. Even now, many people from the hills are migrating to the *terai* flatlands where new land suitable for agriculture is still available. However, even this option will soon be unavailable.

4.4. *Overall performance assessment*

This low-input integrated production system has been functioning for quite some time, though at low production levels, primarily because of the existence of the horizontal contour strips of trees. The greatest contribution of these trees is their protective function in reducing the erosion hazards and thereby making crop production possible on those steep slopes where farming would otherwise be impossible without having extremely expensive terraces and other physical measures of soil conservation. However, it has to be emphasized that these tree strips cannot often stop the erosion completely but only reduce the magnitude of erosion and/or improve the efficacy of the physical soil-conservation devices.

The rainfall distribution pattern is so unsatisfactory that much of the total annual rainfall, which is reasonably high in several places, is received in a short span of time from July to September. This not only aggravates soil erosion, but also diminishes crop growth drastically during eight months of the year.

The hill farming system is a thoroughly neglected system. Although it extends over quite a large area and accounts for the sustenance of a large proportion of Nepal's population, it has not been the subject of any scientific research attention worth mentioning. As a result, the system has continued without any positive change or technological innovations for the past several decades, and the poor farmers continue to become poorer and poorer as the population increases.

The important element of the system that can be extrapolated to other areas with similar problems is the use of multipurpose trees on such steep areas for erosion control and production of multiple outputs. Areas that are rated as unsuitable for crop production because of erosion problems will increasingly

be brought under the plough to cope with increasing population pressure, and then systems like this could serve as field examples where the concept of integrated agroforestry systems have been translated into practice.

5. Improvement possibilities

Two sets of possibilities can be visualized for the improvement of this system. First, improvement through component technologies, and secondly, innovations in farming systems.

5.1. *Component technologies*

A significant sign of improvement that has become evident in the recent past is that young, literate farmers – the majority of the older farmers are illiterate – have begun to be interested in better inputs such as improved crop varieties, improved breeds of cattle, better fruit trees and vegetables for marketing, use of fertilizers, etc., and these efforts have shown substantial improvement possibilities. Several arms of the extension machinery of His Majesty's Government of Nepal are now working in the area. These include agricultural development offices, livestock and veterinary offices, forest offices, and an agricultural development bank that gives credit facilities on favourable terms.

5.2. *Improved farming systems*

Elements of improved farming systems will include use of more fruit trees and the incorporation of a variety of multipurpose trees in the contour tree strips. Agriculture also has a good potential in the area. Intercropping of medicinal plants with the tree species also seems to offer a viable possibility, especially in areas that are very unsuitable for food-crop production. The special report *Medicinal Plants of Nepal* commissioned by the Food and Agriculture Organization of the United Nations (Malla 1982) gives a good account of the medicinal plants, their uses, availability and potential role in farming systems and community forestry programmes. Some of these medicinal plants have already been mentioned as components of the farming systems of the study area (Table 7.1).

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8. Agroforestry in the arid zones of India*

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Abstract. The arid regions of India cover 300,000 km^2 and are spread over six States, mostly in the north-western parts of the country. In spite of the hostile environmental conditions several types of indigenous agroforestry are being practised in this region. The Central Arid Zone Research Institute (CAZRI) has made considerable progress in improving these indigenous practices and also in developing new land-use technologies, some of which involve agroforestry approaches. Notable among these are sand-dune stabilization, shelterbelt plantations, tree-planting techniques in difficult land forms, silvopastoral and agrisilvicultural systems, introduction and improvement of fruit trees and other indigenous trees. Some of these technologies are adopted on a large scale by farmers in the arid zone of India and have attracted attention in other arid parts of the world. This paper is a summary of the results of these agroforestry initiatives of CAZRI.

1. Introduction

The arid and semi-arid lands are characterized by hostile environmental conditions such as low and erratic rainfall, intense solar radiation and high wind velocity. During most of the year, the evapotranspiration far exceeds precipitation. The productivity potential of the land is also usually low. The soils are immature, structureless and very coarse in texture with low water-holding capacity and poor nutrient status. Under such agroclimatic conditions, crop production is a gamble if not impossible. Therefore, people in the arid parts of India depend mainly on livestock production for their sustenance. However, growing agricultural crops under tree crops is also an age-old tradition in this region. This paper describes these traditional practices and outlines the efforts that are being made to improve them.

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2. General description of the arid regions

2.1. *Geographical location*

The arid regions of India cover 317,090 km^2 and lie between 24° and 29° N latitude and 70° and 76° E longitude. The region is spread over six States, namely, Rajasthan, Gujarat, Punjab, Haryana, Maharashtra, Karnataka and Andhra Pradesh, the north-western part of the country constituting almost 90% of the total arid zone area (Fig. 8.1). In Rajasthan State, 11 out of a total of 26 districts are affected by aridity: these are Ganganagar, Bikaner, Jaisalmer, Barmer, Jodhpur and Churu, and most parts of Nagaur (96%), Jalore (88%), Jhunjhunu (69%), Sikar (65%), and Pali (48%). Thus Rajasthan State alone accounts for 60% of the arid zone of India (Table 8.1). The paper focuses on this region.

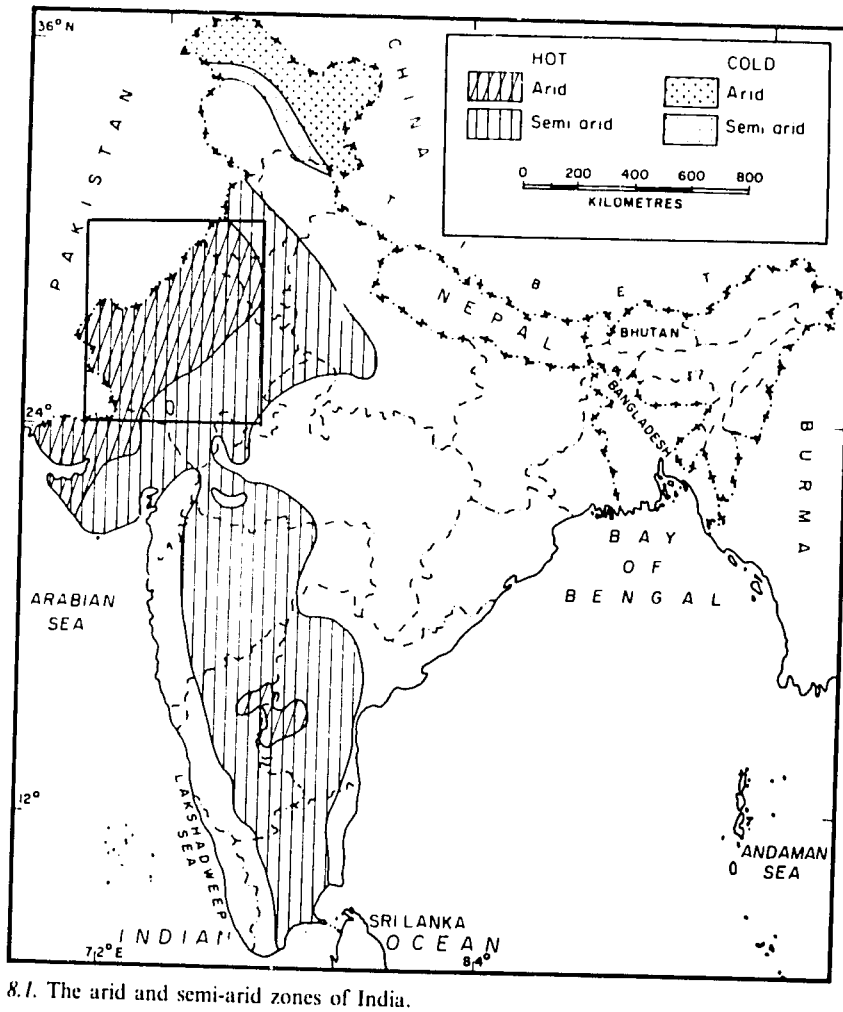

Fig. 8.1. The arid and semi-arid zones of India.

Table 8.1. Distribution of arid areas in the different States of India.

State	Area (km^2)	% total land area of the State
Rajasthan	196,150	61
Gujarat	62,180	19.6
Punjab and Haryana	27,350	9
Maharashtra	1,290	0.4
Karnataka	8,570	3.0
Andhra Pradesh	21,550	7.0
Total	317,090	11.8 (of India)

2.2. *Biophysical environment*

The predominant land form in western Rajasthan is a sand- and alluvia-covered peneplain, in which rock outcrops appear at a few places. Abichandani and Roy (1966) divided the Rajasthan Desert into four physiographic regions: (i) the dune and sand-sheet deposits, (ii) a comparatively dune-free area with rocky outcrops in Barmer, Jaisalmer and Bikaner Districts, (iii) the rocky outcrops in Jalore, Siwana, Nagour, Jodhpur, Phalodi and Bikaner, and (iv) the central Luni and Jawai basin comprising all alluvial deposits of past river streams. The sand cover of the Thar Desert extends for 640 km from north-west to south-east with an average extent of 300 km from west to east. It has a well defined boundary in the east marked by the Aravalli Range.

Climate

An analysis of the isohyet map of the arid regions of north-western India indicates that the mean annual rainfall varies from 100 mm in the north-west to 450 mm in the eastern parts of the Rajasthan desert. Over 90% of the total annual rainfall occurs between June and September. The mean maximum temperature during the summer is 40 C, the highest recorded temperature being close to 50 C. The mean winter temperature varies from 14°C to 16°C, the lowest being around 4 C. The lowest temperature recorded is −4.4°C. The potential evapotranspiration during summer is 7–9 mm/day; during the monsoon it is 5.3–6.4 mm/day and in the winter 1.8–2.9 mm/day. A high wind velocity is characteristic during summer and the monsoon season throughout the north-western arid zone. The wind speeds are lowest during the post-monsoon period.

Soils

In western Rajasthan (arid region), dunes are a dominant formation with 58% cover (Fig. 8.2). The concentration of these dunes varies from place to place

Table 8.2. Extent of sand dunes in western Rajasthan, India.

Extent of sand dunes	Area (sq km)	% of total area
No dunes	85,659.81	41.50
0–20% of area affected	18,902.85	8.90
20–40% of area affected	39,782.25	18.60
40–80% of area affected	34,322.11	14.70
60–80% of area affected	10,164.91	4.80
80–100% of area affected	24,856.60	11.50
Total	213,688.53	100.00

(Table 8.2). The dunes are mostly the parabolic type, but longitudinal, transverse and barchan types also occur. They are extremely sandy with 1.8–4.5% clay, 0.4–1.4% silt, 63.7–87.3% fine sand and 11.3–30.3% coarse sand. They are very poor in organic matter (0.04–0.12%), and have a low to medium phosphorus content (0.5–0.1%). The nitrogen content is low, ranging between 0.02 and 0.07% and the CaO content is in the range of 1.0–1.5%. The infiltration rate is very high, ranging from 7 to 15 cm/hour. In the complete absence of aggregation of any type, the soils are highly erodible (Dhir 1984). Gupta (1968) observed that in most of the aeolian sands the depth of sand deposits decreased from the west to the east.

Vegetation

The vegetation of the hot arid zone is very sparse and consists of scattered thorny trees, shrubs and grasses, classified as tropical thorn forests

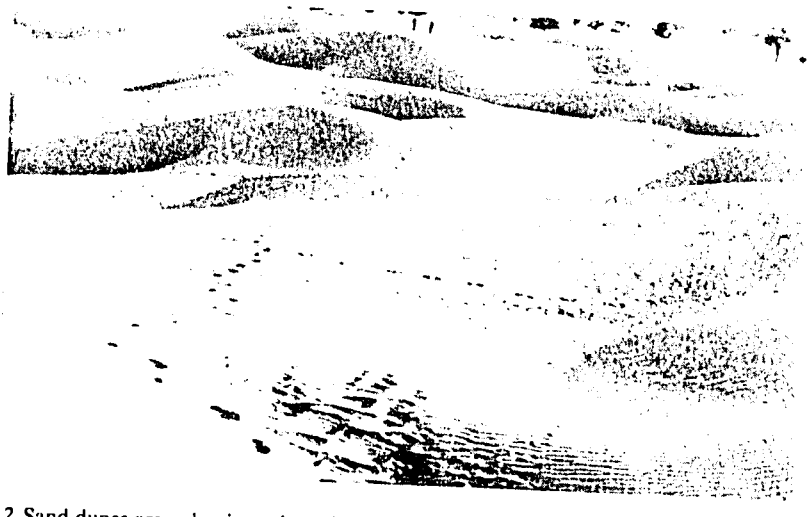

Fig. 8.2. Sand dunes are a dominant land form (58% of area) in western parts of Rajasthan State. (Photo: CAZRI.)

(Champion and Seth 1968). Satyanarayan (1963) classified the vegetation of the arid zone into five types on the basis of land forms:

1. *Mixed xeromorphic thorn forest.* These are the plant communities on the hills, mainly (i) *Acacia senegal* and *Anogeissus pendula* and (ii) *Euphorbia caducifolia.* The common trees and shrubs are *Wrightia tinctoria, Dichrostachys cineraria, Maytenus emarginatus, Cordia garaf, Moringa concanensis, Euphorbia caducifolia, Commiphora wightii, Grewia tenax* and *Barleria prionitis.*

2. *Mixed xeromorphic woodland.* This occurs on sandy soils with kankarpan at varying depths. The common tree species are *Salvadora oleoides, Prosopis cineraria, Acacia nilotica* var. *indica, Capparis decidua, Zizyphus nummularia* and *Leptadenia pyrotechnica.*

3. *Dwarf semi-shrub desert.* The plant communities of this formation are found mainly on flood plains and river beds. The common species are *Salvadora persica, Tamarix dioica* and *Acacia nilotica.* Other associated species are *Aerva persica, Leptadenia pyrotechnica, Zizyphus nummularia* and the grasses *Cenchrus* spp. and *Desmostachya bimnata.*

4. *Psammophytic scrub vegetation.* The plant communities of this formation occur on aeolian deposits or stabilized sand dunes where the soils are very deep. The common plant species are *Calligonum polygonoides, Acacia jaquiemontii, Crotalaria burhia, Calotropis procera* and *Aerva persica.* The common grass species are *Lasiurus sindicus, Cenchrus* spp. and *Panicum turgidum.* The size and concentration of the dunes markedly affect the composition of the associated plant communities. In the areas with high-to-medium-sized dunes, the common species are *Calligonum polygonoides* and *Panicum turgidum,* while in stabilized sand dunes the common species are *Prosopis cineraria, Salvadora oleoides, Capparis decidua, Zizyphus nummularia* and *Tecomella undulata.*

5. *Succulent and halophytic plant community.* This is found on low-lying and saline areas generally known as "Rann". The common halophytes are *Haloxylon salicornicum, Sueada fructicosa* and *Salsola foetida.*

2.3. *Land-use systems*

Forest cover. About 10.2% of Rajasthan State is under forest (34,913 km^2), but in western Rajasthan only 1.5–1.8% of the land is covered by forest (Table 8.3).

Agriculture

A study of the pattern of land use in the arid districts for the period 1951/52–1973/74 revealed that the net sown area increased by 54.11% in the 20 years from 1951. Barren, cultivable and uncultivable wastelands, permanent pastures and fallow land declined by 23.75% during this period. There

Table 8.3. Land utilization in the arid zones of India.

Land-use category	Area (million hectares)	% of total arid zone area
1. Forest	0.58	1.88
2. Not available for cultivation (area put to non-agricultural uses: barren and uncultivable lands)	6.70	23.85
3. Other uncultivated land excluding fallow land, permanent pastures and grazing lands + land under tree crops and groves + cultivable waste)	5.42	19.30
4. Fallow lands (current fallow + others)	3.3	11.72
5. Net area sown	12.2	43.25
Total reported for land utilization	28.1	
Total geographic area (of arid zone)	31.7	

was a significant decline in the grazing lands because marginal lands were brought under cultivation. Because of the adverse weather and soil conditions, only one crop is sown a year. "Bajra" (pearl millet, *Pennisetum glaucum*), cluster bean (*Cyamopsis tetragonoloba*), mung bean (*Vigna mungo*) and moth bean (*V. aconitifolius*) are the common crops.

The growing of annual crops on such lands is not an economically viable activity. It has been estimated that the net return per hectare of agricultural land employing family labour ranges between Rs 70 and Rs 150 with an average of Rs 108 (1 US $ = Rs 8 in 1979). After accounting for the family labour employed in cultivation at Rs 5 per man-day, the net annual returns per hectare to land and enterprise ranged from Rs 55 to Rs 15 and the average worked out at Rs 18 (Gupta and Mohan 1979). Complete crop failures are also common.

Thus, cultivation of agricultural crops as the only land-use activity is uneconomical and extremely risky. Therefore most of the desert farmers raise livestock as a subsidiary occupation and allow shrubs and trees to grow in the cultivated tract as a means of covering the risk and uncertainty of crop production.

Traditional agroforestry

As already mentioned, the growing of trees and shrubs in the crop field is an age-old practice. A recent survey has identified seven types of agroforestry

Table 8.4. Traditional agroforestry systems in the arid zone of Rajasthan.

Zone	Tree/shrubs with agricultural crops
Jaisalmer-Pugal-Girob (below 150 mm isohyte)	*Zizyphus nummularia* ("bordi") grown with agricultural crops. The *Prosopis cineraria* ("khejri") trees are very few.
Barmer-Osian-Bikaner belt	Crops grown in association with *P. cineraria* and *Z. nummularia*
Jodhpur-Nagaur-Shekhavati belt	Crops mainly grown in association with *P. cineraria* and a limited number of *Z. nummularia* plants are available.
Nawalgarh-Dikar	Mainly *P. cineraria* dominates in agricultural fields but a few *Ailanthus excelsa* are also in agricultural fields.
Pali	The dominating tree species are *Acacia nilotica* var. *cupressiformis* and *A. nilotica* var. *radiane*. Both the "kharif" (summer monsoon) and "rabi" (winter) crops are grown with these trees.
Arid and semi-arid areas bordering eastern Ajmer	*Prosopis cineraria* dominates but *Acacia leucophloea* is also present. Some crops are grown in association with these species.
Jalore District	In this tract *Salvadora persica* and *S. oleoides* dominate; crops are grown with these trees.

Source: Malhotra 1984.

practices in Rajasthan (Malhotra 1984): these are summarized in Table 8.4. Fig. 8.3 shows the spread of "khejri" (*Prosopis cineraria*) trees on the agricultural lands, one of the common systems.

Fig. 8.3. "Khejri" (*Prosopis cineraria*) trees on agricultural fields, a very common sight in western Rajasthan. (Photo: P.K.R. Nair, ICRAF.)

3. Recent studies on improvements to traditional agroforestry

The objective of introducing tree species in agricultural fields is not only to cover the risk of crop failure but also to meet demands for fuel, fodder and timber. Trees also enhance soil fertility. But systematic attempts to identify appropriate agroforestry systems for different localities and to improve them for higher productivity and better economic returns had seldom been made until the early 1970s. Therefore, research on agroforestry and silvopastoral systems was initiated at the Central Arid Zone Research Institute (CAZRI), Jodhpur, India in the early seventies. The most important results of these efforts are summarized below. Details are reported in the Institute's Annual Reports and other publications, especially in a recent compendium (Shankarnarayan 1984).

3.1. *Silvopastoral studies*

A comprehensive account of the scope of silvopastoral management in the arid region was given by Muthana and Shankarnarayan (1978). Silvopastoral studies were undertaken at the Regional Research Station of CAZRI at Pali, Jodhpur in 1970 and involved treatments comprising four tree species, namely, *Acacia tortilis*, *Azadirachta indica*, *Albizia lebbek* and *Holoptelia integrifolia*. Four different grasses, namely, *Cenchrus ciliaris*, *C. setigerus*, *Dichanthium annulatum* and *Pannicum antidotale* were introduced between these tree species. Trees without grasses were used as a control.

The results revealed no significant differences in grass production under different trees. The mean dry forage yield in *D. annulatum* was 2,800 kg/ha, followed by *C. ciliaris* (2,510 kg/ha) and *P. antidotale* (2,160 kg/ha).

Intercropping with grasses had no effect on tree growth. The maximum tree height (2.16 m) was recorded for *Azadirachta indica*, followed by *Acacia tortilis*.

Another trial at CAZRI consisted of treatments with three levels of N (0, 20, 40 kg/ha) and two levels of P_2O_5 (0, 20 kg/ha) and combinations of them on silvopastoral systems of *Prosopis cineraria*, *Acacia tortilis* and *Albizia lebbek*, along with five grasses, namely, *Chrysopogon fulvus*, *Cenchrus ciliaris* (cv *Molopo*, and 3108), *Sehima nervosum* and *Cenchrus setigerus*. Fertilizer application improved grass production, but trees did not affect it. The maximum recorded dry-forage yield was in *C. fulvus* with 40 kg N/ha (5,200 kg/ha) as compared to the control (1,200 kg/ha). No significant effect of fertilizer was observed in the other three grasses.

In addition to these studies, some more work was done by Ahuja *et al.* (1978) and Sharma *et al.* (1980). But information on interaction between raised pasture and tree seedlings in the early establishment phase under a

silvopastoral combination was lacking. In another study reported by Muthana *et al.* (1985), it was observed that growth of *Acacia tortilis* was suppressed during the first three years when the tree seedlings were raised with *Cenchrus* spp. After the third year the plants achieved a better growth rate indicating that the plants had, by then, developed a deeper root system and made the optimum use of the soil moisture. In addition to height, the collar diameter (CD), diameter at breast height (DBH) and clear bole length were also recorded. Although trees had no significant effect on grass production, CD and DBH of *Acacia tortilis* were depressed when grown with grasses, whereas clear bole length increased (Tables 8.5 and 8.6). This suggested that in the early stages when there was competition with grasses the main shoot of the

Table 8.5. Mean annual height increment (cm) of *Acacia tortilis* seedlings when planted with and without grass (*Cenchrus ciliaris*).

Treatments	1978	1979	1980	1981	1982	1983	1984
S_1 G_1	32.4	56.2	67.2	74.1	62.0	74.4	23.1
S_1 G_1	14.6	60.1	67.3	95.0	68.9	69.2	19.2
S_1 G_0	60.7	129.5	114.6	43.5	66.3	34.8	15.2
S_2 G_0	31.3	198.3	108.4	58.2	54.4	48.4	23.1

SEm for years	±10.895
F test	H.S.*
CD at 5%	31.028
SEm for treatments	±8.236
F test	H.S.*
CD at 5%	23.455

H.S. = highly significant

Where S_1 = 10 × 5 m spacing of tree
S_2 = 10 × 10 m spacing of tree
G_0 = trees without grass
G_1 = trees with grass

Source: Muthana *et al.* 1985.

Table 8.6. Growth parameters of seven-year old *A. tortilis* grown with and without grass (*C. ciliaris*).*

Treatments	CD	DBH (cm)	CB
S_1 G_0	16.0	11.1	107.7
S_2 G_0	13.8	9.5	96.7
S_1 G_1	10.8	7.4	115.3
S_2 G_1	11.4	8.5	115.9
	Difference between treatments		
S_1 G_0 and = S_1 G_0	+5.2	+3.7	−7.6
S_2 G_0 and S_2 G_1 =	+2.4	1.0	−19.2

* See Table 8.5 for experimental details.

Source: Muthana *et al.* 1985.

Table 8.7. Economics of the silvopastoral systems with *A. tortilis* seven years after establishment.

*Treatments	Fuel yield *(q/ha)	Grass yield *(q/ha)	Revenue (Rs)		
			Fuelwood	Grass	Total
S_1 G_0	60	-	3,000	-	3,000
S_2 G_0	32	-	1,600	-	1,600
S_1 G_1	50	55.8	2,500	1,395	3,895
S_2 G_1	28	52.9	1,400	1,323	2,793
Grass only		46.0	-	1,150	1,150

* See Table 8.5 for details
q = quintal (100 kg)
1US$ = approx. Rs 12 (April 1986)

Source: Muthana *et al.* 1985.

tree grew straight to get the maximum solar radiation. The economic analysis of this system revealed that a combination of trees with grasses would yield better returns in comparison with separate plots of trees and grasses (Table 8.7).

3.2. *Agrisilvicultural study*

Muthana and Arora (1977) studied the effect of *Holoptelia integrifolia* on crops of mung bean and cluster bean ("guar") under different treatments: (a) crops grown between rows of unlopped eight-year-old trees; (b) crops grown under lopped trees, and (c) control (crops without trees). Under unlopped trees, the grain yield was low which indicated that shade had a negative effect on grain yield (Table 8.8). Thus, lopping not only provided fodder for cattle but also enabled the crops to give higher grain yields. In traditional land-use systems, it is a common practice to frequently harvest the foliage of *Prosopis cineraria* and *Zizyphus nummularia* for fodder as well as higher grain yield.

Table 8.8. Grain yield (kg/ha) under lopped and unlopped eight-year-old *Holoptilia integrifolia*.

Species	Unlopped tree	Lopped tree	Crop without trees
Mung (*Vigna mungo*)	201.75	252.06	246.21
"Guar" (*Cyamopsis tetragonoloba*)	93.90	244.14	253.14

In another study initiated in 1983, six-month-old seedlings of *Acacia albida* and *Prosopis cineraria* were planted at 5 × 5 m, 5 × 10 m and 10 × 10 m distances; pearl millet, cluster bean and mung bean were planted in between the rows of trees. Pearl millet was discontinued after the first year.

Table 8.9. Growth of different tree species under different spacings (1983–1985).

Treatments	Height (cm)			Height increment in 3 years (cm)
	1983	1984	1985	
T_1 G_1	38	46	53	15
T_1 G_2	43	48	59	16
T_1 G_3	45	52	58	13
T_2 G_1	78	170	206	128
T_2 G_2	66	146	178	112
T_2 G_2	85	139	174	89

T_1 = *Prosopis cineraria*
T_2 = *Acacia albida*
G_1 = 5 × 5 m spacing
G_2 = 5 × 10 m spacing

Growth of *P. cineraria* was very slow; seedlings grew only 13–16 cm in height in the first three years. In comparison, the growth of *A. albida* was much faster; during the three-year period, it attained a height of 89–128 cm. In *P. cineraria* the height of the seedlings was comparable in all the treatments, but in *A. albida*, growth was fastest in plants spaced at 5 × 5 m. At wider spacings the tree growth was comparatively slow (Table 8.9). The results of grain production for three consecutive years revealed that *P. cineraria* did not interfere with grain production of mung and cluster bean

Table 8.10. Grain yield of mung and "guar" under different tree species (1983–1985).

Treatments	Mung (q*/ha)			"Guar" (q/ha)		
	1983	1984	1985	1983	1984	1985
T_1 G_1	7.85	8.50	0.68	3.60	7.15	1.16
T_1 G_2	8.68	7.90	1.11	3.70	6.53	1.34
T_1 G_3	7.44	6.08	0.75	5.45	5.14	1.28
T_2 G_1	8.08	9.30	0.81	3.32	6.11	6.65
T_2 G_2	7.92	7.51	0.74	0.34	6.34	1.28
T_2 G_3	7.08	6.70	0.61	5.08	5.37	0.76
Control						
Crops without trees	6.40	7.30	1.06	3.20	6.41	0.95

* q = quintal (100 kg)
Details of treatments are given in Table 8.9.

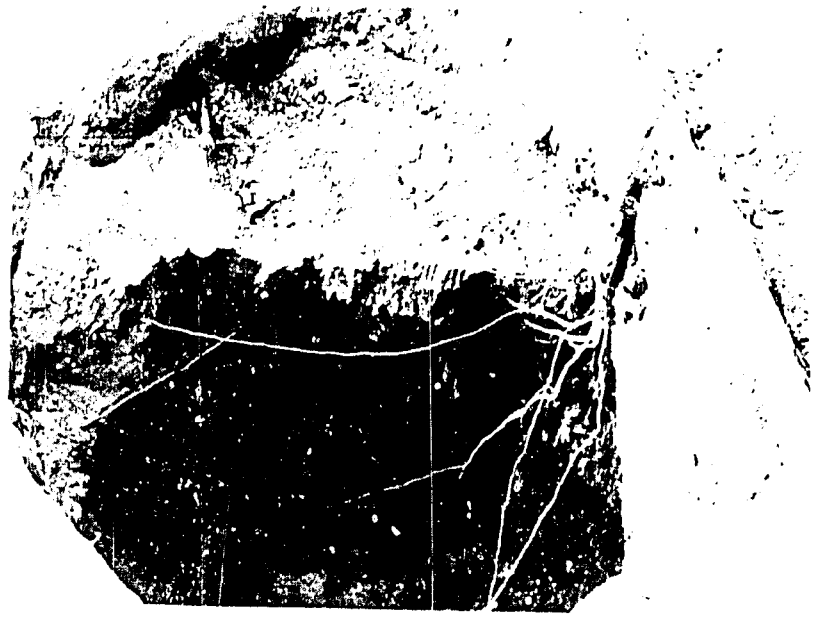

Fig. 8.4. The development of the root system of *Acacia albida* in Rajasthan: the tap root grows vertically downwards. At about 25 cm below the soil surface, about a dozen laterals emerge and grow horizontally up to about 5.5 m. (Photo: CAZRI.)

under different spacing treatments. However, during the third year "guar" yield was adversely affected when it was grown with *A. albida*. In the closer tree spacing the yield was reduced drastically; in wider tree spacing, the "guar" grain yield was 1,280 kg/ha, while in closer spacings it was down to 650 kg/ha (5 × 5 m) and 760 kg/ha (5 × 10 m) (Table 8.10). The yield reduction in closer spacings may perhaps be due to competition for moisture. This was further substantiated by studying the root systems of *A. albida* and *A. cineraria*.

In *A. albida*, the main (tap) root grew, without laterals, vertically downwards. At about 25 cm depth, about a dozen laterals emerged and grew horizontally up to 5.5 m (Fig. 8.4). In the case of *A. cineraria*, the tap root grew downwards up to 45 cm and then bifurcated into two roots, each of which grew vertically downwards up to 1.7 m depth. This horizontal spread of *A. albida* roots in the subsoil enabled the tree to utilize the moisture and nutrients more efficiently and thus grow faster.

At the same time, it is likely that the better growth of *A. albida* trees would have caused greater competition (with crops) for the limited supply of moisture and a consequent reduction in crops yield.

These and other agrisilvicultural experiments and their results are described in detail in two recent reviews by Mann and Daulay (1981) and Shankarnarayan (1984). Figure 8.5 shows an experimental plot of an agrisilvicultural combination on the Institute farm.

Fig. 8.5. Grain legumes under *Hardwickia binata*, one of the experimental (agrisilviculture) plots on CAZRI farm. (Photo: CAZRI.)

3.3. *Effect of trees on microclimate*

Ramakrishna and Sastri (1977) studied the effect of seven-year-old *A. tortilis* trees on the microclimate of the cluster bean crop. The relative humidity under the tree canopy during the active cropping period of "guar" was 7% higher than that in the plot of crop without trees. The air and soil temperatures were also lower under the tree canopy. The sub-surface (0.5 cm depth) temperature under the tree canopy was lowered by 10–16 C, while at 30 cm depth the temperature was lowered by 4–5 C.

3.4. *Effect of trees on soil*

Trees improve the physical and fertility conditions of the soil. The extent of this improvement is dependent upon the type of tree and various other factors. In general, in the arid and semi-arid lands, soil-fertility improvement is a slow process. In *P. cineraria* plantations, the silt and clay content of the soil increased up to a depth of 120 cm, whereas in the open field devoid of trees changes in soil physical conditions were confined to a depth of 90 cm (Singh and Lal 1969). Such improvements in soil physical conditions resulted in the maintenance of higher soil moisture beneath this tree (Aggarwal *et al.* 1976; Gupta and Saxena 1978).

Beneath *P. cineraria*, the pH of the soil was 8.0 as against 8.2 in the open. Similarly, electrical conductivity under this tree was 0.01 m mhos/cm while it was 0.22 m mhos/cm under *P. juliflora* and 0.20 m mhos/cm in the open. The reduced pH beneath this tree is believed to be due to the higher organic matter content and soluble Ca and lower $CaCO_3$ content. Similarly, under this tree there was considerable enhancement of the soil N content, mainly due to higher leaf litter accumulation (Ahuja *et al.* 1978). Substantial enrichment of P and K in the surface layers has also been recorded, though the differences were only marginal at lower depths. The content of micronutrients such as Zn, Mn and Cu was higher both at the surface and lower depths, while Fe was increased only in the surface layer beneath *P. cineraria*. Because of its deep root system, this tree may not cause any competition with undersown crops for soil moisture and nutrients and can thus result in better growth of the companion crop plant. Such improved growth of the understorey species also increases the organic C and N under this tree. Beneath other trees like *P. juliflora*, *A. senegal*, *A. lebbek* and *T. undulata*, there were only marginal changes in the organic content C and N (Aggarwal and Lahiri 1971).

Thus, maintenance of favourable soil moisture and improvement in the soil physical and fertility conditions by *P. cineraria* makes this tree suitable for agrisilvicultural and silvopastoral systems. Further lopping of the tree just before the cropping season eliminates the adverse effects of shading on the understorey crop.

4. Other agroforestry approaches to arid-land management

CAZRI has also been involved in developing various other land-management approaches to arid-zone development, and some of these include agroforestry components. The notable ones are briefly discussed below.

4.1. *Sand-dune stabilization*

As mentioned earlier, 58% of the arid zone of western Rajasthan is covered by drifting or semi-established sand dunes of up to 100 m in height (see Fig. 8.2). These sand dunes are generally devoid of vegetation. Due to the high velocity of prevailing winds, sand drifts from the dunes and engulfs the nearby agricultural fields, canals, wells, railway lines, highways, buildings, etc., and thus causes serious problems. The technique of afforestation for stabilizing sand dunes was developed in CAZRI as early as the 1960 (Bhimaya *et al.* 1961; Kaul 1968). It consists of:

(i) protection against biotic interference;
(ii) treating the affected dunes by fixing micro-windbreaks in parallel strips or chessboard design using locally available shrubs, starting from the crest down to the heel of the dunes. The common locally available bushes are *Zizyphus nummularia*, *Crotolaria burhia* and *Laptadenia pyrotechnica*;
(iii) afforestation of such treated dunes by direct seeding and planting.

The direct seeding of grass species (*Lasiurus sindicus*, *Cenchrus ciliaris* and *Sacharum munja*) and creepers (*Citrullus colosynthis*) is carried out in lines 2–5 m apart on the leeward side of micro-windbreaks. Then nursery-raised seedlings are planted at the onset of the monsoon. The tree species suited for sand-dune stabilization are *Acacia tortilis*, *Prosopis juliflora*, *P. cineraria*, *Acacia nubica*, *A. senegal*, *Dichrostachys glomarata*, *Colophospermum mopane* and *Calligonum polygonoides*.

For semi-stabilized or stabilized dunes, some other species are also suitable. These are *Acacia salicina*, *Eucalyptus camaldulensis*, *E. terminalis*, *E. melanophloia*, *E. coolabaha*, *Hardwickia binata*, *Cassia siamea*, *Albizia lebbek*, *A. amara*, *Tecomella undulata*, *Azadirachta indica* and *Holoptelia integrifolia*. Characteristics of some of these and other arid-zone tree species are given in Table 8.11.

Figure 8.6 shows a plot where sand-dune stabilization with *Acacia tortilis* has been in progress for 11 years, and Table 8.12 gives the fuelwood yield from this *A. tortilis* plot.

Fig. 8.6. Sand-dune stabilization by a fuelwood plantation of *Acacia tortilis*. (Photo: P.K.R. Nair, ICRAF.)

Table 8.11. Characteristics of some arid-zone tree species.

Tree species	Time of collection	No. of seeds 10 gm	Pre-treatment, if any	% germination
Acacia tortilis	Nov. Feb.	195	50% conc. sulph. acid 30 min. in summer and 40 min. in winter	90-95
A. senegal	Aug. Sept.	86	Soaking in water for 24 h	70-75
A. ancura	Mar.-April	659	50% conc. sulph. acid 15 min.	60
A. jacquimontii	Mar.-April	126	40 min. in 50% H_2SO_4	
A. albida		143	30 min. in 50% H_2SO_4	80
A. catechu	Dec. Feb.	415	24 h soaked in water	90
A. nilotica	May-June	79	60 min. in 50% H_2SO_4	
Prosopis cineraria	May-June	231	15 min. in 50% H_2SO_4	90
P. juliflora	Apr.-Nov.	202	–	50
Azadirachta indica	June-July	27	–	75
Tecomella undulata	April-June	800	–	50
Dalbergia sissoo	April	256	–	70
Hardwickia binata	June-July	56	–	60
Dichrostachys mutans	Dec-Jan.	453	15 min. in 50% H_2SO_4	95
Colophospermum mopane	Dec.-Jan.	25	–	85
Leucaena leucocephala	Nov.-Dec.	425	15 min. in 50% H_2SO_4	95
Albizia lebbek	Dec. Aug.	118	–	75
Parkinsonia aculeata	Feb.-July	160	45 min. in 50% H_2SO_4	80

Table 8.12. Fuelwood production of *Acacia tortilis* in arid zones under different spacings.

Plant-to-plant spacing (m)	Fuelwood yield (t/ha) in 12 years Green (wet)	Dry
6 × 6	57.7	39.2
4.5 × 4.5	61.0	44.4
3.0 × 3	76.4	55.6

4.2. *Tree establishment in shallow soils*

Some experiments on planting tree seedlings in shallow soils (22.5 cm depth) overlying hard calcareous pans had also been conducted (Bhimaya and Kaul 1960). Seedlings of *Albizia lebbek*, *Eucalyptus camaldulensis* and *Casuarina equisetifolia* when planted in 30-cm diameter and 60-cm-deep pits had the highest survival rate, but their growth remained stunted. But 60-cm-diameter and 90-cm-deep pits (perforating much of the hard pan) led to seedlings with 100 per cent survival and much better growth. Thus, in shallow soils, transplanting in deep pits was found to be a better technique for raising plantations (Kaul and Gyanchand 1966). The tree species suitable for such establishment are *Acacia tortilis*, *Prosopis juliflora*, *P. tamarugo*, *Cassia siamea*, *Albizia lebbek*, *A. amara*, *Azadirachta indica*, *Ailanthus excelsa*, *Holoptelia integrifolia*, *E. camaldulensis*, *E. melanophloia*, *E. coolabah*, *Zizyphus nummularia*, *Dichrostachys glomerata*, *Dalbergia sissoo* and *Hardwickia binata*.

It was also reported that in semi-rocky areas in the foothills, where the soil is shallow, 60 cm^3 pits that are half filled and combined with a crescent-shaped ridge across the slope gave the best performance in terms of survival rate and growth of seedlings. Some species recommended for such areas are *Acacia tortilis*, *Prosopis juliflora*, *Acacia senegal*, *Butea monosperma* and *Anogeissus rotundifolia*.

Wherever soil deposition exists, pits of 45 cm^3 or 60 cm^3 are dug out and are half filled before planting the seedlings. The other half of the dug-out soil is used for making a crescent-shaped ridge 15–20 cm high across the local slope to collect the run-off rain water.

There are also extensive areas with highly saline soils; they have hardly any vegetative cover except some salt bushes and a little sparse tree growth on hummocky areas. Afforestation of such areas is only possible by ripping open the hard pan to a depth of a metre using a tractor and following it with cross harrowing. After this operation, ridges one metre wide at the base and one metre high are constructed. Planting is done in the pits on the crest of the ridges so that the salt can be leached down from the ridges to lower depths to provide better soil conditions and rooting depth for the transplants. Tree

establishment techniques for alkali soils (pH 10) have also been developed at the Central Soil Salinity Research Institute, Karnal, India (Yardav 1981).

4.3. *Shelterbelt plantation*

Shelterbelts are wide strips of trees, shrubs and grasses planted in rows raised at right angles to the wind direction to deflect air currents, reduce wind velocity and give general protection to roads, canals and agricultural fields. Woody stems, branches and thick foliage help reduce wind hazards (Kaul 1959).

Experimental shelterbelts of *Acacia nilotica* and *Dalbergia sissoo* were established over 102 km in square blocks at the Central Mechanized Farm, Suratgarh in Bikaner District, Rajasthan. Soil working consisted of digging ditches with a triangular cross-section, i.e. 45 cm wide and deep. Planting pits of 30 cm^3 were dug, staggered on either side of the ditches. Additionally, three shelterbelts of 300 metre length having three rows in each belt at 150 metres apart were established to study the effectiveness of the tree species in arresting the sand movement and the growth of crops on the windward and leeward sides (Gupta *et al.* 1984).

Daily observations of wind speed in summer and the monsoon period were recorded at different distances (2H, 5H and 10H) on the leeward side of the shelterbelts. The data are given in Tables 8.13 and 14. Reduction in wind speed was greater in the monsoon period (July-September) than the summer period before the monsoon, and maximum wind reduction was at 2H (see Table 8.13).

Table 8.13. Percentage reduction of wind speed at different distances in the leeward side of different shelter belts (1977 1979).

Plant species	Summer season			Monsoon season		
	*Distances from shelterbelts					
	2H*	5H	10H	2H	5H	10H
Prosopis juliflora	33	17	12	38	26	21
Cassia siamea	36	17	13	46	36	24
Acacia tortilis	36	25	13	46	36	20

* H refers to the height of the shelterbelt.

Source: Gupta *et al.* 1984.

Table 8.14. Effects of different types of shelterbelts on soil erosion.

Type of shelterbelt	Total amount of soil loss (kg/ha) from 20 April to 26 June		
	1979	1980	Mean
Prosopis juliflora	93.2	609.3	351.2
Cassia siamea	91.5	277.1	184.3
Acacia tortilis	106.0	494.1	300.0
Bare soil (without shelterbelts)	262.7	831.0	546.8

Source: Gupta *et al.* 1984.

There was a 5–14% reduction in evapotranspiration from April to July. In general, the use of shelterbelts brought about a 50% reduction in the magnitude of wind erosion. In the *Cassia siamea* shelterbelt, the soil loss was 184.3 kg/ha, while in bare soil (i.e. without any shelterbelt) it was 346.8 kg/ha.

Species tried and found suitable for shelterbelts included *Acacia tortilis*, *A. salicina*, *A. aneura*, *A. nilotica* var. *cupressiformis*, *Prosopis juliflora*, *Cassia siamea*, *C. auriculata*, *Azadirachta indica*, *Albizia lebbek*, *Tamarix articulata*, *Eucalyptus camaldulensis*, *Zizyphus nummuiaria*, *Inga dulce* and *Parkinsonia aculeata*.

4.4. *Improvement of fruit trees and other indigenous trees*

As a part of its regular programmes, CAZRI has been undertaking studies on several multipurpose trees from other parts of the world which might be suitable for arid lands, as well as on improving locally available trees and shrubs. Two species with which substantial progress has been made are the "khejri" tree (*Prosopis cineraria*) and the "ber" (desert apple) *Zizyphus mauritiana*.

Results of studies up to the late 1970s on various aspects of *P. cineraria* have been compiled as a monograph by Mann and Saxena (1980). Some fast-growing strains of the tree are now being studied, some of which have attained a mean height of 399 cm (range 230–520 cm) in seven years.

The cultivation of *Zizyphus mauritiana* has become very popular in the arid regions of India in recent years. CAZRI has undertaken screening, selection and improvement of the plant, and three cultivars, namely, "Seb", "Gola" and "Mundia" are now popular in the 250-450 mm rainfall regions (Pareek and Vashishtha 1978). These can be propagated vegetatively by budding on to the root stocks of any species of *Zizyphus* such as *Z. nummularia*, *Z. rotundifolia*, *Z. jujuba* and *Z. spina-christii*. The budding is usually done from July to September on newly sprouted, soft branches. The planting density

Fig. 8.7. "Ber" (*Zizyphus mauritiana*) with *Prosopis cineraria*. (Photo: P.K.R. Nair, ICRAF.)

varies from 74 to 104 plants per hectare, depending on rainfall. A budded plant starts fruiting in about 18 months and attains full bearing of over 50 kg fruit per year after about five years. Yields of up to 150 kg of fruit per plant have also been recorded. Yields can be increased by the application of growth stimulants/regulators, and by irrigation. Figure 8.7 shows a stand of "ber" in association with *Prosopis cineraria*.

5. Extrapolatability

The CAZRI technologies (including others that have not been mentioned in this paper) are being disseminated to extension agencies and farmers through the Institute's extension services and programmes. These technologies, especially sand-dune stabilization, shelterbelt plantation, tree-planting techniques in different land forms, silvopastoral and agrisilvicultural systems, use of fruit trees and other indigenous trees, are now being adopted on a large scale in the

arid parts of Rajasthan State as well as other such parts of India. There is also considerable international enthusiasm on these technologies and their adoption in other arid parts of the world.

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9. Multipurpose trees and shrubs on farmlands in Tamil Nadu State (India)*

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Abstract. Farmers in Tamil Nadu State integrate numerous species of multipurpose trees and shrubs on their farmlands in close association with agricultural crops and/or livestock. Dominant among them are *Borassus flabellifer*, *Tamarindus indica*, *Ceiba pentandra*, *Acacia leucophloea* and *A. nilotica*.

These woody perennials are better able to cope with poor growing conditions. Their increasing integration on farmlands represents a strategy to minimize the risk of crop failure. Some species (e.g. *Prosopis juliflora* and *Delonix elata*) are deliberately used to ameliorate infertile or saline soils in order to permit the growing of annual crops. In addition to producing fuelwood, charcoal, fruit and fodder and providing many service functions, these species require fewer inputs and give the farmer a choice of management options in the event of poor crop growth. The productivity of these traditionally managed and little-studied agroforestry systems can be considerably improved by scientific interventions.

1. Introduction

Tamil Nadu State possesses a great diversity of ecozones, including semi-arid to humid lowlands and even tropical highlands. Numerous traditional agroforestry systems and practices exist in the State which involve the use of multipurpose tree species on farmlands or rangelands. This paper identifies and describes the role of management of the major tree/shrub species involved in the more prominent, but as yet little studied, agroforestry systems and practices in Tamil Nadu. Furthermore, the various examples of agroforestry and multipurpose indigenous trees provided will help to reinforce a broad concept of agroforestry (Lundgren and Raintree 1983). This is important because a surprisingly large number of land-use scientists and policy makers still think of agroforestry as a branch of forestry or as an alternative term for taungya.

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2. General description of the area

2.1. *Biophysical environment*

Tamil Nadu State is located in southern India (8.08–13.92°N and 76.25–80.3° E) (Fig. 9.1). The State covers 130,057 km^2 and altitude varies from sea level to 2,600 m.

Altitude has a marked influence on rainfall and temperature regimes. The State receives rain from the south-west monsoon (July to September) and the north-east monsoon (October to December), the latter being the main source of rain for the eastern parts. The average rainfall varies from 625 to 1,250 mm, although in the highlands it can exceed 2,500 mm. Temperature varies from 10.9° to 46.2°C in the lowlands. In the uplands of Palni and Nilgris, however, it ranges from 0.5° to 27.6°C with occasional frosts on 2–4 days in December and January.

There are four major groups of soils in the state (FAO/UNESCO Soil map of the world – Sheet VII_2):

- Chromic/orthic luvisols (US Alfisols): the major soil types in the State; freely drained; pH 6.5–8.0; the main limitations are shallowness and susceptibility to erosion;
- Chromic vertisols: found in most districts except Nilgris. They form 45–60% of the cultivated area of Ramanathapuram and South Arcot Districts; heavy consistency and poor drainage can be the main limitations;
- Eutric fluvisols (US Entisols): these are found mainly in deltaic areas;
- Dystric regosols (US Entisols): found mainly along the coast; these sandy soils have a low nutrient status and water-holding capacity; they are susceptible to wind and water erosion.

In the upland areas with high rainfall (e.g. the Nilgris), ferralsols (US Oxisols) occur; low fertility and moisture-holding capacity are their major limitations.

The wide variety of ecological conditions present in the State is also reflected in the great diversity of vegetation types encountered:

- Tropical wet evergreen forest (dominant species: *Maesua ferrea*, *Palaquium ellipticum*);
- Tropical moist deciduous forest (*Terminalia* spp., *Tectona grandis*, *Pterocarpus marsupium*, *Bambusa arundinacea*);
- Tropical dry deciduous forest (*Anogeissus latifolia*, *Terminalia tomentosa*, *Dendrocalamus strictus*);
- Tropical dry forest (*Acacia* sp., *Dicrostachys cinerea*, *Santalum album*, *Chloroxylon swietenia*, *Hardwickia binata*);
- Mangroves (*Rhizophora*, *Avicennia*, *Exoecaria* spp.);
- Montane wet temperate forest (*Michelia nilagirica*, *Gordonia obtusa*).

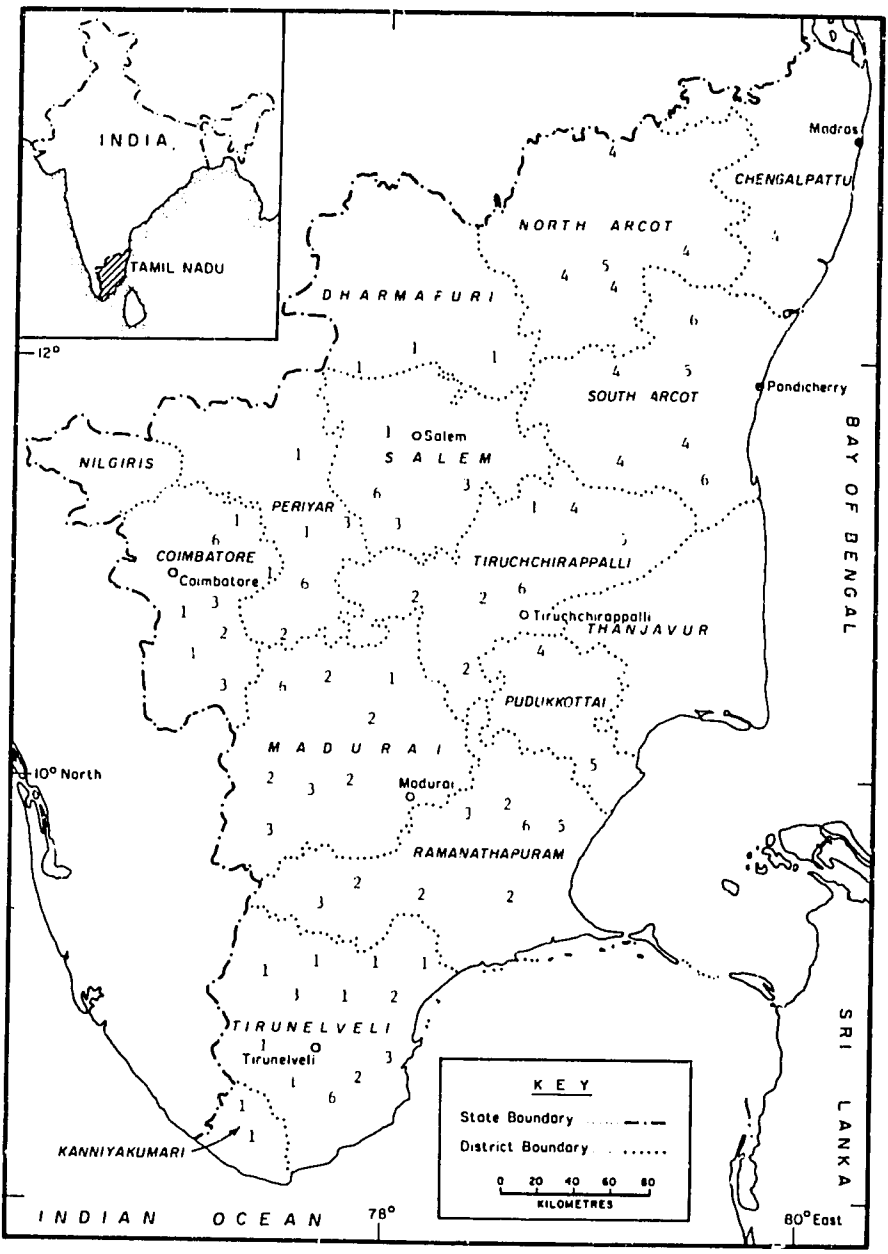

Fig. 9.1. Approximate spread of dominant multipurpose trees on farmlands in Tamil Nadu State. The numbers on the map denote the following species: 1. *Borassus flabellifer* (palmyrah palm); 2. *Tamarindus indica* (tamarind); 3. *Ceiba pentandra* (kapok); 4. *Acacia leucophloea*; 5. *Acacia planifrons*; 6. *Acacia nilotica*. Additionally, *Prosopis juliflora* occurs widely, especially on wastelands, throughout the State.

2.2. *Socio-economic conditions*

The State has a population of 48.4 million with a male:female ratio of 1:0.9768 and an adult literacy rate of 46.75% (Government of Tamil Nadu 1982a). The average population density is 372 per km^2 with 32.95% of the population being urban based. The State has an annual revenue of Rs 60,895 million giving a per capita income of Rs 1,269.*

2.3. *Land-use systems*

Table 9.1 shows the proportion of available land used for various purposes in Tamil Nadu.

Agriculture

Most of the agriculture in the area is rain fed. The eastern part of the State is characterized mainly by subsistence agriculture since it only receives rain from the north-east monsoon (i.e. a cropping season of 3–4 months). In the western areas, which receive rain both from the north-east and the south-west monsoons, and in areas along major rivers, deltas, irrigated land and the uplands, agriculture involving commercial crops such as rubber, tea and cashew is common. Table 9.2 lists other major crops and the area occupied by them.

Table 9.1. Land use in Tamil Nadu State.

Land use	Area (ha)	Percent of total area
Agricultural crops	6,253,563	48.1
Forest	2,028,183	15.6
Current agricultural fallows	1,274,115	9.8
Cultivable wasteland	364,033	2.8
Barren/uncultivable wasteland	611,055	4.7
Other fallows	442,040	3.4
Miscellaneous tree crops	195,018	1.5
Permanent pastures/grazing land	156,014	1.2
Non agricultural/forestry use	1,677,152	12.9
Total	13,001,170	100.0

Source: Government of Tamil Nadu (1982b).

* 1 US $ = Rs 12.50 (May 1985)

Table 9.2. Major crops in Tamil Nadu State.

Crops	Area (ha)
Rice (*Oryza sativa* L.)	2,756,451
Groundnut (*Arachis hypogaea* L.)	983,344
Sorghum (*Sorghum bicolor* (L. Moench.)	695,580
Pulses (mostly green gram, black gram, pigeon pea)	616,125
Pearl millet (*Pennisetum glaucum* L.)	408,510
Cotton (*Gossypium hirsutum* L.)	357,197
Finger millet (*Eleusine coracana* (L.) Gaertn.)	279,917
Kodo millet (*Paspalum scorbiculatum* L.)	177,541
Sugarcane (*Saccharum officiarum* L.)	154,423
Little millet (*Panicum miliare* Lam.)	132,750
Gingelly (*Sesamum indicum* L.)	131,618
Chillies (*Capsicum* spp.)	106,857
Tobacco (*Nicotiana tabacum* L.)	12,710
Castor (*Ricinus communis* L.)	10,287

Source: Government of Tamil Nadu (1980).

The livestock population in the State was estimated at 24.1 million, consisting of 10.8 million cattle, 3.07 million buffaloes, 5.2 million sheep, 4.2 million goats and 0.68 million pigs (Government of Tamil Nadu 1982b).

Forestry

The total area under plantation and natural forests was estimated to be 2,028,183 ha in 1981. Natural forest types have been identified earlier in this chapter. Plantations of *Eucalyptus tereticornis*, *E. grandis*, *E. globulus*, *E. citriodora*, *Pinus patula* and *Acacia mearnsii* exist. Table 9.3 shows the output of forest produce for 1980/81.

Agroforestry

Numerous systems/practices exist which may be classified as agrisilviculture or agrosilvopasture (Nair 1985). A common feature of all these agroforestry

Table 9.3. Forest produce in Tamil Nadu State, 1980/81.

Forest produce	Quantity	Value($\times 10^6$ Rs)
Sandalwood	6,029 tonnes	47.20
Pulpwood	154,843 tonnes	32.54
Rosewood	5,283 m^3	10.90
Bamboo	59,374 tonnes	2.28
Fuelwood	57,440 m^3	0.93

Source: Government of Tamil Nadu (1982b).

systems is that they involve the deliberate retention and management of one of more multipurpose trees on farmlands and rangeland. Within the two categories mentioned above, the systems described in the following sections can be distinguished by the presence of a dominant (in terms of usefuiness) multipurpose tree species.

3. Agrisilvicultural systems/practices

3.1. *Multipurpose trees intercropped with cereals and pulses under rain-fed conditions*

Except where otherwise stated, the trees described below are intercropped with a variety of cereals and/or pulses (Table 9.2), the cropping systems being more or less similar in all cases.

Borassus flabellifer L. (palmyrah palm)

It is conservatively estimated that there are 40 million palmyrah trees growing in the plains of Tamil Nadu. Of these, 17.5 million occur in Tirunelveli, 7.0 million in Coimbatore and Periyar, 5.3 million in Ramanathapuram, 2.5 million in Kannyakumari and 2.0 million in Dharmapuri Districts, respectively. Usually, the trees are randomly dispersed on crop lands but are also planted on the bunds of paddy fields (Fig. 9.2). They may be found on a wide range of soil and salinity. Effects of shading on understorey crops are likely to be negligible due to the small-sized crowns composed of the fan-like leaves of the widely spaced (10.15 m apart) trees. Reduction in crop yields due to root competition is probably compensated for by sales of the various products obtained from the palm; moreover, the farmer has a cash income during the dry season when there are no crops on his fields.

The major product of the palm is *nera*, a sugary exudate from the cut end of a flowering spathe. Tapping for *nera* usually commences when the tree is 14–16 years old (10–12 m tall) and is limited to about five months a year (January to May). Narrow-mouthed earthen pots, limed on the inside to prevent fermentation of the *nera*, are attached to the cut ends of flowering spathes and the *nera* is collected on a daily basis. In the northern districts, *nera* yield from a tree averages 2 litres a day, while in southern districts it varies from 2.5 to 3 litres a day. Other products from the palm include leaves and the fibre from petioles which are widely used for thatching and making a variety of handicrafts.

A farmer having around 100 trees per ha (10 × 10 m spacing) can earn between Rs 500 and 600 over the five-month tapping period each year. The annual income to Tamil Nadu State from the sale of palmyrah products such

Fig. 9.2. Borassus flabellifer on field boundary. Note the small crowns of the palms. (Photo: E.C.M. Fernandes.)

as palm sugar, candy made from *nera* and handicrafts made from leaf fibre has been estimated at Rs 120 million. The export of palmyrah leaf fibre (to some 40 countries) alone earns about Rs 10 million in foreign exchange.

It has been estimated that over 28,000 families are engaged in the processing of palmyrah products. This activity usually commences at the end of the cropping season and thus provides a good source of income during a period of low demand for on-farm labour. Women are being encouraged to take up processing of palmyrah products by the Tamil Nadu Co-operative Banking Society.

Tamarindus indica L. (tamarind tree)

Although tamarind occurs naturally throughout the State, deliberate planting of the tree on agricultural lands is becoming increasingly popular in Madurai (west), Coimbatore, Periyar, Tirunelveli and Ramanathapuram Districts.

Tamarind grows on a wide variety of soil types and the spacings commonly adopted are 8 × 8 m, 8 × 12 m and 12 × 12 m. The seedlings range from 40 cm to 2 m in height at time of planting. A farmer in Krishnagiri area of Dharmapuri District develops 2-m-tall seedlings within a year by manuring and clipping of auxiliary buds. The resultant lanky seedlings are planted, supported by small poles for a year and protected from browsing by fencing with thorny *Acacia* or *Prosopis* twigs. The seedlings develop adequate thickness to support themselves within a year and commence fruiting in about seven years. Pod yield stabilizes at about 15 years. Although improved

varieties have not been developed, local farmers usually identify "mother" trees that consistently produce large numbers of fruits and raise seedlings from the seeds of these. For example, in Dharmapuri District, a tree producing pods 25 cm long and 5 cm wide has been reported.

A mature tree (20 years) can yield 100–500 kg of pods a year, giving 40–250 kg of edible pulp (endocarp). Usually, pod yield is cyclic with bumber yields coming every third year. The pulp is widely used as a condiment in Indian cooking and is also exported. It is an important ingredient of Worcester and barbecue sauces. The price varies from Rs 3 to Rs 7 per kg. Furthermore, the seed is ground and the starch obtained from the cotyledon is processed to give a pectin-like gum which is used for sizing textiles, paper and jute products.

Depending on site conditions, a mature tree can be 20–25 m tall with a dense crown. Reduction in understorey crop yields due to shading will be severe where mature trees are present. Most farmers, however, plant tamarind on the poorer sites where crop yields would be low. This, coupled with the fact that tamarind fruit which is harvested in the dry season provides an income when there are no crops on the fields, offers some compensation for shading effects on crops. Most tamarind trees are semi-deciduous, shedding some of their leaves in the dry season. Since the crowns are large and dense, such leaf shedding is likely to contribute substantially towards the soil organic matter. Once the pod yield starts to decline (over 50 years), the trees are cut down for fuelwood or charcoal.

Ceiba pentandra (L.) Gaertn. (kapok tree)

Two varieties of kapok are grown in the State. In Madurai, Ramanathapuram and Tirunelveli Districts, the local variety with whorled branching, sparse canopy and small pods (<20 cm long and 5 cm wide) is popular. In Coimbatore, Periyar and Salem districts, a variety with a dense canopy, locally known as "Singapore" kapok, is preferred due to its large pods (20–30 cm long and 5–8 cm wide).

The trees are planted either on field bunds or on crop land at a spacing of 5 × 5 or 8 × 8 m and intercropped with cereals or pulses till their canopies close in 7–8 years. Seedlings are planted in 30 cm^3 pits and start fruiting in 3–4 years. Stabilized pod yield, usually obtained from the seventh or eighth year, can vary from 1,000 to 1,200 pods per tree depending on management. Well managed, 15-year-old trees yield 2,000–3,000 pods annually (Fig. 9.3). The small-podded variety yields up to 6 kg of floss per 1,000 pods, while the larger pods yield 7–9 kg. Farmers obtain a price of Rs 20–25 per kg of floss, i.e. an annual return of Rs 120 from one tree. In addition, the wood is sought for the matchwood industry and the trunk of a 20-year-old tree (25–30 cm diameter and 10 m tall) can fetch Rs 300–500.

Fig. 9.3. Ceiba pentandra on field boundaries showing profuse pod production. (Photo: E.C.M. Fernandes.)

Yields from interplanted crops can be expected to decline from the fourth to the seventh year when the tree canopy closes, especially with "Singapore" kapok which has a dense canopy. Thus, if a farmer wishes to prolong intercropping, the local variety of kapok tree (with a sparse canopy) should be used and the "Singapore" variety used mainly on field boundaries. The use of the dense-canopy variety on bunds and field boundaries could provide windbreaks to protect crop land against the strong gusts of wind common during the monsoons. The trees shed all their leaves in the dry season thereby increasing their value as economically valuable fallow species for rehabilitation of poor or degraded farmland.

3.2. Prosopis juliflora (*Swartz*) *DC.* (*mesquite*) *for reclamation of saline soils*

Prosopis juliflora occurs naturally throughout the "wastelands" of Tamil Nadu State (Table 9.1). It caters for the fuel needs of a great majority of the rural poor and its availability has greatly reduced illicit felling for fuel in natural forests (TNAU 1984). Mesquite is an extremely hardy species, growing on a wide range of soil types, including heavy clays, and has a good tolerance to drought, waterlogging and salinity. The tree coppices vigorously and is seldom browsed, although mature pods are fed to livestock.

In Ramanathapuram District, where rainfall is confined to the north-east monsoon and substantial saline patches occur, farmers use *Prosopis juliflora* as a fallow species for four years. This ameliorates the soil condition sufficiently to enable the farmers to grow annual food crops for at least two years, after which the trees are allowed to reinvade the site for another four years. In addition to soil amelioration, the other major use of the tree is for fuelwood (Rs 250–300 per tonne at source) or charcoal. The return from charcoal, however, is higher than that from fuelwood, and thus many families are involved in the manufacture of charcoal. It is estimated that 15,000 tonnes of charcoal, mostly from mesquite, are transported annually to Madras (the capital of Tamil Nadu) from Ramanathapuram.

This system involving the use of *Prosopis juliflora* for soil amelioration offers a cheap and ecologically acceptable way to reclaim not only the saline sites but also large areas of wasteland in Tamil Nadu. Direct seeding is cheap and subsequent survival good as the species is not browsed. Economic returns are encouraging and many "panchayats" (village governing councils) report incomes in excess of Rs 2,000 per ha after six years of mesquite growth (for fuel or charcoal) on wastelands.

3.3. Delonix elata (*L.*) *Gamble for green manure on rice fields*

This leguminous species is common in Dharmapuri, South Arcot and North Arcot Districts where it is grown either on field bunds or in village commons to provide green manure for rice fields.

Delonix elata is propagated almost exclusively from cuttings and the tree pollarded at a height of about 2 m to yield between 20 and 50 kg of green leaves a year which are incorporated into the soil during or just after ploughing (Fig. 9.4). Any woody branches are usually dried and used for fuel. In some villages, the trees are grown on the village commons and the stems pollarded and green manure shared by all. In times of fodder scarcity, the leaves may be fed to livestock, although it is not considered to be good fodder.

There is considerable potential for increasing the stocking of this particular species as many field bunds are not presently used for growing trees. Planting

Fig 9.4. Green leaves from the prunings of *Delonix elata* standing on the bunds or from nearby areas being incorporated before preparing the field for transplanting rice seedlings. (Photo: E.C.M. Fernandes.)

material is easily available locally and the benefits of this species are well appreciated by the local people. Increased use of green manure from the tree could reduce the need for fertilizer.

3.4. *Windbreaks on crop land*

Extensive areas in the western part of Madurai District have been planted up with windbreaks to protect crop land from the ferocity of the pre-south-west monsoon winds that occur in May and June.

Windbreaks usually consist of a central row of *Azadirachta indica*, flanked by rows of *Prosopis juliflora* and *Euphorbia tirucalli*. In some areas, a central row of eucalyptus may be grown. All these species are drought tolerant and are generally not browsed, thereby giving good establishment. *Prosopis juliflora* coppices well and may be harvested for fuelwood.

Many other areas in Tamil Nadu State suffer wind damage. The establishment of such protective and productive windbreaks can considerably benefit these crop lands and minimize wind erosion.

4. Agrosilvopastoral systems/practices

4.1. Acacia leucophloea (*Roxb.*) *Willd. on farmland*

This system covers over 100,000 ha in the dry tracts of Coimbatore and Periyar Districts where annual rainfall is around 600 mm, although the rainfall pattern from year to year is highly erratic.

Acacia leucophloea regenerates profusely when the land is ploughed after the first rains. Farmers encourage growth of the young seedlings and also sow crops like *Pennisetum glaucum* and *Dolichlos uniflorus* (horsegram). If the rains continue favourably, the crops can be harvested as grain, otherwise they will be used as fodder.

At the end of the first year only 1,000 or so tree seedlings remain. This number is further reduced by natural mortality to around 500–800 per ha at the end of the third year when the trees are 1.0–1.5 m tall, and the farmer continues to till the soil up to the base of the trees to sow his crops. After about ten years when the trees are around 10 m tall and 20 cm in diameter at breast height, the farmer thins out the trees to between 60 and 100 per ha so as to allow adequate sunlight to reach the understorey crops. Studies have shown a 20–23% increase in the height and dry-matter yield of fodder sorghum growing beneath the trees as compared to the crop grown without tree cover (Seshadri 1976). The trees develop large spreading canopies when they are 15–20 years old and farmers thin them out to between 25 and 60 per ha. Such trees yield up to 100 kg of pods annually, which form an excellent high-protein fodder supplement in the dry season.

Due to the uncertainty of the rains, an increasing number of farmers are now planting *Cenchrus ciliaris* instead of cereals and pulses. *C. ciliaris* is a hardy fodder grass which dries up in the summer but regenerates naturally soon after the first rains. The emphasis is thus shifting from an agrosilvopastoral to a silvopastoral system while still giving the farmer the flexibility to raise crops should conditions permit. The drought-tolerant "Kangayam" breed of cattle has been developed in this area.

4.2. Acacia planifrons *Wight & Arn. as an economically valuable fallow species on farmland*

This species occurs extensively in the coastal parts of Tirunelveli and in localized pockets of Ramanathapuram and Coimbatore Districts.

Farmers encourage regeneration of this species on their crop lands by feeding the pods to goats and then penning the animals on the crop land. In order to ensure good regeneration, the land is ploughed prior to penning the animals on it. The passage of the seed through the digestive tracts of the goats softens the seed coat and a high degree of germination (up to 80%) is obtained. This high rate of germination usually results in a population of 3,500–5,000 seedlings per ha, which is later thinned to between 1,250 and 1,500 at the end of the rains.

The trees are maintained at an approximate spacing of 3 × 3 or 3 × 4 m. Between the trees the farmer sows sorghum, pulses, peanuts or chillies and this intercropping continues for the next four or five years until the tree canopy closes. The trees are felled between the seventh and tenth year, depending on the financial exigencies of the farmer. Some of the trees are retained for farm needs while the rest are sold for pulp or fuel. The prices obtained vary between Rs 200 and 250 per tonne at source with the buyer felling and transporting it. In addition to the wood obtained when the trees are felled, the trees provide valuable fodder pods during the dry season.

This system is another example of significant interaction between the tree, crop and animal components. It enables the farmer to produce food and wood simultaneously and at the same time to conserve the soil resources required for future production.

4.3. Acacia nilotica (*L.*) *Willd. ex Del. as a multipurpose tree on farmland*

In Thanjavur and Tiruchirapalli Districts, *Acacia nilotica* trees are cultivated on the bunds of rice fields. The trees provide fodder pods and wood for construction of bullock carts and fuel.

This species has a high tolerance to watterlogging and it grows rapidly, benefiting from the irrigation and fertilizer given to the rice fields. During the dry season (March to July), large herds of goats migrate from Ramanathapuram and Tirunelveli District to this area. Local farmers pay herd owners a nominal sum to pen their animals in their fields. This arrangement allows the herd owners to harvest the pods and tender shoots of *Acacia nilotica* which are used as a supplement to the crop stubble grazed by the animals. In return the farmers' fields are manured by the animals.

This traditional system involves significant ecological and economic interactions between the tree, crop and animal components. Studies are required to

Table 9.4. Multipurpose trees and shrubs on farmlands in Tamil Nadu.*

Species	Uses	Remarks
Albizia lebbek (L.) Benth.	Timber, fuelwood	Scattered on farms
Albizia falcataria (L.) Fosberg	Fodder leaves, stem for dugout canoes	Scattered
Ailanthus excelsa Roxb.	Matchwood, timber	Field boundaries
Artocarpus heterophyllus Lam.	Fruit, food seeds, fodder leaves, timber	Around homesteads
Annona squamosa (L.)	Fruit, soil conservation	Around homesteads, denuded farmland
Annona reticulata (L.)	Fruit, soil conservation	Around homesteads, denuded farmland
Bassia latifolia Roxb.	Seed oil, timber	Scattered
Calophyllum inophyllum L.	Seed oil	Around homesteads
Calotropis procera (Aiton.) R. Br.	Green manure, bark fibre	Field boundaries
Cassia siamea Lam.	Green manure, fuelwood	Field bunds
Commiphora caudata (Wight et Arn.) Engl.	Live fence, fodder	Around homesteads
Commiphora berryii (Arn.) Engl.	Live fence, fodder	Around homesteads
Dalbergia sissoo D.C.	Timber, fuel, fodder	Irrigation canals
Ficus bengalensis L.	Fodder leaves, ornamental	Scattered
Ficus religiosa L.	Fodder leaves, shade	Scattered
Hardwickia binata Roxb.	Fodder, timber, fuel	Scattered
Holoptelia integrifolia	Fodder, timber,	Scattered
Pithecolobium dulce Benth	Fodder, fruit, timber	Scattered
Pongamia pinnata (L.) Pierre.	Seed oil, timber	Scattered
Pterocarpus marsupium Roxb.	Timber, fodder leaves, bark, antibiotic fodder leaves	Scattered
Santalum album L.	Fragrant heartwood	Field boundaries
Sesbania grandiflora Pers.	Vegetable, fodder, live support for betel vine, shade	On crop land
Thespesia populnea Soland.	Fodder, yellow dye, timber fuel	On field bunds
Tectona grandis Linn. F.	Timber, fuel	Irrigation canals
Wrightia tinctoria	Green manure	Field bunds

* Other than those described in the text of paper.

quantify the magnitude of the interactions so that suitable modifications can be made to maximize the positive interactions. *Acacia nilotica* browse is known to contain certain toxic substances, the quantity of which varies according to season, maturity, etc. With detailed information on these aspects there is scope for improving the overall utilization of available feed. Also, the more the supplementary high-protein fodder available to the animals the better is the manuring effect on fields likely to be.

In addition to the woody species identified in the above systems/practices, numerous other multipurpose trees exist on farmlands. Table 9.4 lists these and their uses.

5. Marketing infrastructure

Within Tamil Nadu, there are 180 regulated markets, 115 co-operative marketing societies and 25 agricultural co-operative societies. Although these cater mainly for agricultural produce, farmers have no difficulty in selling the various tree products of the agroforestry systems described above. With the exception of tamarind and kapok, which are harvested by the owners (sellers), it is the buyers who arrange for felling and transport of the woody species. In most cases the produce is sold within a radius of 100 km from the production site.

Facilities for transport of produce are good. The State is well served with 68,315 km of surfaced and 53,139 km of unsurfaced roads. In addition, there are about 3,800 km of rail tracks.

6. Dynamics of agroforestry systems in Tamil Nadu

Farmers in Tamil Nadu well appreciate the advantages of existing agroforestry systems and are undertaking integration of even more trees on crop lands. It is highly likely, therefore, that there will be a proliferation of agroforestry systems in the coming years. There are several reasons for this:

1. The recent stable demand and high prices for wood (fuel, timber, pulp, construction) unlike the poor, unstable prices for agricultural crops, are a major incentive for farmers to plant more trees in association with their crops.
2. The high cost of farm labour and inputs required for annual crops, coupled with the uncertainty of monsoon rainfall, has prompted farmers to integrate trees on farmland in order to minimize the risk of poor crop harvests. In addition to stable prices for tree products, trees are able to withstand drought better and they require fewer inputs. Thus, even if the crops fail, the farmer is still able to realize some income.
3. Since the government adopted the policy that the "land is for the tiller", an increasing number of absentee landlords are bringing their lands under their direct supervision. This is conveniently achieved by planting significant areas of their crop lands with trees, i.e. an economically productive tree fallow. The trees require fewer inputs and give the landlord time to decide on his management options.

4. Government-backed financial institutions are increasingly providing low-interest credit facilities for agroforestry-based investments.

The often-voiced view of the undesirability of planting large numbers of trees on crop lands should be considered in the light of national pricing policies for food crops. In the case of agroforestry systems, the aim is to maximize the complementarity between trees, crops and/or animals so as to achieve sustainable production. Sound management is invariably the key to achieving this objective.

7. Conclusions

Agroforestry systems are well established in Tamil Nadu, though at subsistence level, and are becoming increasingly popular among local farmers. There is potential for improvement of the many traditionally managed systems described here, so that their production potential may be better realized. Thus it is important that these systems are studied in detail: as a first step, accurate baseline data of the systems need to be collected in order to facilitate in-depth evaluation and subsequent improvements. The Tamil Nadu Agricultural University is the best-placed institute for such an inventory.

Institutes of the Indian Council for Agricultural Research (ICAR), such as the Central Arid Zone Research Institute (CAZRI), Indian Grassland and Fodder Research Institute (IGFRI) and the All-India Dryland Agriculture Project, are currently involved in the improvement and evaluation of many multipurpose tree/shrub species that are potentially valuable for this area. Improved fruit trees, such as *Ziziphus mauritiana* ("ber"), *Punica granatum* (pomegranate) and *Psidium guajava* (guava), deserve special mention. Germplasm materials and management packages could be made available to farmers in Tamil Nadu via ICAR's "lab to land programmes" and other extension channels for which adequate infrastructure and facilities exist in the State.

Screening of multipurpose trees that are presently favoured by local farmers in order to identify high-yielding trees should be undertaken. This will provide a germplasm base for further development/selection of superior trees. In addition, an effective mechanism is needed for distribution of presently available germplasm materials (such as grafted seedlings and rooted cuttings) of improved multipurpose trees to farmers. This alone could result in significant medium-term gains in the productivity of existing agroforestry systems. The "agroforestry wing" of the Tamil Nadu Agricultural Department which currently funds tree-planting activities can have a major role to play in this programme.

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10. Agroforestry farming systems in the homesteads of Kerala, southern India*

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Abstract. Kerala State on the south-western coast of India is in the tropical humid zone, has a predominantly agricultural economy, and a very high density of population and therefore high pressure on cultivable land. The farmers there undertake cultivation of an array of crops – tree crops, seasonals and biennials – all in intimate mixtures on the same piece of land around the homesteads. Farm animals and poultry, and sometimes fisheries, are also essential components of the systems. The close association of agricultural crops, tree crops and animals in the homesteads represents an excellent example of sustainable and productive agroforestry homegardens. Optimum utilization of available resources of land, solar energy and technological inputs and an efficient recycling of farm wastes are important characteristics of the systems. This paper attempts to describe and evaluate the systems' stability, productivity and sustainability, and to identify to their merits and constraints as well as research needs.

1. Introduction

Kerala State, which covers only 1.18% of the total land area of India, supports over 3.5% of the country's population (census of India, 1981). The State, with an area of 38,963 sq km, has a population of over 25 million, amounting to a density of 655 persons per sq km, the highest of all the Indian States (State Planning Board 1985). In the coastal and midland areas, population density often exceeds 1,500 persons per sq km. A large majority of the population of the State live in villages and depend on agriculture for a livelihood. Because of the high density of population, the size of farm holdings is very small, commonly ranging from 0.02 ha to 1.00 ha. The farmers of the State usually undertake intensive farming with a variety of crops on the limited area available in order to obtain food, fuel, fodder, timber and cash from the homesteads. The homesteads thus present an excellent example of the basic concepts of agroforestry homegardens (Fernandes and Nair 1986).

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Coconut palm is an important component of these homegardens, and some publications based on crop combinations with coconut in the State have been published (Nair 1979, 1983; Nelliat and Shamabhat 1979). However, quantitative descriptions of woody components other than coconut, and the homegarden systems involving them, have seldom been attempted. In view of the importance of these components and systems of agroforestry homegardens to the livelihood of the people of Kerala, this paper attempts to describe the essential aspects of the structure and function of these farming systems and to evaluate their potential for exploitation and development.

2. General description of the area

Kerala State is 580 km long and lies between the Arabian Sea in the west and the Western Ghats in the east, between 8°18′ and 12°48′ N latitudes and 74°52′ and 77°22′ E longitudes. It is broadest (120 km) in the middle, tapering to the northern and southern ends.

The land area of Kerala can be divided into three broad natural physiographic divisions, namely, "highland", "midland", and "lowland", each running almost parallel to the other along the length of the State. The mountainous land along the Western Ghats in the eastern part of the State is the "highland"; it is under forests interspersed with small streams and the region accounts for 48% of the area and 15% of the population of the State. The palm-fringed coastal belt runs parallel to the Arabian Sea; it has picturesque backwaters and almost level topography, and it constitutes the "lowland" (10% area and 26% population). In between these two lies the "midland" (42% area and 59% population) intersected by numerous rivers, low hills and valleys.

The State as a whole has a humid tropical climate, so that the growth of vegetation is regulated mainly by rainfall. The rainfall pattern is bimodal monsoon; the south-west monsoon from June to August accounts for the major share of the total annual rainfall. The north-east monsoon from October to January is also very important agriculturally. The mean annual rainfall of the State is 2,960 mm, with a mean annual number of rainy days of 126. Rainfall is distributed relatively more uniformly over the rainy seasons in the southern parts of the State as compared with the northern parts, as a result of the influence of both the south-west and north-east monsoons. The mean annual temperature throughout the State is around 27°C, the peak temperatures being 29–31°C during the period from March to May.

2.1. *Soils*

The soils of the State have been broadly classified into four major classes: namely Oxisols (50%), Inceptisols (25%), Entisols (20%) and Alfisols (5%).

The major textural classes of Kerala soils and their general fertility status and physicochemical characteristics are given below (Kerala Agricultural University 1984, 1985b).

- Laterite (Oxisols): generally poor in N, P, K and organic matter, acidic (pH 5.0–6.2) and well drained, and respond well to management practices.
- Red loam (Alfisols): essentially kaolinitic in nature, acidic in reaction, highly porous and friable, and low in organic matter and essential plant nutrients.
- Coastal alluvium (Entisols): developed from recent marine deposits; the texture is dominated by the sand fraction; excessively drained with very rapid permeability and therefore leaching of nutrients is a major problem; improper drainage because of high water table is also a problem in many areas.
- Riverine alluvium (Entisols): occur mostly along the banks of rivers and tributaries and show wide variation in physicochemical properties depending upon the nature of alluvium deposit; very deep with sandy or loamy texture; respond well to management.
- Greyish *Onattukara* (Entisols): have characteristic hydromorphic features like grey horizon, mottling streaks, hard pans, organic- matter decomposition, Fe and Mn concretions, etc.; moderately supplied with organic matter, N and K, but deficient in lime and phosphate; acidity is a problem.
- Hydromorphic saline (Entisols/Inceptisols): found in areas near backwaters and estuaries bordering the coast where frequent inflow of tidal waters causes salinity, maximum accumulation of toxic salts takes place during summer months; these soils are imperfectly drained, and in some areas undecomposed organic matter in lower layers causes acidity.
- Acid saline (Inceptisols): very deep, drained, dark brown alluvial soils having silt loam to silty clay loam surface texture; the sub-soils show the presence of lime shells; the clay content decreases with depth; these soils are slightly acidic, medium in organic matter and poor in total and available nutrients; they are sometimes seriously affected by salinity.
- *Kari* soils (Inceptisols): these black and poorly drained, heavy textured soils resemble peat soils; decomposed organic matter is often observed in the lower layers; highly acidic in reaction, the pH approaching 3.0 during summer months; accumulation of salts to toxic levels often affects crop growth and yield.
- Forest loam (Inceptisols): restricted to the highlands of the State; these soils are, in general, shallow; have dark brown to black-coloured surface soils due to the presence of organic matter; are acidic, rich in nitrogen and phosphorus but poor in bases.
- Black soils (Inceptisols): are dark brown though low in organic matter, calcareous and moderately alkaline (pH 7.5–8.5), and clayey (50% clay), with high CEC; they do not exhibit features of the typical vertisols except for the cracking nature during dry periods; are moderately fertile.

3. Agroclimatic zones

The State is divided into eight major agroclimatic zones on the basis of topography, soils and sea-water intrusion (Fig. 10.1) (Kerala Agricultural University 1984, 1985b; Sreedharan and Achuthan Nair 1985). These are:

The Southern Zone: comprises the four southern districts; has plentiful seasonal rainfall in the coastal plains and moist, hot weather in the interior region; the soils are predominantly laterite or red loam;

The Central Zone: consists of three central districts, excluding the high ranges and coastal saline areas; being on the windward side of the Western Ghats, receives heavy rainfall, though with erratic distribution; the main soil types are laterite, alluvium, and saline;

The Northern Zone: consists of three northern districts; receives heavy rains during both the south-west and north-west monsoons, but December May is very dry; the soils of the area are sandy loam, laterite or alluvium;

The High-Altitude Zone: comprises the two districts in the Western Ghats at an elevation of 700 2,100 m a.s.l. The bulk of the rainfall is received during the south-west monsoon; the soils are mostly loamy forest soils; dense forests, steep hills and deep valleys are in abundance in this zone;

The *Onattukara* Zone: located in the coastal belt in the southern districts of Quilon and Alleppey; consists of recent sediments of sand with level topography; salt-water inundation is common in this area;

The *Kuttanand* and *Kole* Zones: the former represents a 60 km-long and 25 km-wide stretch of low-lying lands on the west coast, separated from the Arabian Sea by a narrow strip of land in the districts of Alleppey and Kottayam; the region experiences hot summers with plentiful rainfall and high himidity; it lies 2 3 m below sea level and is submerged under water for the major part of the year; has acid sulphate soils.

The *Kole* Zone: lies in Trichur and Malappuram Districts in the central part of the State; it is also low lying along the coastal strip; has clay loam soils;

The *Pokkali* Zone: located in the central part (Ernakulam District) of the State; comprises marshy areas where salt-water incursion is a problem; lies at about sea level and is subjected to tidal waves and periodical inundation by saline water; the soils are of acid sulphate nature;

The Low-Rainfall Zone: covers the Attappady hills and eastern parts of Palghat District in the north-eastern part of the State; has a mean annual rainfall of 960 mm; the maximum temperature reaches about 44 C in February March; soils are inceptisols.

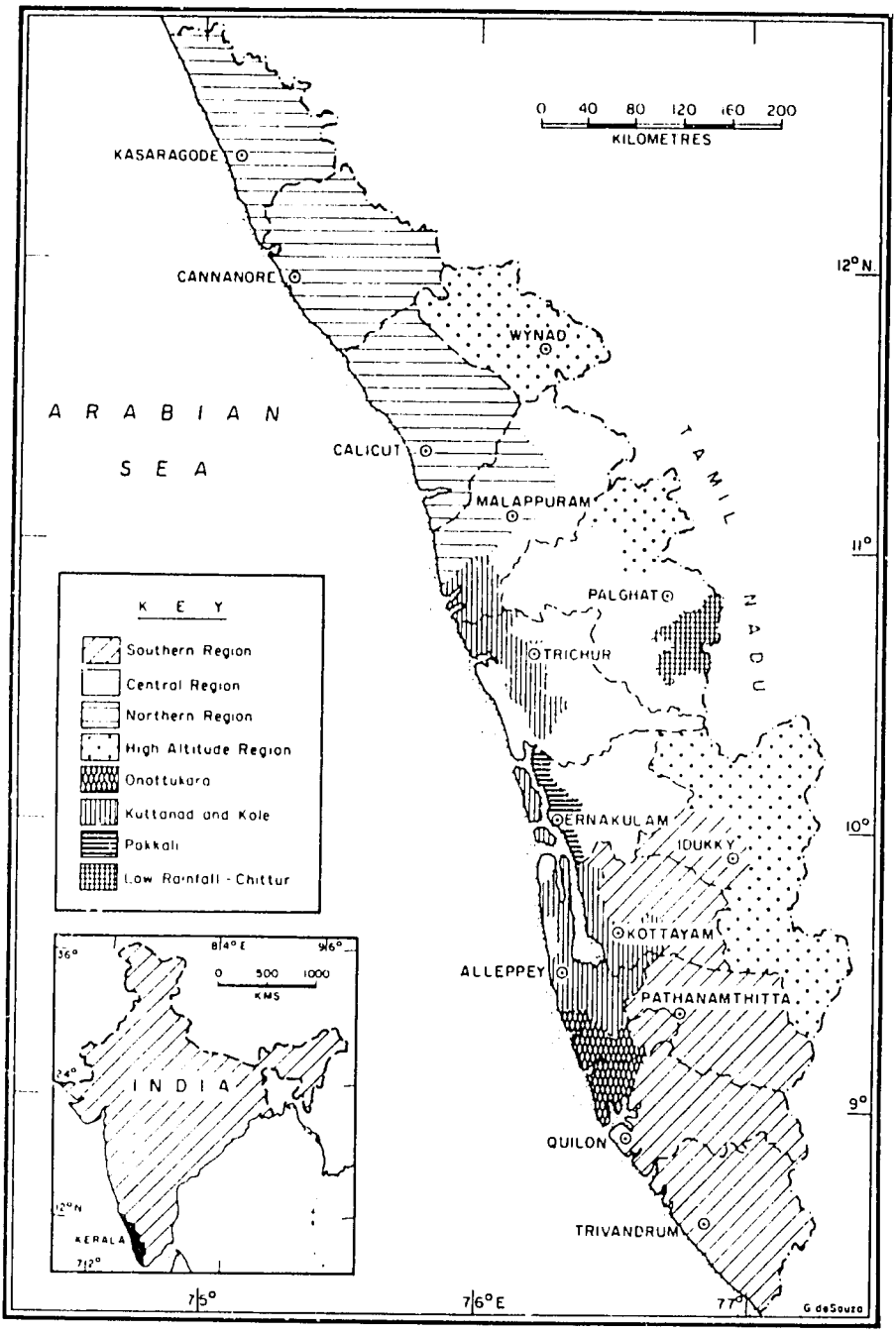

Fig. 10.1. Map of Kerala showing the different agroclimatic zones.

Table 10.1. Inventory of crop species/trees in the homesteads of Kerala.

Crop	Scientific name	Growth form/ economic produce	Main growing/harvesting seasons	Average production/ plant or unit area	Average market price/kg (Rupees*)
Field crops					
Arrow root	*Marantha arundinacea*	Perennial herb - rhizome	May-January	8-10 t/ha	0.50
Cassava	*Manihot esculenta*	Shrub - tuber	May - January	5-15 t/ha	0.50
Chinese potato	*Coleus parviflorus*	Herb - tuber	April/May-December	10-12 t/ha	2.00
Dioscorea	*Dioscorea* spp.	Herbaceous climber - tuber	May-January	12.5-25 t/ha	1.00
Rice	*Oryza sativa*	Grass - grain	June-September	2 t/ha	1.50
Sweet potato	*Ipomoea batatas*	Perennial herb - tuber	June/July and Sept./Oct.	15-20 t/ha	0.50
Elephant yam	*Amorphophallus campanulatus*	Herb - tuber	February-December	15-20 t/ha	1.00
Pulses					
Cowpea	*Vigna unguiculata*	Annual herb - grain	August-November	150-350 kg/ha	2.50
Horse gram	*Dolichos uniflorus*	Shrub - grain	August-November	600 kg/ha	6.00
Mung bean	*Vigna radiata*	Annual shrub - grain	August-November	300-500 kg/ha	6.00
Pigeon pea	*Cajanus cajan*	Perennial shrub - grain	August-November	450-650 kg/ha	6.00
Fruits					
Anona	*Anona* spp.	Tree - fruit	February-April	50 kg/tree	1.00
Banana	*Musa* spp.	Perennial herb - fruit	June-March	1,500 bunches of 20 kg each/(30 t) ha	3.50
Bread fruit	*Artocarpus altilis*	Tree - fruit	April-May	300 fruits (1-4 kg each)/tree/yr	1.50
Garcinia/choisy	*Garcinia indica*	Tree - fruit	June-July	100 kg/year	15.00
Gooseberry	*Emblica officinalis*	Tree - fruit	November-January	10-15 kg/tree/yr	2.00
Guava	*Psidium guajava*	Tree - fruit	July-Aug. and Dec.-Jan.	500-800 fruits/tree/yr	3.00
Jack fruit	*Artocarpus heterophyllus*	Tree - fruit	January-April	500-1,000 kg/tree/yr	0.50
Mango	*Mangifera indica*	Tree - fruit	February-March	100 kg/tree	4.50
Papaya	*Carica papaya*	Tree - fruit	Perennial	30-150 fruits/tree/yr	1.00
Passion fruit	*Passiflora edulis*	Perennial climber - fruit	Perennial	20,000 fruits/ha	2.00
Pineapple	*Ananas comosus*	Perennial herb - fruit	February-April	—	3.00

Pomegranate	*Punica granatum*	Perennial shrub fruit	April May	50 fruits tree/year	6.00
Sapota	*Achras zapota*	Tree fruit	February May	25 kg tree year	4.00
Tamarind	*Tamarindus indicus*	Tree fruit	March April	200 kg tree year	12.00
Oils and fats					
Coconut	*Cocos nucifera*	Tree fruit	At monthly or bimonthly intervals	40 60 nuts palm/yr	1.50/nut
Groundnut	*Arachis hypogaea*	Annual herb - kernel	April May Aug. Sept. Dec. Jan. April May	1,200 1,500 kg pods/ha	3.00
Sesame	*Sesamum indicum*	Annual herb - seed	August December	250 500 kg/ha	8.00
Beverages					
Cacao	*Theobroma cacao*	Tree bean	December January	300 kg dried beans/ha	25.00 (dry beans)
Coffee	*Coffea* spp.	Tree or shrub - bean	December	800 kg h	10.00 (dry beans)
Spices and condiments					
Cardamom	*Elettaria cardamomum*	Perennial herb seed	October/November	100 kg dried capsules ha	150.00
Cinnamon	*Cinnamomum zeylanicum*	Tree - bark	May/June Nov. Dec.	150 250 kg quills/ha yr	50.00 (quills)
Clove	*Syzygium aromaticum*	Tree dried flower buds	January/February	2 kg dry buds tree	150.00
Ginger	*Zingiber officinale*	Perennial herb - rhizome	April-Jan./Feb.	10 t ha (fresh ginger)	10.00 (dry ginger)
Nutmeg	*Myristica fragrans*	Tree - fruit	November January	1,500 2,000 fruits yr	70.00 (mace)
Pepper	*Piper nigrum*	Perennial woody climber - fruit	January February	2 kg green pepper/vine	40.00
Turmeric	*Curcuma longa*	Perennial herb rhizome	April/May Dec./Jan.	3 5 t dry turmeric/ha	8.00 (dry)
Vegetables					
Bhindi	*Abelmoschus esculentus*	Herb - fruit	June/July Oct. Nov.	10 t/ha	2.00
Bitter gourd	*Momordica charantia*	Climber - fruit	June/July-Oct./Nov.	30 t/ha	3.00
Brinjal	*Solanum melongena*	Herb - fruit	June/July Oct./Nov.	25 t/ha	2.00
Cucumber	*Cucumis sativus*	Trailing herb - fruit	June/July Oct. Nov.	10-25 t/ha	1.00
Moringa	*Moringa* spp.	Tree - fruit	March May	10 kg/tree	3.00
Snake gourd	*Trichosanthes cucumerina*	Climbing annual - fruit	June/July-Oct./Nov.	35 t/ha	1.00
Watermelon	*Citrullus lanatus*	Creeper - fruit	December-February	20 35 t/ha	3.00
Winged bean	*Psophocarpus tetragonolobus*	Perennial climber - fruit	December-January	1,500 fruits/ha	2.00

Table 10.1. (continued)

Crop	Scientific name	Growth form/ economic produce	Main growing/harvesting seasons	Average production/ plant or unit area	Average market price/kg (Rupees*)
Fodder grasses					
Brazilian lucerne	*Stylosanthes guianensis*	Grass – foliage	Perennial	10 t/ha	0.05
Guatemala grass	*Tripsacum laxum*	Grass – foliage	Perennial	25–30 t/ha	0.50
Guinea grass	*Panicum maximum*	Grass – foliage	May/June–Aug./Sept.	20 t/ha	0.50
Napier grass	*Pennisetum purpureum*	Grass – foliage	May/June–Aug./Sept.	25–35 t/ha	0.50
Trees					
Bamboo	*Bambusa arundinacea*	Multipurpose tree	—	—	—
Erythrina	*Erythrina indica*	Multipurpose tree	—	—	—
Glyricidia	*Glyricidia sepium*	Multipurpose tree	—	—	—
Leucaena	*Leucaena leucocephala*	Multipurpose tree	—	—	—
Mahogany	*Swietenia macrophylla*	Tree – timber	—	—	—
Morinda	*Morinda tinctoria*	Tree – timber	—	—	—
Portia tree	*Thespesia populenea*	Tree – timber	—	—	—
Teak	*Tectona grandis*	Tree – timber	—	—	—
Wild jack	*Artocarpus hirsuta*	Multipurpose tree	—	—	—
Others					
Arecanut	*Areca catechu*	Tree – fruit	December–May	5 kg nuts/palm	30.00/100 nuts
Betel vine	*Piper betel*	Perennial climber – leaf	—	2–30 million leaves/ha	5.00/100 leaves
Cashew	*Anacardium occidentale*	Tree – kernel	Dec./Jan.–April	5 kg/tree/year	8.00 (raw nuts)
Lemon grass	*Cymbopogon citratus*	Perennial grass – leaf	—	50–120 kg oil/ha/yr	65.00 (oil)
Palmyrah palm	*Borassus flabellifer*	Tree	July–September	—	—
Rubber	*Hevea braziliensis*	Tree – latex	April–December	500 kg dried rubber/ha	15.00
Vetiver	*Vetiveria zozanoides*	Perennial grass – roots	Jan.–Feb.	5 t dried roots/ha/yr	5.00 (roots)

* 1 US$ = approx. Rs 12.20 (April 1986).

Table 10.2. Area, production and productivity of important crops of Kerala State (1981/82).

Crop	Area (ha)	Production (tonnes)	Production (kg/ha)
Rice	806,871	1,339,393	1,660
Pulses	33,910	22,286	657
Pepper	108,242	27,511	388
Ginger	13,477	34,379	2,556
Turmeric	3,200	6,027	1,383
Cardamom	54,516	2,800	51
Arecanut	61,251	10,702 (m. nuts)	175
Tamarind	11,329	24,068	2,124
Mango	60,181	280,017	4,653
Jack fruit	61,037	248,232,000	4,067
Banana	14,068	182,415	13,022
Other plantains	35,921	145,112	4,040
Pineapple	5,373	66,810	12,435
Papaya	10,267	61,520	5,780
Cashew nut	139,960	78,898	564
Sweet potato	5,316	34,674	6,523
Topioca	248,069	3,745,412	15,097
Sesamum	15,037	4,000	266
Coconut	666,618	3,006 (m. nuts)	4,509
Lemon grass	6,371	232	36
Coffee	35,625	26,687	460
Rubber	237,769	139,455	587
Cocoa	23,381	2,894	124

Source: Kerala Agricultural University (1986).

Note: Productivity refers to monocrop stands.

4. Crops

An inventory of the major crop species/trees grown in the homesteads of the State and the production of major crops are presented in Tables 10.1 and 10.2, respectively.

5. Structure of the system

5.1. *Cropping system*

In Kerala 21% of the cropped area is under irrigation. Due to the varied soil, land, physiographic and climatological factors the cropping systems of Kerala have certain distinguishing features. There are four major groups: (a) coconut based, (b) rice based, (c) homestead based, and (d) cassava based (Nair 1983). The homestead system forms the focus of this paper.

A homestead is an operational farm unit in which a number of crops (including tree crops) are grown in conjunction with livestock, poultry and/or fish mainly for the purpose of satisfying the farmers' basic needs. Homestead farming is an age-old practice in Kerala, and is prevalent throughout the State.

Although the homegardens appear to be a random mixture of trees, shrubs and herbs, a certain general pattern seems to exist (Nair and Krishnankutty 1984). Wide variation in the intensity of tree cropping is noticeable between homegardens situated in the same agroclimatic zone. This can generally be attributed to the differences in socio-economic conditions of the household and their response to externally determined changes, particularly prices of inputs and products, dependence on land, tenurial conditions, etc. Table 10.3 shows the tree-crop intensity in homesteads.

It can be seen from Table 10.3 that a reduction in the size of holding has led to an intensification of cultivation. In such a situation, it is common that, as the intensity of tree cropping is increased, miscellaneous tree species having no immediate direct benefit are replaced with multiple-use species such as *Leucaena*. Although this has reduced the species diversity, the intensity of cultivation of the selected species has considerably increased.

A schematic representation of the interactions in an intensive homegarden is presented in Fig. 10.2.

The components are so intimately mixed in horizontal and vertical strata, as well as in time, that complex interactions exist between the soil, plants, other components and environmental factors in the farmer's plot. The farmer chooses his crops and crop combinations based on his own wisdom and perceptions acquired over generations of experience, the criterion being his home requirements of food, fuel, fodder and timber. Cattle rearing is also undertaken in most of the homesteads, particularly in the suburban and rural areas, as a complementary enterprise. More than 50% of the cultivated area in the State is under this system.

Table 10.3. Tree crop intensity in homesteads.

Size of holding (ha)	Mean tree cropping intensity*	Mean No. of trees/ha
Very small (0.02–0.19)	50.52	620.8
Small (0.02–0.80)	37.79	276.8
Medium (0.81–2.00)	26.54	211.7
Large (2.00)	23.24	121.1

Source: Nair and Krishnankutty (1984).

* Expressed as the percentage of total area occupied by the tree canopies.

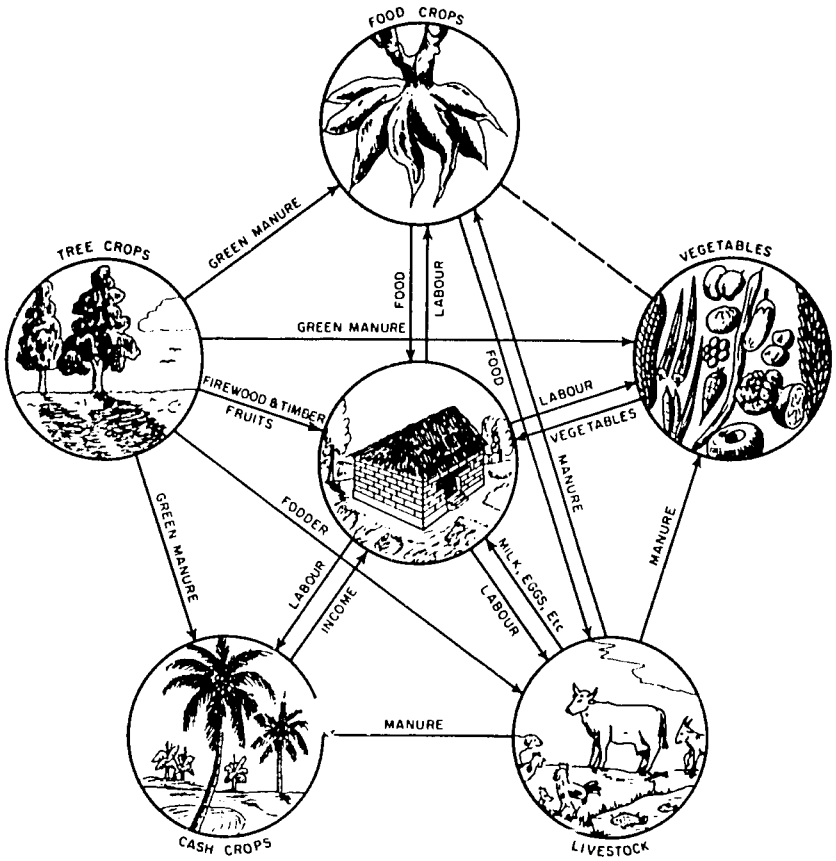

Fig. 10.2. Schematic presentation of the interaction among major components of the homestead agroforestry system of Kerala.

5.2. *Crop and tree components*

Among the crops grown in the homestead, coconut is the most dominant and important. Known as "Tree of heaven" (*kalpa vriksha*), and "Tree of a hundred uses", coconut plays a vital role in the economy of the State. Kerala State has even derived its name from coconut – *kera* in the local language, Malayalam, means coconut. Kerala alone accounts for 70% of the total area and production of the crop in India. There are only two distinct varieties of coconut – the Tall and Dwarf – of which the Tall is extensively cultivated for copra, oil and fibre. A number of hybrids and cultivars are also being developed and popularized. The growth characteristics and planting pattern of coconut palms facilitate successful growing of other crops in between or under them (Nair 1979; Nelliat and Shamabhat 1979). Further, the labour input required for managing the crops is comparatively less than that for many other crops, which makes it an ideal crop for people engaged in other

occupations. Intercropping and/or other forms of crop combinations with coconuts is a very common practice, especially around the homesteads throughout the State.

The other important perennial crops in the homesteads are arecanut, black pepper, cacao, cashew and various tree species.

The arecanut palm (*Areca catechu*) is the main source of the common masticatory nut, popularly known as betel nut or *supari*. It is extensively used by all sections of people as a masticatory and for several religious and social ceremonies. This crop is grown mainly in areas with assured irrigation facilities in homesteads situated in the valleys and plains.

Among the States of India, Kerala has almost a monopoly in the cultivation and trade of black pepper, "the king of spices". It is grown mostly as an intercrop in the homesteads using other tree crops as live standards. As a monocrop, it is grown in hilly regions using standards such as *Erythrina indica*, *Garuga pinnata*, *Leucaena* sp. and *Gliricidia* sp. Though a number of cultivars are grown, the most popular one is Karimunda. A high-yielding hybrid known as Panniyoor-1 is now extensively grown in places with ample sunlight.

Cashew is yet another important export-oriented crop grown as pure stand and also in the homesteads in marginal and submarginal soils in the Northern Zone. This tree crop is fairly drought resistant and is common in areas where rainfall is erratic and drought may be prolonged. Cashew-nut processing developed as a cottage industry has enhanced employment opportunities for the rural people.

Cacao is successfully grown with coconut and arecanut where irrigation is available, and it is an economically attractive system. Tree species like nutmeg, clove and cinnamon are very popular in the homesteads of the Southern Zone where rainfall is more evenly distributed within the year. The upper storey growth of coconut provides enough shade and a favourable microclimate for these crops.

Cultivation of ginger and turmeric is very popular almost everywhere in the State. Satisfactory yield in the partially shaded conditions existing in the homegardens, fair market demand, easy processing and long storage life after processing are factors that encourage widespread cultivation of these crops in the homesteads.

The coffee-based homestead system is a notable feature of the high-altitude region. In this system, coffee is intercropped with perennial crops like black pepper, jack fruit and others. Lately, coconut has also been introduced in this region and forms an ideal shade crop for coffee, especially in the early stages of its growth (Kerala Agricultural University 1985b).

Another important cash crop grown in the warm high-altitude region is cardamom. This species flourishes in humid environments and requires dense shade for its proper growth. Trees like jack fruit, mango and tamarind provide excellent shade for the cardamom in the homesteads.

Rubber is grown in areas where the rainfall is evenly distributed in the hill slopes and also in the plains of the southern region. In the initial stages of its growth a number of intercrops can also be grown, and it is fast becoming a homegarden tree crop.

Among the tropical tubers, cassava and yam are the most common and important subsidiary food crops. Cassava is grown in the homesteads under partially shaded conditions, with lesser tuber productivity compared to open area stands. Other tuber crops like taro, elephant-foot yam, dioscorea, lesser yam, arrowroot, sweet potato and chinese potato are more shade tolerant and hence give better results when grown in the homestead.

Banana and pineapple are also common fruit crops in the homesteads. A number of cultivars of banana are widely cultivated, Nendran being a very popular one. Pineapple is a common floor crop grown along with vegetables in the homegardens. The canning industries with pineapple open up avenues for employment for the rural people of the Central Zone. Further, a number of fruit crops like guava, papaya, annona, sapota, mango and jack fruit are also grown in most homesteads.

Pulses like red gram, cowpea, black gram, horse gram and oil seeds like groundnut, sesamum and castor bean are also common. The pulses provide a protein supplement in the rural diet. The commonly grown vegetables include bhindi (okra), brinjal, bitter gourd, cucumber, snake gourd, water melon and winged bean; these are grown for home consumption as well as for cash sale. Medicinal plants like lemongrass and vetiver are widely cultivated in some homesteads, especially in the Central Zone.

A homegarden in Kerala, similar to homegardens elsewhere, consists of a number of trees, having both productive and protective functions, which are integrated into the system in different spatial and temporal arrangements. The various species of trees, mostly planted along plot peripheries, interact closely with agricultural crops. Among these, teak (*Tectona grandis*), a commercially valuable timber species, is common in the homesteads of the "midlands". A few wild jack trees (*Artocarpus hirsuita*), casuarina (*Casuarina equisetifolia*) as windbreaks in the homesteads of coastal tracts of the Northern Zone, and silver oak (*Grevillea robusta*) used as a shade tree for coffee in the high-altitude region, are the other common tree species in the homesteads. Moreover bamboo (*Bambusa arundinacea*) is commonly grown along the plot peripheries in the Central and Northern Zones. Known as the "poor man's timber", this multipurpose plant plays an important role in providing building material for the poor in the villages, where they are widely used as posts, rafters and reepers in building construction, and bamboo thorns are used for fencing. Bamboo stems tied together as a mat are also used for partitions in homes and for drying grains; bamboo poles are used as a physical support for banana, and rural cottage industries like basket making are bamboo based. Bamboo thorn for fencing is sold at Rs 30–35 (US$ 2.5–3) per head load that can cover

10 metres (Kerala Agricultural University 1985a). A 10-metre long bamboo pole costs Rs 40–50 in the market.

The portia tree (*Thespesia populenea*), numbering 5–10 per household, is a common sight in the homesteads of the south and central regions and in the mangroves of the marshy, low-lying areas. The tree is often used as a live fence. The timber from this tree is of superior quality and is used for agricultural implements, furniture and even for bullock carts.

Softwood trees like "pala" (*Alstonia scholaris*), "matty", (*Ailanthus triphysa*) and "elavu" (*Bombax ceiba*), are also planted along the boundaries of homesteads. Even the small-sized wood of these species finds a ready market in the match industry which is a flourishing cottage industry in the State. A "matty" tree fetches about Rs 100 (US$ 8.00) for eight years of growth. Of late, *Albizia falcataria*, a fast-growing softwood tree, is being widely planted in the Southern Region, and is used for catamarans by the fishermen in the coastal tract. This tree fetches more than Rs 120 (US$ 10.00) after eight years. Often, fishermen offer high prices for well-developed trees. This tree is also being sold outside the State.

Mangroves form an essential part of the homesteads of backwater areas in the lowlands of Pokkali, Kuttanad and the coastal tracts of the Northern Zone. The mangroves protect the homesteads from mud and sand washed down by rivers and also from high tide. Often they constitute the boundaries between homesteads. A few mangrove species like *Acanthus illicifolius*, *Avicennia officinalis*, *Carbera odollam*, *Rhizophera conjugata* and *Rhizophera mucronata*, are commonly seen.

"Kaitha" (*Pandanus tectorius*) is seen extensively in the homesteads near canals and backwaters in marshy areas throughout the State. The leaves of this plant are extensively used for the manufacture of mats and fancy articles. The white bracts are very fragrant. An oil called "Keoro oil" is distilled from its roots and the flowers are used in many Ayurvedic preparations. A number of flourishing small-scale industries in the co-operative sector are based on this plant.

Some of the common crop associations are given as Figs. 10.3–10.5.

5.2. *Mixed farming*

Most farm families have a variety of animals in their homesteads – cows, buffaloes, bullocks, goats, sheep and birds like chickens and ducks. In certain places pigs are also reared. Cows and buffaloes are maintained for milk, bullocks for draught, chickens and ducks for eggs and meat. A homestead usually owns 1–2 cows/buffaloes and 15–20 chickens. In the Northern Zone the homesteads will have 4–5 goats.

Fodder grass and legumes are widely grown to meet the daily requirements of fodder for cattle; the important fodder grasses are Guatemala grass, Napier

grass and guinea grass (Table 10.1). Wherever rubber is grown, leguminous cover crops like *Calopogonium muconoides* and *Centrosema pubescens* are also grown to enrich the soil and smother the weeds; their foliage can also be fed to the animals.

In the homesteads of backwater areas and coastal tracts ducks are common and pig keeping is practised in the homesteads of central Kerala. Invariably each farm family possesses at least one pair of bullocks, but their number is dwindling due to the high cost of cattle feed/fodder.

The waste materials from crops and homes are used as fodder/feed for animals/birds and the barn wastes are used as manure for crops. Because of shortage of fodder and grass and the increasing cost of rearing cattle, farmers do not retain the bullocks for a long time: the usual practice is to buy the animals from the markets during the time of peak field operations, especially from June to July, and to sell them immediately after completion of field operations, usually at a lower price.

A number of improved breeds of cows like Jersey, Holstein and Brown Swiss are reared by farmers. A duck breed known as "Khaki Cambell" is most common. Among the goats, a breed known as "Malabari" is the most popular one and among chickens, Austrolope, Rhode Island Red and White Leghorn are the ones commonly reared.

Authorized agencies in the co-operative sector undertake collection and distribution of dairy and poultry products. These agencies also arrange to supply cattle/poultry feed.

In the low-lying regions of the Kuttanad and Pokkali zones aquaculture/mariculture is extensively practised with great success in the homesteads adjoining canals, paddy fields and ponds. The most important fishes/prawns grown are catla (*Catla catla*), rohu (*Labeo rohita*), mrigal (*Cirrhina mrigala*), pearl spot (*Etroplus suratensis*), Indian prawn (*Penaeus indicus*) and tiger prawn (*Metapenaeus indicus*). As mentioned above, mangrove gardens of this region form an ideal habitat for fish farming. The organic wastes falling from the mangrove vegetation serve as a good feed for the fish and the numerous inlets provide a good breeding place for the fish population.

Beekeeping is also popular in some homesteads, especially those of the relatively more resourceful farmers. One study incorporating the mixed-farming concept was conducted by the Kerala Gandhi Smarak Nidhi (a voluntary organization) in the homesteads (Kerala Gandhi Smarak Nidhi 1985). In the study, conducted in a 0.12 ha plot of undeveloped arid land in Trivandrum District of the Southern Zone, the farmer undertook a three-tier planting of fodder, cassava, vegetables, a number of bananas, cloves and coconuts, with *Leucaena* being planted all around. There were 23 coconut seedlings, 12 cloves, 56 bananas, 49 pineapples and 30 pepper vines; fodder grasses were planted in a 0.03 ha plot. The rest of the land was covered by other crops. A cow which was part of the scheme not only provided milk for consumption

and sale but also organic manure. Chemical fertilizers were not used at all. The net income derived during the first three years (when the cash crop had not started yielding) amounted to Rs 1,550, Rs 3,848 and Rs 3,950 in the first, second and third years, respectively.

The expected net income from the cash crops at the current (1986) market price, when these crops will start full bearing, are cloves Rs 3,800, coconut Rs 900, other plants Rs 1,500 and livestock Rs 3,000 making a total of Rs 9,200 a year from the 0.12 ha plot.

This case study provides a good example of a sustainable organic farming system which could be used as a model for future developments.

6. Interaction between components

A typical homestead with a multitude of crops presents a multi-tier canopy configuration (Figs. 10.3 10.5). The leaf canopies of the components are arranged in such a way that they occupy different vertical layers, with the tallest component having foliage tolerant of strong light and high evaporative demand and shorter components having foliage requiring or tolerating shade and high humidity (Nair 1979). The major portion of the upper canopy goes

Fig. 10.3. Photograph of a coconut-based homestead; crops in the foreground include ginger, banana, elephant yam (*Amorphophallus companulatus*); the major tree species (other than coconut) include jack fruit (*Artocarpus heterophyllus*), moringa (*Moringa* spp.), *Erythrina indica*, and young mango trees. Black pepper vines are trailed on to coconut and erythrina.

Fig. 10.4. Photograph of an arecanut (*Areca catechu*) homegarden. The components are somewhat similar to those of Fig. 10.3. The house can be seen in the centre of the garden.

Fig. 10.5. Mixed farming model of the homestead system. In addition to the multispecies multilayer plant associations, milch animals also constitute a major component of the system.

to coconut. This is followed by other crops like black pepper, cacao and tree spices. The lower storey of the harvesting plane is occupied by banana and cassava and other tuber crops. At the floor level, pineapple, vegetables and other herbaceous crops are grown. The canopy architecture and pattern of component interaction are similar to those of their tropical homegardens, as described by Fernandes *et al.* (1984), Fernandes and Nair (1986) and Soemarwoto and Soemarwoto (1984).

Wherever coconut is present as the dominant component the intercrops that are grown vary according to the age and canopy size of the coconuts. During the initial stages of coconut's growth, all sun-loving crops form the lower tier. From the bearing stage (eight years) to about 25 years, when the shade is rather dense, shade-loving crops like yams, turmeric and ginger are grown. Afterwards the incoming solar radiation in the garden increases and the homesteads can be filled with a number of annual and perennial crops.

7. Functional aspects of the system

Out of 3.5 million operational holdings in Kerala, nearly 3.1 million (87%) are very small (< 1.0 ha size), with an average size of 0.22 ha. These account for 42% of the total area under cultivation. In another 24% of the cultivated area the small holdings are 1–2 ha in size. This situation of a large number of the holdings, as well as a large proportion of the cultivated area being under them, has significant implications for land productivity and income (Kerala Agricultural University 1985). The intensity of cropping in the homesteads is very high, mostly with rather low levels of biomass productivity of individual components.

7.1. *Labour utilization potential*

On average, each household consists of 6–8 people who provide the necessary workforce. In the small holdings, planting, cultural operations and harvesting of different crops occur throughout the year and are attended by the farm family. Most of the crops in the homegarden are labour intensive except coconut.

As compared to monocropping, the homesteads involve high labour utilization. For example, the average requirement of labour on a one-hectare homegarden with an intensive crop mix and livestock is about 1,000 man days per year as compared to 150 man days for coconut monocropping and 400 man days for rice monocropping (Nair 1979; Nelliat and Shamabhat 1979; Sreedharan 1984). During certain seasons, such as during sowing and/or harvesting of different crops, an acute shortage of labour is a common

experience. The coir industry, cocoa processing, the cassava industry, fruit canning, jaggery making, the match industry, etc. offer greater scope for employment, and the raw materials for all these are provided mostly by the homegardeners.

In addition to the above, there are also immense possibilities for employment for rural people by way of plaiting of coconut leaves for thatching houses, basket making and mat making from bamboo and Pandanus, distillation of vetiver and lemongrass oil, fishing, dairy farming, etc.

7.2. *Capital*

Income for the livelihood of the farmers is mainly by the sale of products like rubber, coconut, pepper, cashew, ginger, turmeric and cacao, and surplus paddy.

July–August is a lean season for all farmers as far as cash is concerned. This is a time when expenses are at a maximum and income from the crops is at its minimum. This period coincides with the south-west monsoon when planting and cultural operations of most crops take place. Added to this, the schools re-open at this time and, with an average of at least two school-going children per family, the farmers incur a lot of expenditure for school uniforms, books and other expenses. To meet the immediate cash requirements, the farmers try to sell all disposable farm animals such as poultry, goats/sheep, cows, buffaloes, etc., and also borrow from village money lenders at excessive interest rates. The loans will be repaid at the time of the harvesting of cash crops – arecanut, coffee, cashew, pepper, ginger, turmeric, etc. – during December-January. Most of the farmers save money, chiefly for meeting their children's education expenses or for the marriage of girls. High expenditure on marriage is the most important social expense.

Rural credit for short-term, medium-term and long-term agricultural loans is well developed in Kerala. Agricultural credits are being arranged through co-operative banks and agricultural credit societies at the primary level. Even fertilizers, agricultural implements like tillers, tractors, pump sets and other inputs can be arranged through these societies.

7.3. *Inputs*

Farmers usually store seeds from a current season's crops for the following season(s). Seed materials/seedlings are also obtained from authorized governmental agencies such as the State Department of Agriculture, Agricultural University, etc., and also from private suppliers all at reasonable prices. Chemical fertilizers are increasingly being used for all crops. However, plant-protection chemicals are not widely used.

7.4. *Marketing*

The production and marketing processes in Kerala are intertwined in the economic system in as much as the farmer has a significant influence on the production activity. The major commodities involved are arecanut, cacao, coconut, coffee, cashew, ginger, pepper, rubber, turmeric and vegetables. In the case of commodities which are not marketed through organized channels, the annual prize fluctuations are quite substantial and the farmers are put at a very great disadvantage (State Planning Board 1985).

In respect of a large number of agricultural commodities, a major portion of the trade transactions take place in the villages where they are produced. About 200 markets in Kerala conduct daily, weekly or bi-weekly sales. There are also about 90 primary marketing societies in the co-operative sector. These approved agencies arrange procurement of produce from the farmers and this enables the farmers to fetch fair prices. Other than this, there are commission agents, middlemen and brokers, wholesale merchants and retailers to operate the market. The main practices are negotiation, bargaining, commission basis and auction sale (State Planning Board 1985).

There are also problems relating to absence or lack of grading at primary level, lack of storage and transport facilities, lack of proper market intelligence, defective weighing, adulteration, etc.

8. System dynamics

Being a densely populated State, the pressure of population in Kerala is reflected in the agricultural activities and dynamics of the homesteads. There is practically no scope for increasing the area under plough. Therefore, agricultural and other land-use strategies aim at increasing the productivity of the area under cultivation through exploitation of the available resources. This applies to homestead gardening also.

There have been some noticeable trends in the cropping patterns of Kerala over the past few years *vis-à-vis* market price of commodities, social changes and attitudes of the people. Large-scale introduction of cacao in the homesteads occurred in the late 1970s when the price of cacao in the Indian market touched an all-time high of Rs 45 (then US$ 5.50) per kg of dried beans (State Planning Board 1985). But in subsequent years, to the great dismay of farmers, there was a sharp decline in cocoa prices, resulting even in the removal of cacao plants from the homesteads. Now, cacao is being replaced by fodder grasses, banana and tuber crops. Similarly, the area under arecanut had also decreased a few years earlier after a decline in its price. The main food crop, rice, faces innumerable constraints in production, such as scarcity of labour, high cost of inputs and very low prices for the produce. This has

forced many of the farmers to switch from rice to coconut. In Kerala, there is a tendency to seek "white-collar" jobs in Government or private sectors, with the result that educated members of the family may not be available for agricultural operations. Thus, farmers go for cultivation of coconut in preference to labour-demanding rice. In the uplands of the low-rainfall areas, palmyrah has been the main crop. Nowadays, it is also being replaced by coconut consequent to the commissioning of irrigation projects in those areas.

An area of about 0.15 million ha in Kerala is affected by the so-called root (wilt) disease of coconut – a malady of uncertain aetiology. Reduction in yield of root (wilt)-affected palms is estimated to vary from 10 to 80% (Nelliat and Shamabhat 1979). Because of this, the net returns from the disease-affected coconut gardens steadily decrease. Intercropping with suitable crops is considered an effective way of increasing the economic returns from such coconut areas. So, systems of mixed farming in disease-affected coconut gardens, involving fodder grasses and legumes for building up and maintaining soil fertility, are being tested and popularized.

Rubber is the only commodity in the State for which prices have been steady for the past few years. For this crop, labour input is comparatively less once the tree attains the tapping stage. This has tempted many farmers to undertake cultivation of rubber, even in the homesteads. Banana and tuber crops are also slowly being replaced by rubber in areas where distribution of rainfall is uniform.

Black pepper, an important cash crop and foreign-exchange earner, is being grown using coconut, arecanut and *Erythrina* as live standards. However, this poses problems at the time of harvest of coconut and arecanut as climbers find it difficult to climb the trees due to the presence of pepper vines on the trunk. *Erythrina*, on the other hand, is frequently infested by stem borers which destabilize the bearing pepper vines. Therefore, concrete pillars and teak poles are also being used as standards, but they are excessively expensive. Of late, *Leucaena* (var. K-8) and *Garuga pinnata* have also been tried as live standards for black pepper. *Leucaena*, being a multi-purpose tree crop, holds much promise.

The current cattle population in the State is 3.4 million adult units, which require more than 5.6 million tonnes of fodder (State Planning Board 1985). But the total fodder production in the State is estimated to be only 4 million tonnes, which includes dry straw, crop residues, weeds, etc. A promising way of filling up this large deficit of 1.6 million tonnes, is to grow fodder grass in the homesteads, possibly through integration of pasture, livestock and tree crops. Growing of forage grasses and legumes, feeding them to cattle and recycling the dung and other basic wastes to crops as manure is an existing practice. This has helped to maintain the prolonged productivity of coconut palms by improvement in the physical, chemical and biological properties of

the soil. The use of fermented cowdung to generate biogas for meeting domestic fuel needs of farm families is also becoming popular. Though the biogas plant requires some initial expenses for its establishment, it needs no running expenditure. The practice reduces the demand for wood fuel; moreover, the slurry from the gas plant can be used as enriched farmyard manure for crops.

In the backwater areas and coastal regions, intensive mixed farming with fish culture is also practised. The cattle dung and poultry litter are dropped in the adjoining canals/tanks where fish are grown. In return, the excess fish are fed as fish meal to poultry and cattle. In the Pokkali region, where rice cultivation is done in stagnant water up to one metre in depth, prawn culture is successfully practised. Only one crop of rice is taken in these fields and the straw stubble is used as feed for the prawns. Farmers often benefit more from prawn culture than from rice culture. One hectare of land can thus produce 2,000 kg rice and an estimated 750 kg prawns (selling at Rs 10 per kg), per year, the total returns being Rs 11,500 per ha and the expenses, excluding family labour, Rs 4,990 per year (Mathew 1985; Sreedharan 1984) (1 US$ = approx. Rs 12.20, April 1986).

9. Evaluation

9.1. *Merits*

The multitude of crop species in the homesteads helps to satisfy the primary needs of the farmers, such as food, fodder, timber and cash. This also helps to conserve the fertility by nutrient cycling in spite of the high intensity of cropping(s) (Nair 1984). The increased microbial activity in the rhizosphere of crops is another positive contribution in the multicropping systems (Nair and Rao 1977). High labour utilization and risk minimization are the other benefits associated with the system (Nair 1979).

Mixed farming leads to substantial improvements in the physical and biological characteristics of the soil (Nelliat and Shamabhat 1979). The use of waste materials for feeding the cattle, poultry and fish results in efficient recycling of these wastes, whereas increased utilization of family labour in this enterprise reduces expenditure on hired labour. Adoption of mixed-farming practices in root-disease-affected areas has helped to enhance the productivity of the coconut palms as well as of land (Nelliat and Shamabhat 1979). The homestead system also prevents exposure of the bare soil to the beating action of the torrential rains experienced in these areas, and consequently leads to reduction in soil erosion (Nair 1983, 1984).

9.2. *Constraints*

In order to sustain high levels of production from this intensive system, inorganic fertilizers have to be used despite recycling efforts. This leads to an increase in the cost of cultivation.

In spite of the increased family-labour utilization, labour scarcity is being experienced at times, especially during periods of peak agricultural operations.

Because of the scarcity of land it becomes difficult to earmark separate areas of production for forage crops. The growth of fodder crops is rather poor under shade (Pillai and Sreedharan 1985).

Lack of irrigation facilities often limits crop production, especially in areas where there is uneven distribution of rainfall as in the Northern Zone (Kerala Agricultural University 1984).

The rapid conversion of rice fields into coconut gardens is leading to a decline in food production in the State. Even at present more than 50% of the food requirements of the State are met by imports from neighbouring States; conversion of more rice fields to other crops would further reduce rice production in the State.

In the homestead polyculture, plants are usually arranged in a haphazard manner without giving adequate attention to the ecophysiological requirements (water, light, nutrients, etc.) of the individual understorey crops in the system, and this leads to a reduction in the yields of individual crops.

The high plant density in the homesteads leads to excessive humidity within the plant community (Nair 1979) that can cause fungal diseases like bud-rot (*Phytophthora palmivora*) of coconut, especially during the rainy seasons.

The farmers of the State have a general feeling that the trees will take away all nutrients and cast shade, adversely affecting field crops. They also entertain a notion that the trees will harbour injurious birds and insects (Kerala Agricultural University 1985a).

Lack of adequate research results is one of the major constraints to greater use of tree crops in the homesteads in certain places.

10. Potential and prospects

Planting of a number of multipurpose fruit trees such as mango, jack fruit, gooseberry, portia tree, wild jack, etc. in the homesteads provides the basic needs of food, fuel, fodder, timber and manure for the farmer.

Introduction of crops like *Leucaena* for fuelwood in the homesteads would help the farmer to overcome the fuelwood shortage. Pulses, vegetables and fruit crops in the homesteads provide a diversity in food products and improve the quality of farmers' diets. This is particularly important in rural

areas where the people are malnourished.

There is scope for limited mechanization in the homesteads, as evidenced by use of tractors and power tillers for preparatory cultivation for rice and equipment and machinery for coconut climbing and dehusking.

Recycling of organic materials envisaged in the mixed-farming system aims at conversion of waste materials into useful products for agriculture and other needs.

11. Research needs

In spite of the importance of these systems to the economy of the State and its people, practically no research has been undertaken to improve the productivity of these homegardens. Whatever research results are available pertain to monocrop systems so that they are of little value in these polycultural situations. The following are some of the research aspects that merit immediate attention:

- Evolving shade-tolerant varieties of fodder grasses and legumes and standardization of their management;
- Water and nutrient requirements of crops in a polycropping system;
- Rooting pattern and root distribution studies of the component crops for understanding nutrient-moisture interaction and utilization;
- Spatial and temporal arrangement of crops for efficient conversion of solar energy;
- Identifying crop associations which can be fitted into different intensities of shade;
- Working out of an integrated production approach involving crop/livestock/microbes/fertilizer/pests;
- Extrapolatability of one system into similar agro-ecological zones and economic analysis;
- Complementary and competitive interaction effects between crop components.

Along with studies on the above aspects, research on various aspects of the related systems also needs to be intensified.

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11. Intercropping under coconuts in Sri Lanka*

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Abstract. Coconut is a major commercial crop of Sri Lanka. Growing a number of other crops in association with coconuts is a widespread practice in all coconut-growing areas of the country. The rationale for the practice is that other crops can profitably be grown between or under the coconuts during the different growth stages of the palms and thus the overall productivity of the land under this long-duration crop can be substantially increased.

The paper gives a concise account of the practice in Sri Lanka indicating the crops most commonly grown as intercrops, the arrangement of different crops and early research results on the productivity of the intercrops and their effect on coconuts. Adequate supplies of water and labour are the two major inputs needed for the success of the system. Drought, lack of funds, price instability, lack of technical know-how on intercrop management, and problems of timely availability of inputs are the major constraints experienced by farmers in expanding intercropping. Research on both biological and socio-economic aspects is needed to overcome these constraints and extend this potentially attractive system.

1. Introduction

Coconut (*Cocos nucifera* L.) is cultivated on about 400,000 ha or 25% of the total cultivated area of Sri Lanka. It is the most widely cultivated plantation crop of the island nation, the other major two being tea (244,916 ha) and rubber (222,311 ha), and is thus second only to rice (874,221) in terms of the area under the crop. Although coconut is grown in all the districts of Sri Lanka, about 70% of the area under the crop is concentrated in the "coconut triangle" formed by the districts of Kurunegala, Puttalam, Gampaha and Colombo on the central west coast (Fig. 11.1). Other important coconut areas include the districts of Kalutara, Galle, Matara and Hambantota, accounting for about 15% of the total area. The rest of the area is found mostly in the small homegardens in other districts.

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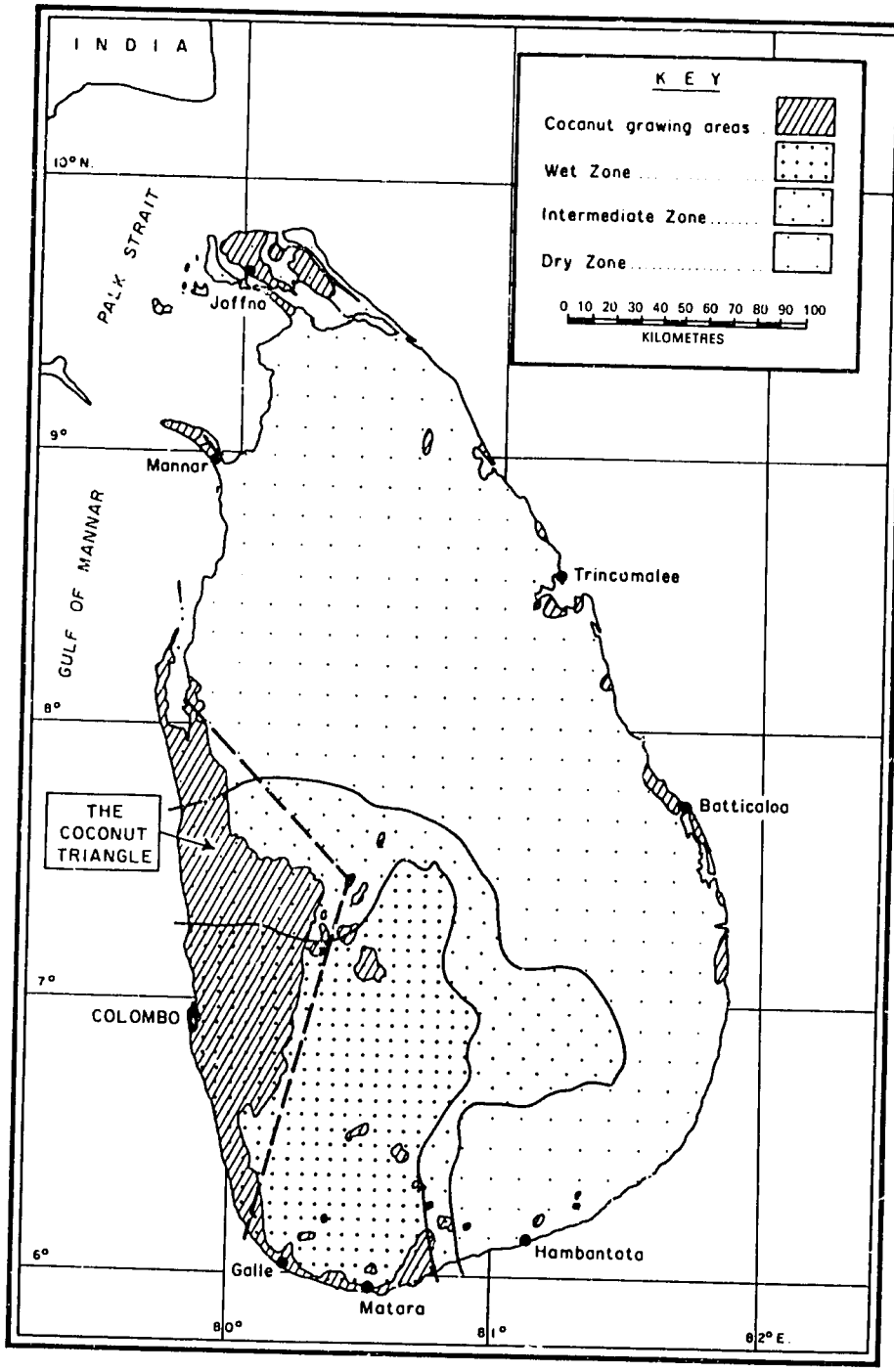

Fig. 11.1. Map of Sri Lanka showing the three major rainfall zones and the coconut-growing areas.

It is a widespread practice in all coconut growing areas of Sri Lanka to grow a large number of other crops in association with the coconuts. The practice has been encouraged by the Government of Sri Lanka since 1973 by introducing several subsidy schemes. This paper examines the situation with respect to coconut intercropping in Sri Lanka and summarizes the results obtained so far. Cattle grazing on pasture under coconuts is also a common practice in some parts of the country (Coconut Research Board 1986a), but this paper does not cover that system in detail.

2. General description of the area

2.1. *Biophysical environment*

Sri Lanka is a tropical island between 5°55′ and 9°51′ N latitude and 79°42′ and 81°53′ E longitude. The total area is 65,610 km^2, and it extends to a maximum of 410 km in the north-south direction and 225 km in the east-west direction. There are different forms of tropical climates within the country depending on rainfall, temperature and altitude (topography). There are three major rainfall zones (Koelmeyer 1957):

- The Wet Zone that has more than 500 mm rain per month during May to September (south-west monsoon), with a mean annual rainfall of 2,500 mm or over;
- The Intermediate Zone, which is a part of the Wet Zone, with a mean annual rainfall of 1,875–2,500 mm;
- The Dry Zone with less than 500 mm of rain per month during the south-west monsoon season of May to September and a total annual rainfall of up to 1,875 mm;

Areas of the Dry Zone with a mean annual rainfall of less than 1,250 mm are usually called "Arid Zone".

In Sri Lanka, coconut is grown most prominently in the low-country Wet and Intermediate Zones, as indicated in Fig. 11.1. It is also grown to some extent in the Dry Zone wherever facilities for irrigation exist. In view of the changing distribution pattern of rainfall followed by unprecedented drought periods, considerable attention has now been focused on the subject of supplementary irrigation of coconut plantations during droughts, especially in the Intermediate and Dry Zones. On the basis of the hydrology of the area and long-term rainfall records, it has been estimated that available ground-water potential ranges from around 2,400 cu m ha^{-1} per annum in the Wet Zone to 800 cu m ha^{-1} in the Dry Zone, without affecting the water table (Fernando 1983).

Temperatures are generally around 27 C with only a slight difference in the diurnal and seasonal fluctuations. The relative humidity in coconut-growing areas is also high with a mean of 85%. There is no marked difference in day lengths between seasons, which favours the cultivation of a wide variety of other crops in major coconut-growing areas.

The major soil types found in the coconut belt are generally related to the nature of parent material, topography and agroclimate of the area. In the Wet Zone, for example, the dominant soil type in which coconut is grown is a shallow to moderately deep gravelly clay loam, passing to laterite at depth. In the Intermediate Zone, coconut groves are distributed mainly in the sandy loam type of soil passing to soft lateritic subsoil. In the Dry Zone, coconut plantations are either flat or undulating, excepting for a few low to moderately sloping areas. As such, the majority of coconut plantations in Sri Lanka occupy fertile land of different agroclimatic and soil-environment types suitable for intercropping with a wide range of crops.

2.2. *Land-use systems*

With the exception of the area covered with montane rain forest and wet *patanas* (grass lands), rice cultivation is possible and popular in Sri Lanka in all places lying below 1,200 m altitude and having irrigation facilities. Some cultivated land in Sri Lanka, especially in the dry northern and eastern plains, and to a lesser extent in the south-west, is under shifting cultivation (*chena*).

Besides these two cultivated land systems, three big plantation systems are important for the island's economy: rubber, tea and coconut. Rubber plantations are in the wet low country up to an elevation of 700 m and tea up to an elevation of nearly 2,300 m, tea plantations being the only form of land use in areas above 1,200 m. Coconut is very important in the internal economy and food system of the country. It used to be a major export crop in the past, but according to 1982 figures (Government of Sri Lanka 1983) about 70% of the total nut production was used for domestic consumption, leaving about 30% as the exportable surplus. Coconut, therefore, has a dual role in meeting the increasing local demand as well as continuing to serve the vital export market. Cacao, cinnamon, cardamom, citronella and pepper as minor export/cash crops also contribute to the economy of Sri Lanka. Forests account for 24.9% of the area of the country (Gueller and Balasubramanian 1980).

Sri Lankan farmers practice a number of agroforestry systems. The most prominent ones are *chena*, which is a form of shifting cultivation, some forms of taungya, intercropping under coconut, Kandy gardens or homegardens (see

Chapter 12), growing tea and coffee under the shade of trees, and windbreaks/ shelterbelts (Tejwani 1984).

3. Structure of the coconut intercropping system

3.1. *Components*

The growth habit and morphology of the coconut palm permit a number of other crops to be grown with or under it during its different growth stages (Nair 1979). A large number of compatible crops – both annuals and perennials – are grown under coconuts in different geographic and ecoclimatic regions (Hettiarachchi 1974; Karunaratne *et al.* 1978; Liyanage 1976, 1980; Nair 1979, 1983; Nelliat and Bhatt 1979; Varghese *et al.* 1979). The major crops grown in association with coconuts in the different climatic zones of Sri Lanka are listed in Table 11.1.

Sample surveys of intercropping under coconuts conducted recently (Government of Sri Lanka 1981a, 1981b; Anonymous 1983) in the Wet and Intermediate Wet Zones indicated that bananas, black pepper, coffee and ginger, in that order, formed the intercrops most preferred by the farmers. The second group in order of preference consisted of turmeric, betel, vegetables and pineapple. Factors such as profitability, marketing facilities and convenience were listed as the major reasons for farmers' preference for the crops mentioned.

3.2. *Arrangement of components*

The three planting systems recommended for coconuts (sole stands) in Sri Lanka are the square (7.9 × 7.9 m), rectangular (8.5 × 7.3 m) and triangular at 8.5 m equilateral, each system accommodating a density of about 160 palms per hectare (Manthriratna and Abeywardena 1979). In the coastal belt, palm densities are relatively high, often up to 210 palms per hectare.

Based on the evaluation of the pattern of utilization of the basic resources – soil and solar energy – in monocrop coconut stands of varying age groups (Nair 1979, 1983), it is now generally accepted that coconut stands can conveniently be intercropped when they are either young (up to about eight years after planting) or fully grown and bearing (from about 25 years after planting). According to these considerations, and taking into account the age group of the palms, it is estimated that 70–80% of coconut plantations in Sri Lanka can be intercropped (Government of Sri Lanka 1981b; Santhirasegaram, 1966, 1967).

Table 11.1. Intercrops grown under coconuts in Sri Lanka.

Types of crops	Crops		Wet zone	Intermediate wet zone	Intermediate dry zone
1. *Food crops*					
Tubers	Cassava	*Manihot esculenta*	x	x	
	Sweet potato	*Ipomoea batatas*	x	x	
	Taro	*Colocasia* spp.	x	x	
	Yams	*Dioscorea* spp.	x	x	
Cereals	Finger millet	*Eleusine coracana*			x
	Maize	*Zea mays*		x	
	Sorghum	*Sorghum bicolor*		x	
Legumes	Cowpea	*Vigna unguiculata*		x	x
	Green gram	*Vigna radiata*		x	x
	Groundnut	*Arachis hypogaea*		x	x
	Soybean	*Glycine max*		x	
	Winged bean	*Psophocarpus tetragonolobus*	x	x	
Fruit crops	Banana	*Musa* spp.	x	x	x
	Citrus	*Citrus* spp.		x	x
	Papaya	*Carica papaya*		x	
	Passion fruit	*Passiflora edulis*	x	x	
	Pineapple	*Ananas comosus*	x	x	x
	Pomegranate	*Punica granatum*			
2. *Spices and condiments*					
	Arecanut	*Areca catechu*	x	x	
	Betel leaves	*Piper betel*	x	x	
	Chillies	*Capsicum* spp.	x	x	x
	Ginger	*Zingiber officinale*	x	x	
	Turmeric	*Curcuma longa*	x	x	
3. *Minor export (cash) crops*					
	Black pepper	*Piper nigrum*	x	x	
	Cacao	*Theobroma cacao*	x	x	
	Cinnamon	*Cinnamomum zeylanicum*	x	x	
	Clove	*Syzygium aromaticum*	x	x	
	Coffee	*Coffea* spp.	x	x	
	Nutmeg	*Myristica fragrans*	x	x	
Others	*Pasture grass	*Brachiaria miliiformis*	x		x
	Sesame (oil seed)	*Sesamum indicum*			

* Also see Nair (1983).

The crop mixtures that are commonly associated with mature coconuts are as follows:

- Coffee/banana
- Banana mixed with either ginger/turmeric or pineapple
- Pineapple/papaya
- Banana/mixed with coffee/cacao
- Coffee/black pepper
- Cacao/coffee (dwarf San Roman variety)/black pepper.

The arrangement of components depends on the nature of the intercrop. Generally speaking, a circular area of about 2 m radius around the palm is left free of intercrops and the intercrops are grown in the interspaces according to the recommended planting systems of the sole crop of the intercrop concerned. Figure 11.2 shows a schematic planting pattern involving black pepper, cacao

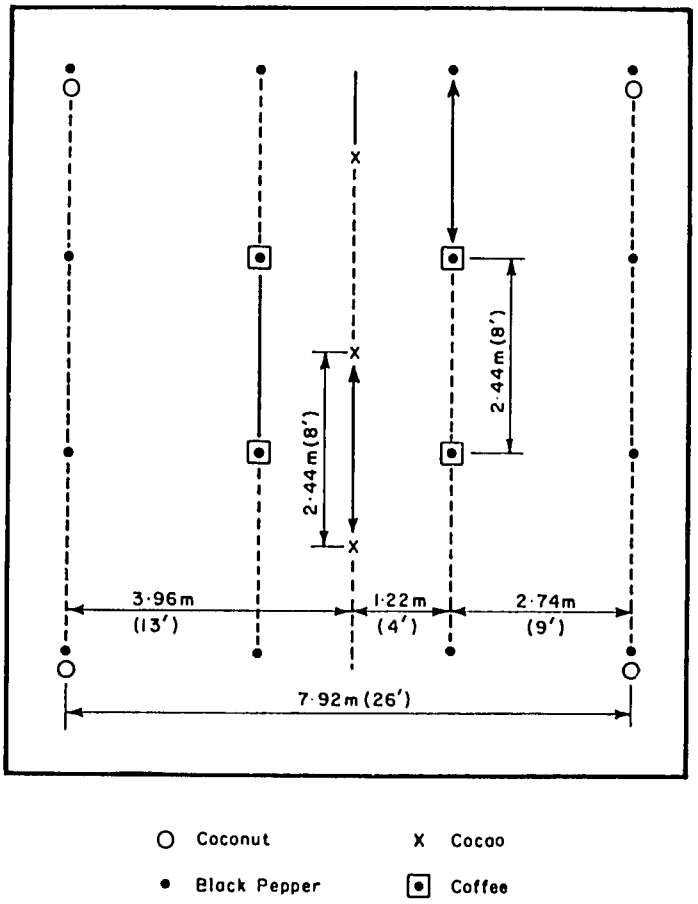

Fig. 11.2. Schematic patterns of planting black pepper, cacao and coffee as intercrops with coconuts, giving a plant density of 795 black pepper, 550 cacao and 640 coffee per hectare in addition to 159 coconut palms.

Fig. 11.3. Cassava as an intercrop under coconuts. (Photo: CRI.)

Fig. 11.4. Black pepper and cacao as intercrops with coconuts at CRI. (Photo: P.K.R. Nair.)

and coffee with coconuts. Photographs of cassava, cacao and black pepper as intercrops with coconuts are given in Figs. 11.3 and 11.4, respectively, to show the planting arrangements of the different components.

3.3. *Interaction of components*

Theoretical considerations of plant-community interactions in multispecies combinations with coconuts have been discussed by Nair (1979) in the light of the limited research data that were available at that time. In practical terms, the main expectation from an intercropping system in a perennial plantation-crop system is that the overall return from a unit piece of land is increased without adversely affecting either the current or the long-term productivity of the main (perennial) crop. At the same time, the returns from the additional crops should justify the adoption of the intercropping practice and should contribute to the long-term productivity of the system. Thus, intercropping in coconut stands is viewed as a means of increasing the total productivity of lands that are "committed" to the coconut crop for up to, say, 70 years (which is the normal life span of the "Tall" type most commonly grown all over the world). Results of intercropping experiments conducted at the Coconut Research Institute (CRI) of Sri Lanka, and summarized in Table 11.2, indicate that intercropping resulted in an increase of nut yields of coconut.

Similar reports are also available from intercropping trials in India (Nair and Varghese 1979; Nelliat and Bhatt 1979; Varghese *et al.* 1979). The explanation given for this beneficial interaction is that the palms benefit from the manure and fertilizers given to the intercrops, elimination of weeds, soil working and other management practices.

Some of the other obvious advantages of intercropping include better and more intensive utilization of land, greater income and generation of more employment from land already planted with coconut, and income from cash crops.

Table 11.2. Yield of coconuts when intercropped with different crops.

Intercrops	*Yield of coconuts ha^{-1} yr^{-1}
Clove	5,549
Black pepper	5,466
Cacao	6,738
Cinnamon	7,080
Coffee	7,318
Annuals in rotation	6,825
Control (no intercrop)	5,172

* Average of four years (1978–1981) results at the Coconut Research Institute.

It is also likely that there will be a negative interaction leading to adverse effects on the main crop (coconut) and/or the intercrop. Such effects are likely to arise and be aggravated if the intercrops are not adequately and properly managed. However, practically no quantitative data are available from Sri Lanka on these aspects.

4. Functional aspects of the system

4.1. *Resource input and utilization*

In Sri Lanka, coconut is generally grown under rain-fed conditions. Experimental evidence shows that there would be no serious competition for soil moisture between coconuts and the intercrops if the annual rainfall is over 1,900 mm. However, in the Intermediate (rainfall) Zone and the drought-prone Dry Zone, it would be risky to grow coconuts as well as long-duration intercrops if irrigation facilities were not available. The earlier-mentioned survey of intercropping (Government of Sri Lanka 1981b) revealed that irrigation facilities were available to 17% of the farmers who practised intercropping in the Intermediate Zone.

Labour is one of the other major resources needed for intercropping. A study conducted by the Agrarian Research and Training Institute, Colombo (1976) revealed that intercropping in coconut stands resulted in a 300% increase in on-farm employment. Some basic farm-management data collected over five years from the intercropping trials at the CRI are given in Table 11.3. It shows that depending on the type and number of intercrops involved, the requirement of labour and the share of labour cost in the total cost of production increased. While the timely availability of labour could pose a problem in some places, the generation of additional on-farm employment can be a very encouraging aspect in owner-cultivated smallholdings. However, only a very small percentage of coconut holdings are owner-cultivated in Sri Lanka (see below).

4.2. *Production*

Some data on the production from intercropping systems have already been presented (Tables 11.2 and 11.3). These are from experiments conducted at CRI. Although coconut intercropping is widely practised in all coconut-growing areas of the country, quantitative data on production aspects from cultivators' fields have not been systematically collected.

Table 11.3. Some basic farm-management data per hectare on intercrops grown with 35-year-old coconuts.*

Intercrop(s)	Input costs**			Output			Net income from intercrop	
	Labour (days)	Labour	Materials	Total	Yield (kg)	Value**	Annual	Cumulative
Coffee								
1st year	144	2,520	1,685	4,205	—	—	−4,205	−4,205
2nd year	77	1,348	1,380	2,728	—	—	−2,728	−6,933
3rd year	89	1,558	1,725	3,283	50	2,000	−1,283	−8,216
4th year	112	1,960	1,625	3,235	225	9,000	5,765	−1,036
Total	514	8,996	8,040	17,036	400	16,000		−1,036
Cacao								
1st year	144	2,511	1,910	4,421	—	—	−4,421	−4,421
2nd year	75	1,308	1,405	2,713	—	—	−2,713	−7,134
3rd year	63	1,099	1,725	2,824	65	1,625	−1,199	−8,333
4th year	48	837	1,625	2,462	227	5,688	3,226	−5,107
5th year	60	1,046	1,625	2,671	525	13,125	10,454	5,347
Total	390	6,801	8,290	15,091	817	20,438	5,347	
Cacao, coffee and black pepper								
4th year	209	3,662	3,200	6,862			16,972	

* Based on five years data at CRI, Sri Lanka

** Value in Sri Lanka rupees; 1US $ = approx. SL Rs 25 (1984).

4.3. *Protective and service aspects*

Monocrop stands of coconuts offer only partial coverage of the ground when the palms are young and also as they advance in age when the stems become elongated. Consequently the soil is more exposed to erosion and degradation during these periods. Incidentally, these are the periods when intercropping is most feasible and desirable. In monocrop coconut stands, it is a common management practice to adopt soil and water conservation practices such as terracing, preparation of bunds and contour drains and burying coconut husks in pits and trenches near the palms to conserve moisture (Coconut Research Board 1976). By practising intercropping and adopting prudent land-management practices for the intercrops, many of these soil-conservation practices which would otherwise be necessary could be avoided. Thus intercropping can be a better way of increasing the sustainability of coconut lands.

4.4. *Socio-economic aspects*

In Sri Lanka, coconut holdings of less than 4 ha are considered smallholdings. The census of agriculture, 1982, which covered 10% of coconut holdings in the districts of Kurunegala, Gampaha, Colombo and Puttalam in the "coconut triangle", indicated that 55% of the total area of coconut in the coconut triangle is composed of such smallholdings (Table 11.4). There is a rather complex relationship between land ownership, owner cultivation/supervision and intercropping. The vast majority of coconut holdings in the country are not cultivated or supervised by the owners. The general pattern is that the majority of coconut farmers are also engaged in paddy rice (and other crops) cultivation. Smallholders who cultivate their own land seldom practise intercropping because most of their time is utilized in growing rice and other crops (in non-coconut areas). On the other hand, holdings which are leased, share-cropped or otherwise managed or supervised by non-owners are intercropped. Sixty-three percent of intercropped coconut holdings are thus cultivated/supervised by non-owners, whereas only 26% of the non-owner cultivated/supervised holdings are non-intercropped.

Table 11.4. Size-class distribution of coconut holdings in the coconut triangle of Sri Lanka.

Size, class, category	Hectarage	Percentage
<0.040 ha	22,996	8.49
0.40–2.0 ha	87,907	32.47
2–4 ha	38,202	14.11
4–8 ha	27,304	10.09
>8 ha	94,343	34.84

Source: Census of Agriculture, Sri Lanka (1982).

5. Constraints and potentials

5.1. *Constraints*

The sample survey of the intercropping in coconut lands (Government of Sri Lanka 1981b) has identified seven important problems/constraints that are faced by the farmers in expanding their intercropping activity. These, in order of relative importance, are drought, lack of funds, price instability, lack of technical know-how, problems of timely availability of labour, availability of planting materials, and thefts. On average, each intercropper faced at least three of these problems, their nature and extent being dependent on the size of the holding and type of intercrop. For example, lack of technical know-how and funds and non-availability of plant materials and fertilizers were the most acute problems faced by smallholders, whereas drought, price instability and thefts were reported as general problems affecting all categories of holding sizes.

In addition to the above, marketing of perishable seasonal crops (e.g., passion fruit, papaya, pineapple) and crops that are produced in bulk (e.g., ginger, turmeric) can also be a serious problem. The problem can be aggravated if intercropping extends to large areas without simultaneously developing processing facilities at the producing centres and/or transportion infrastructure to consuming/processing centres.

5.2. *Potentials*

Notwithstanding the above-mentioned constraints (which are not insurmountable), the system has great scope for expansion in Sri Lanka and extrapolation to other areas. In principle, this is a sustainable system provided that necessary inputs are available at the appropriate times and in the correct quantities and the system is managed appropriately. At present, intercropping practices are being extended to additional coconut areas at an annual rate of 1,000 ha, thanks to the several Government subsidy schemes.

6. Research needs

The constraints identified in the previous section call for research on both biological and socio-economic aspects, and the development of an efficient extension service in order to make coconut intercropping systems more productive, economical, adoptable and successful. The agronomic requirements of individual crops when they are grown as intercrops need to be

standardized. At the same time, the interaction of crops when they are grown in close proximity needs to be studied elaborately so that research results can be obtained on the pattern of sharing of resources and growth factors by all component species of the system. In order to arrive at prudent management recommendations, it is necessary to take into account both complementary and competitive interactions affecting production of individual species as well as total production of the whole system, not only during a short span of time but over a long period on a sustainable basis. A reassessment of the hitherto accepted planting patterns and densities of sole crop coconuts is also worth undertaking with the objective of growing intercrops without adversely affecting the palm's productivity. While most other agroforestry systems consist of perennials that often help improve soil fertility through continuous addition of leaf litter and other organic materials, coconuts do not add much organic material to the soil, and, therefore, ways of maintaining soil fertility in coconut intercropping systems through external application of nutrients have to be designed appropriately. Along with studies on these aspects of coconut intercropping systems, research on various aspects of the related system of pasture and grazing under coconuts also needs to be intensified.

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12. The Kandyan gardens of Sri Lanka

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Abstract. Kandyan gardens represent a homegarden system practised in small homestead holdings, of an average size of 1 ha, in the "mid-country" region of Sri Lanka, mainly Kandy, Matale and Kurunegalle districts. This centuries-old system consists of mixed cropping with a variety of trees and perennial/semi-perennial shrubs such as spices, fruit trees, medicinal plants and timber species, the components being arranged randomly. The total number of trees/shrubs varies from 65 to as many as 1,700 per hectare, with a multistorey canopy configuration. Most of the high-density plantings occur where coffee and arecanut are the dominant components, and, in general, the species diversity as well as plant density on a farm is inversely proportional to the holding size. The paper analyses the production and labour-utilization patterns of the system, discusses its constraints and potentials, and outlines the research needs to improve this sustainable, multiple-output agroforestry system.

1. Introduction

The Kandyan gardens (KG) or Kandyan forest gardens (KFG) of Sri Lanka represent a traditional system of perennial cropping which has been practised for several centuries. It is essentially a system of mixed cropping with a variety of economically valuable tree crops such as spices, fruits, medicinal plants and timber species. However, these systems are usually in small homestead holdings and are practised in a few districts, especially Kandy, Matale and Kurunegalle in the "mid-country" region of Sri Lanka. In the district of Kandy, this is the most predominant cropping system and hence the name "Kandyan gardens" and "Kandyan forest gardens". The mixed forest-gardening system offers a highly diversified and economically viable form of land use. Similar systems are also being practised in several other populated parts of the humid lowlands, for example, in India, Thailand, Malaysia, Indonesia and Papua New Guinea in south-east Asia (Jacob 1982, 1984; Michon and

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Bompard 1986; Nair and Sreedharan 1986). However, the Kandyan forest garden system is different from these other homegarden systems, mostly in terms of the variety of plants grown. Moreover, the farmers who practise the forest garden system in Sri Lanka enjoy a relatively better standard of living by virtue of returns from both the economic cash crops and the subsistence products. With improved management, the system has the potential for increased production and better returns. This paper examines the situation with respect to the Kandyan garden system and endeavours to identify the directions of research for the improvement of the system. The data presented in the paper are based on a survey of 30 farms of the locality (McConnell and Dharmapala 1973) and on results of mixed cropping experiments conducted by the Minor Export Crops Research Project (Bavappa and Jacob 1982; Jacob 1982, 1984; Jamaluddeen and Jacob 1983).

2. General description of the area

The details of climate, rainfall, temperature, topography, soils, etc. of Sri Lanka are described in the paper on intercropping under coconuts in Sri Lanka (Chapter 11; Liyanage *et al.* 1984). A considerable proportion of KFG in the three districts (Kandy, Matale and Kurunagalle) is located in the intermediate-rainfall zone (mean annual rainfall of 1,875–2,000 mm) and in mid-elevations (450–1,050 m) with hilly terrain. The KFG system is practised on a variety of soil types with predominance in strongly to weakly lateritic soils, and in most cases on sloping lands.

The area under various crops and other land-use systems in the three districts where the Kandyan garden system is practised is given in Table 12.1. It is worth noting that these three districts have only 4.1% of land under forest compared to the national average of 24.9%. This is because of the

Table 12.1. Land use in the three districts of Sri Lanka where the Kandyan system is practised.

	Area (ha)			Total area (ha)	% of Sri Lanka's total
	Kandy	Matale	Karunegalle		
Total land	215,770	199,530	477,590	892,890	13.6
Large inland waters	20	–	320	340	0.35
Forest	23,000	33,200	10,500	66,500	4.1
Rice	37,967	18,728	109,704	166,399	19.0
Tea	78,249	7,990	376	86,615	35.4
Rubber	5,881	7,036	5,804	18,721	8.4
Cacao	3,015	4,439	522	7,976	94.3
Cinnamon	17	68	12	97	0.4
Cardamom	1,949	2,294	34	4,277	80.7
Citronella	–	90	—	90	3.6
Black pepper	2,652	3,021	388	6,061	66.8

relatively large areas under export crops such as tea, rubber, cacao, cardamom and black pepper; these three districts account for 35.4, 8.0, 94.3, 80.7, and 66.6%, respectively, of the total area under these crops in Sri Lanka.

3. Structure of the Kandyan gardens

Kandyan homegardens are small homestead holdings, the size of the 30 farms surveyed (McConnell and Dharmapala 1973) varying from 0.4 to 2.0 ha with an average of 1 ha per holding.

3.1. *Composition*

This system is primarily based on trees and perennial and semi-perennial shrubs. The survey of 30 farms revealed that as many as 20 crops or

Table 12.2. Crops grown in the Kandyan gardens.

Name of crop	Number of farms on which the plant is grown (out of the 30 farms surveyed)
Areca (*Areca catechu*)	28
Jack fruit (*Artocarpus heterophyllus*)	26
Coffee (*Coffea* spp.)	26
Black pepper (*Piper nigrum*)	26
Coconut (*Cocos nucifera*)	25
Plantain (*Musa* spp.)	25
Tea (*Camelia sinensis*)	23
Cloves (*Syzygium aromaticum*)	20
Nutmeg (*Myristica fragrans*)	15
Citrus (*Citrus* spp.)	15
Papaya (*Carica papaya*)	15
Vegetables	14
Avocado (*Persea americana*)	11
Kitul (*Caryota urens*)	10
Flowers	9
Mangosteen (*Garcinia mangostana*)	7
Cacao (*Theobroma cacao*)	7
Breadfruit (*Artocarpus altilis*)	5
Yams (*Dioscorea* spp.)	5
Durian (*Durio zibethinus*)	5
Rice (*Oryza sativa*)	3
Fodder grasses	2
Mango (*Mangifera indica*)	2
Cardamom (*Elettaria cardamomum*)	2
Rubber (*Hevea brasiliensis*)	2
Pineapple (*Ananas comosus*)	2
Rambutan (*Nephelium lappaceum*)	1
Passion fruit (*Passiflora edulis*)	1
Ginger (*Zingiber officinale*)	1

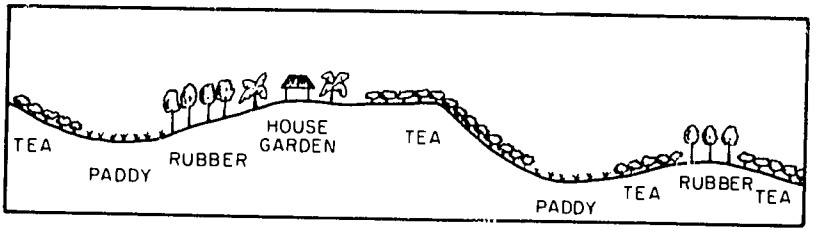


Fig 12.1. Schematic representation of the general land-use pattern in the Kandyan garden system.

components were grown in the system, indicating a very high degree of crop combination and diversification (Table 12.2). The most important crops in the system, by frequency of occurrence, are trees such as areca (*Areca catechu*), jack fruit (*Artocarpus heterophyllus*), and coconut (*Cocos nucifera*); bushes of plantain and coffee; and black pepper vines (*Piper nigrum*). Among minor export cash crops, cacao is grown in about 25% of the farms. A general picture of a Kandy garden system is given as Fig. 12.1. The highest number of crops grown on a farm was 18 (on a 2 ha farm) and the lowest 4 (on a 1.2 ha farm). Eighty percent of the farms grew 8–15 crops. There was no relationship between the farm size and crop diversity.

3.2. *Arrangement of components*

Generally, the crops do not seem to be grown according to any specific pattern or planting arrangement, but appear to be in a random though

Fig. 12.2. Photograph of a Kandyan garden. (Photo: V.J. Jacob.)

intimately mixed pattern (Fig. 12.2). However, it is not logical to conclude that a system that has evolved over centuries and is still providing good sustenance (someone has called it "affluent subsistence") for the farmers, could be casual about location, spacing and site conditions of perennial cash crops. It can be surmised that those who practise the system know, in a practical way, what and where to plant and how to manage the plants. The tea, rubber and coconut smallholders, for example, plant their tree crops according to a pattern, indicating their awareness and perception of the specific site conditions and requirements of the crops.

It is difficult to generalize about the spacing between individual crops and the number of each species grown per unit area. In very simple terms, the total number of trees/bushes per hectare varies from 65 to as high as 1,700 or more. It is difficult to devise an acceptable index of cropping intensity for a situation where crops are grown at several tiers of canopy configuration. Crops such as yams, vegetables and tea are at low levels, coffee, cacao, citrus and plantains at medium heights, and all these under the canopy of trees such as coconut, areca, mango, etc., in a recognizable but not definite order. It is observed that most of the high-density plantings occur on those farms where coffee and areca are the dominant components (Table 12.3). There is a tendency in high-density farms to fill up any space where coffee is not grown with more than the usual number of areca palms, which, because of their slender, tall stems and light crowns, can be squeezed into such gaps.

An analysis of plant density, especially of areca palms, in relation to farm size suggested that the density of plantation was related to farm size – the bigger the farm, the lesser the density. Mean densities (of areca palms) on 0.4, 0.8, 1.2 ha farms were 315, 237, 102 and 56 trees per 0.4 ha (1 acre), respectively. However, as mentioned earlier, holding size has no relation to species diversity.

3.3. *Interaction of components*

Obviously there could be interactions among the plants, and between plants and their environment, in such an intimate system of plant association, but no

Table 12.3. Crop density in relation to coffee and areca in Kandyan gardens.

Item	Average for 7 high-density farms	Average for 7 low-density farms
Area (ha)	0.75	1.54
Total trees (no.) per ha	1,040	113
Coffee bushes (no.) per ha	528	23
Areca palms per ha	170	28

data are available on this aspect. What distinguishes the Kandyan garden system from other land-use systems is the intensive utilization by plants of both the above-ground and the below-ground resources, both vertically and laterally. Nair (1979, 1984) has discussed some of the aspects of plant interactions in such intensive mixtures. It is also possible that being a mixture of many crop species, the risk of crop pests and diseases associated with monocropping systems is minimal. However, all these points are in the realm of conjecture as there are no scientific data available from these systems to either prove or disprove them.

4. Functional aspects of the system

4.1. *Resource input and utilization*

All the farms surveyed were owner cultivated. On average, each farm has 2.54 full-time adult male labour equivalents (AME; 1 AME = 1 adult male = 1.4 adult female = 2.5 children). The distribution and utilization of family labour in the Kandyan garden system (Table 12.4) indicated that picking and harvesting of various crops used the most family labour (37.9%), followed by weeding (19.3%) and drying/processing (19.0%). These data indicate that one of the primary aspects of management is collecting and gathering produce from the tree crops either for sale or consumption by the family. The usually important operations of subsistence agriculture, namely planting/sowing and digging/cultivating, are relatively unimportant and account for only 3.0 and 8.9% of family labour respectively. Many categories of hired labour such as part-time, full-time, day labour with or without meals, contract work, etc. are identifiable, and are used for various farm operations. It is interesting that although family labour is usually available on the farms and most of it not meaningfully employed otherwise, there is quite a heavy dependence on hired labour (from outside) for farm operations. An average of 62% of the total labour requirements on the farm is met by hired labour, the larger the farm

Table 12.4. Use of family labour for different farm operations in Kandyan gardens.

Farm operations	% of family labour used
Planting	3.0
Cultivation	8.9
Weeding	19.3
Harvesting	37.9
Drying	15.0
Marketing	11.9

Table 12.5. Production of crops in the Kandyan gardens.

Crop*	Unit		Yield/Unit		Quantity sold	Quantity consumed on farm	Distribution (%)	
	Plant/area	Produce	Green	Dry			Sold	Used
Black pepper	Vine	kg	4.20	1.10	1.18	0.04	96	4
Kitul	Palm	bottles of vine	16.92	—	16.29	0.63	96	4
Arecanut	Tree	no. of nuts	312	—	307	5	98	2
Plantain	Tree	bunches	0.94	—	0.97	0.15	84	16
Jack	Tree	no. of fruits	12.43	—	0.83	11.60	07	93
Mangosteen	Tree	no. of fruits	174	—	150	24	86	14
Citrus	Tree	no. of fruits	34	—	21	13	62	38
Papaya	Tree	no. of fruits	11	—	2	9	18	82
Nutmeg	Tree	kg	—	0.74	0.74	—	100	0
Cloves	Tree	kg	2.69	0.88	0.88	—	100	0
Rubber	Tree	kg	—	3.52	3.52	—	100	0
Cacao	Tree	kg	—	0.32	0.32	—	100	1
Coffee	Tree	kg	2.09	0.45	0.02	0.03	93	7
Durian	Tree	kg	105	—	79	26	75	25
Vegetables	Ha	kg	985	—	863	120	88	12
		bushels of 27.20 kg 27.20 kg each (60 lb)	—	107	—	107	—	100
Flowers (anthuriums)	Plant	no. of flowers	6.56	—	6.35	0.21	95	5
Mango	Tree	no. of fruits	806	—	762	44	95	5
Rambutan	Tree	no. of fruits	1,700	—	1,500	200	88	12
Pineapple	Plant	no. of fruits	0.80	—	0.60	0.20	75	25
Yams	Ha	kg	1,004	—	892	112	89	11
Breadfruit	Tree	no. of fruits	384	—	318	66	83	17
Tea	Ha	kg	863	—	863	—	100	—
Coconut	Palm	no. of nuts	101	—	76	25	72	25
Avocado	Tree	no. of fruits	186	—	164	22	88	12

* See Table 12.1 for details.

the greater the use of such hired labour. One reason for this phenomenon is that harvesting of crops such as tea, cloves and black pepper is considered skilled work, which is usually not done by family labour, and such operations constitute the major labour requirement for many crops in the system (Table 12.5).

The cash requirement for operating costs is generally low: an average of Sri Lankan Rs 710 per hectare (1US $ = approx. SL Rs 25 in late 1984). The cost of hired labour (87.8%), fertilizers (5.9%), transportation (3.4%), hand tools (1.4%) and chemicals (0.7%) are the items of this expenditure. About 90% of the total cash expenses for farm operations were on a relatively small number of crops such as tea, coconut, black pepper, areca, cloves, coffee, vegetables and rice.

The level of debt incurred on the farms surveyed was low (an average of only SL Rs 229 per farm at the time of survey).

4.2. *Production*

The yield of crops in a forest garden can be quantified in terms of yield of units of individual crops in the gardens, and the value of yields per unit area can better be described in terms of monetary returns/value of the yield. Table 12.6 summarizes the average yield levels of 25 crops covered in the survey of 30 Kandyan gardens described in this paper.

The data in Table 12.6 indicate that the level of total production and income per farm is fairly high and steady throughout the year except in the

Table 12.6. Yield and value of crops harvested from forest gardens during different months of the year.

Month	Average number of crops harvested each month	Monthly value of production per farm (man of 30 forest gardens)	
		*Rs (Sri Lanka)	%
January	5.4	151	3.8
February	6.3	2,382	59.6
March	4.4	230	5.8
April	4.0	149	3.7
May	3.3	135	3.4
June	3.4	123	3.1
July	3.4	143	3.5
August	3.8	134	3.4
September	4.0	164	4.1
October	4.0	130	3.3
November	4.2	127	3.1
December	5.2	130	3.2

* 1US $ = approx. SL Rs 25 (1984).

month of February. However, the pattern of production from an individual farm will depend on the composition of the crop mix on that farm. To evaluate the seasonal distribution of income within the year on individual farms a "time concentration index" is used. This index refers to the square root of the sum of squares of deviation of the monthly income from the average monthly income. If 100 units represent the total yearly income of a farm (i.e., an average of 8.3 units of income per month), and if all of it is received from a monocrop with a single harvest per year, the time concentration index is:

$$\sqrt{(8.3-100)^2+(8.3-0)^2+(8.3-0)^2+\ +\ +\ +} = \sqrt{9167} = 95.8.$$

Similarly, if the total income is evenly distributed throughout the year, the index is 0. It was observed that of the 30 farms surveyed, 11 farms had indices less than 50, and the other 19 had indices more than 50. The high index was identified as being associated with cloves. Of the 11 farms which had a low index, only a few grew cloves; on the other hand all the 19 farms which had indices higher than 50 grew cloves. When cloves were excluded from the calculation, the mean value of the index was only 32, and as many as 25 farms had indices less than 50, indicating that the labour requirement was spread out evenly during the year.

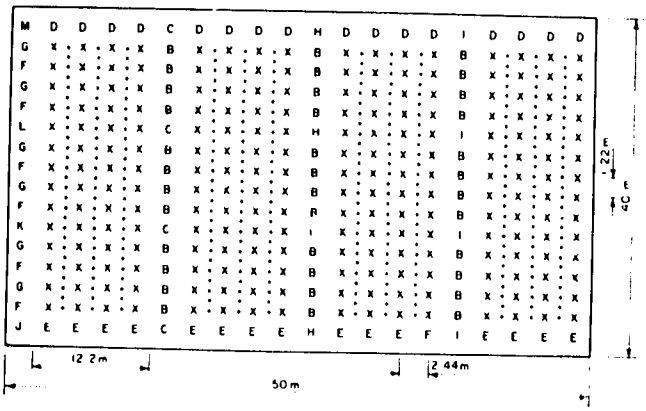
Cloves accounted for 42.2% of all cash farm income, followed by pepper (14.9%), tea (12.3%), coconut (11.9%), banana (5.2%), coffee (3.6%), nutmeg (1.8%), and areca (1.7%). These eight crops contributed 93.6% of the cash income. Six of these crops are low-volume and high-value crops and some of them enter the export market. The low-cash-income products – milk, vegetables, kitul, anthurium, durian, other fruits, economic and food crops – are all subsistence products which are sold only when there is a surplus. Mean cash farm income was Rs 4,085 per ha and Rs 1,120 per adult male equivalent (AME) of farm family members.

One characteristic of the Kandyan garden is the amount and diversity of sustenance it provides. All the farms surveyed had significant non-cash food income, the average amount of such income per farm being Rs 271 per ha annually. Coconut accounted for 42.4% of the non-cash food income produced and consumed, the others being jack fruit seed (16.9%), banana (13.3%), black pepper (8.8), coffee (4.4%), durian (3.8), and vegetables (2.9%).

A look at the hillsides where the Kandyan garden system is practised will convince anyone that it provides an excellent cover for the land at various levels. However, these protective and service aspects have not been quantified or studied in any detail.

5. Constraints and potential

The Kandyan or forest garden system is one of the best examples of an integrated land-use system in the densely populated humid tropics. This



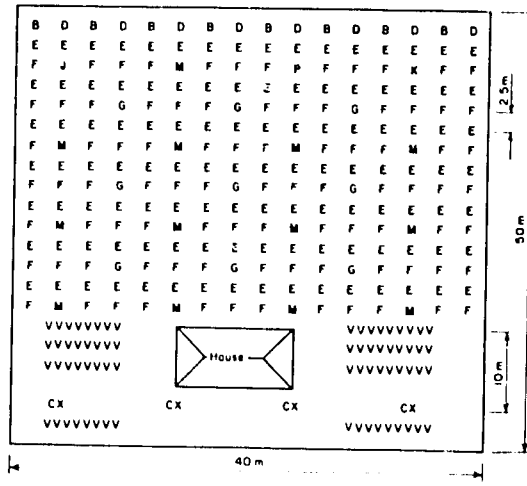
A. Model for high intensity cropping.

Code crop	Spacing	No./ha
Large canopy		
C Coconut	12.2 × 12.2 m	36
H Nutmeg	12.2 × 12.2 m	12
I Clove	12.2 × 12.2 m	12
J Jack fruit	12.2 × 12.2 m	3
K Breadfruit	12.2 × 12.2 m	3
L Avocado	12.2 × 12.2 m	3
N Mango	12.2 × 12.2 m	3
Medium canopy		
X Pepper	2.44 × 2.44 m	1,296
B Coffee (Robusta)	2.44 × 2.44 m	220
D Arecanut	2.44 × 2.44 m	24
E Banana	2.44 × 2.44 m	24
F Pawpaw	2.44 × 2.44 m	22
G Lime	2.44 × 2.44 m	22
Small canopy		
Dwarf coffee (San Ramon)	1.22 × 1.22 m	1,926

Fig. 12.3. Planting patterns for multilayer perennial crop combinations in the smallholdings of Sri Lanka.

system provides food, fuel, fodder, fruit, beverages, spices, small timber, regular cash inflow and work for the farmer on the one hand, and conserves production on a sustainable basis on the other. In spite of this, a major constraint to the improvement of the system is that it has not been understood scientifically.

Scope for improvement of the system is illustrated by the very promising results from a research programme supported by a UNDP/FAO project at the Research Station of the Department of Minor Export Crops in Matale, near Kandy (Bavappa and Jacob 1981, 1982). Experiments on crop combination



B. Model for homestead farming by paddy (rice) farmers.

Code crop	Spacing	No./0.2 ha
Large canopy		
M Mango	10 × 10 m	13
C Coconut	10 × 10 m	4
J Jack fruit	10 × 10 m	1
K Breadfruit	10 × 10 m	1
P Guava	10 × 10 m	1
Medium canopy		
B Coffee (Robusta)	2.5 × 2.5 m	8
D Arecanut	2.5 × 2.5 m	8
E Banana	2.5 × 2.5 m	112
F Pawpaw	2.5 × 2.5 m	87
G Lime	2.5 × 2.5 m	9
X Pepper	on coconut	4
Small canopy		
V Vegetables Tubers, etc.		

Fig. 12.3. Planting patterns for multilayer perennial crop combinations in the smallholdings of Sri Lanka (continued).

were initiated in 1978 in marginal and eroded tea lands. Fourteen different plant species of varying canopy architecture and growth habits were included in carefully designed planting patterns, a model of which is given in Fig. 12.3. The income-generation potential of this model is shown in Table 12.7.

Figure 12.4 is a photograph of a section of such a high-intensity combination five years after planting the crops.

Banana and papaya in the crop mix started yielding in the second year after planting and coffee and black pepper in the third year. It has been estimated that the return from this crop combination after all crops have attained full

Table 12.7. Estimated annual return from a one-hectare mixed cropping model at Delpitiya, November 1987.

Crops/Yield years after	Yield (kg/plant) or no. of fruits/plant							No. of plants	Total yield	Unit* price	Total* value
	1	2	3	4	5	6	7				
Pepper (kg)	Nil	0.2	0.3	0.5	0.8	1.0	1.0	1,296	1,296	25	32,400
Coffee - R (kg)	Nil	Nil	0.2	0.4	0.6	0.75	0.75	220	165	30	4,950
Coffee - S (kg)	Nil	0.1	0.2	0.3	0.4	0.5	0.5	1,914	957	30	28,710
Clove (kg)	Nil	Nil	Nil	0.1	0.2	0.5	1.5	12	18	100	1,800
Nutmeg (no.)	Nil	Nil	Nil	Nil	25	100	500	12	6,000	0.2	1,200
Coconut (no.)	Nil	Nil	Nil	5	15	25	50	36	1,810	1.5	2,700
Mango (no.)	Nil	Nil	10	30	40	50	50	3	150	0.5	75
Jack fruit (no.)	Nil	Nil	Nil	5	10	15	15	3	45	2	90
Breadfruit (no.)	Nil	Nil	Nil	5	15	30	50	3	150	1	150
Avocado (no.)	Nil	Nil	Nil	10	30	50	50	3	3	0.2	30
Arecanut (no.)	Nil	Nil	Nil	10	50	100	100	24	2,400	0.2	480
Banana (no. of bunches)	Nil	1	1	1	1	1	1	24	24	10	240
Lime (no.)	Nil	Nil	Nil	10	20	50	100	44	4,400	20	880
12 crops								3,594			73,705

R = Robusta coffee
S = San Ramon coffee
* = Value in Sri Lanka rupees at 1983 price; 1 US $ = SL Rs 25 (approx.)

Fig. 12.4 Photograph of a combination of black pepper and *Gliricidia sepium* as part of a high-intensity crop combination five years after establishment. (Photo: P.K.R. Nair, ICRAF.)

production would be the equivalent of US$ 2,880 per hectare annually at the 1983 rate of exchange and value of the crops (Table 12.7).

This is just one example of what could be accomplished from the Kandyan homegardens. At present, the system is operating at a very low level of efficiency. With more research back-up and extension efforts, the efficiency of the system can be improved considerably. The system can also be extended to other areas in Sri Lanka. For example, the Land Utilization Committee of Sri Lanka estimated that as early as 1967 about 18,000 ha of tea smallholdings of less than 4 ha each were severely eroded and non-remunerative. Judging from

the results of the UNDP/FAO project, the high-intensity crop model of the Kandyan garden pattern offers great scope for improving the productivity of these lands. Sri Lanka's environmental conditions are such that a vast number of high-value export crops can be grown. There is a good chance of stepping up the production of these crops on the degraded tea and rubber smallholding land through appropriate crop-diversification efforts. With appropriate modifications, the system can also be extrapolated to other areas with similar environmental conditions outside Sri Lanka.

6. Research needs

The Research Station at Matale has conducted some studies on the improvement of the Kandyan homegarden system. However, these efforts need to be greatly stepped up in view of the scope for improvement. Some of the agronomic aspects that need to be examined in detail before the suggested new models (Bavappa and Jacob 1981) are recommended to farmers include:

- Selection of appropriate species and assessment of their compatibility with each other;
- Arrangements and spacing of various component crops according to the level of input and management;
- Use of improved, high-yielding, fast-growing cultivars and varieties;
- Response of various individual components and the system as a whole to management constraints;
- Input output relations at various levels;
- Long-term effects and sustainability of various combinations.

Acknowledgements

Being a system description, this paper has drawn upon various sources, notably the report of McConnel and Dharmapala (1973). The authors are also grateful to Dr K.G. Tejwani for the assistance rendered in preparing the manuscript and to Dr P.K.R. Nair, ICRAF, for encouragement in publishing it.

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13. Homestead agroforestry in Bangladesh*

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Abstract. The homestead agroforestry system is very important in the economy of Bangladesh. The many woody species grown in the homesteads are a significant source of fuelwood; they also provide fodder, building materials and other forms of wood. In the context of the prevailing shortage of fuelwood and excessive deforestation in Bangladesh, this homestead agroforestry system needs to be strengthened.

A field survey was undertaken to assess the prospects and feasibility of initiating a programme for the improvement of homestead agroforestry systems. It showed that the prospects are good because most respondents own their homesteads and believe there is room for more trees on them. Although they know that raising trees is relatively difficult, and requires special practices, they are familiar with the government nurseries and local agricultural extension officers, and are confident about the success of the programme. Results also indicate that multipurpose trees and specific modules for involving women in the farm operations are likely to enhance success of the programme.

1. Introduction

Trees in the homesteads play an important role in the rural economy of Bangladesh. Often called "homestead forests", such plantings are particularly important sources of fuelwood because fuelwood cannot be transported long distances from existing forest areas. Further, existing natural and plantation forests are generally managed for commercial products; they are an inadequate fuelwood source even for nearby residents, and are clearly of no help to larger populations living at a distance.

In addition, FAO (1982) estimated that cutting (forest clearing) exceeded wood production by 800,000 m^3 in 1980 in Bangladesh. That report concluded that "the predominant need will remain that for smallwood, principally fuelwood", and that "... large deficits for this material will continue to arise in the northern and central regions...". Hammermaster (1981) estimated that

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8.9% of the village and homestead forest volume was harvested in the year studied and observed that that was "well in excess" of growth. In the absence of other wood sources, improved village forestry and homestead agroforestry are important to the development of Bangladesh and the well-being of its people.

The Homestead Agroforestry Research and Development Project, currently being formulated by the United States Agency for International Development (USAID) – Dhaka Mission, has been proposed as a means to increase fuelwood supplies from homestead agroforests. This paper evaluates the general conditions with respect to homestead agroforestry in Bangladesh and reports the results of a field survey conducted to assist the Project Design Team.

2. General description of the area

2.1. *General location*

Bangladesh is located between 20° 35′ and 26° 75′ north latitudes and 87° 03′ and 92° 75′ east longitudes. It is bordered by the Bay of Bengal on the south and by India on all other sides except for a small south-eastern border with Burma. The total area of the country is about 141,000 km^2. The population was estimated at 90 million persons in 1981 with a 20-year average growth rate of 2.6% per annum (Wennergren 1984). Thus Bangladesh has a very dense and rapidly increasing population.

The climate is dominated by the monsoon which usually begins in June and ends in October. Average rainfall is reported to vary from about 3,000 mm at Cox's Bazar in the south-east to 1,600 mm at Dinajpur in the north-west. About 85% of this occurs during the monsoon season (Johnson 1982). Temperature is fairly uniform nationwide, with extremes of near 0°C to 40+ °C being recorded. Water, rather than temperature, is the limiting climatic factor for agriculture and other vegetative growth.

2.2. *Biophysical environment*

Four general physiographic regions are present: the hills, the delta, the plains and the dryland regions. The hills occur in the eastern Chittagong and Sylhet Districts and contain tropical evergreen forests of highly variable quality and productivity. Plantations and slow-growing second-growth hardwoods are also present. Teak (*Tectona grandis*) and garjan (*Dipterocarpus* spp.) are the principal timber species.

Fig. 13.1. A degraded sal (*Shorea robusta*) forest in the plains region.

The delta region, in the Khulna and Barisal Districts, contains the *sundarbans*. These are the world's largest mangrove forests and are the largest forested area in Bangladesh (FAO 1982). The natural mangrove forests have low productivity. Mangrove plantations are being established, but these are still immature. The *sundarbans* are the largest source of commercial timber, followed by the hill forests. Sundry (*Heritiera fomes*) and gewa (*Excoecaria agallocha*) are important trees harvested.

The drylands occur mainly in Rajshahi District in west-central Bangladesh. Little natural or plantation forest exists in this region. The plains regions occupies the remainder of Bangladesh. This region is dominated by the Ganges, Brahmaputra and Meghna river systems. This region, as well as the dryland region, floods during the monsoon season. The plains region once had substantial sal (*Shorea robusta*) forests, but these have been largely replaced by agriculture (Fig. 13.1).

2.3. *Land-use systems*

Bangladesh's economy and employment are dominated by agriculture. About 86% of the population lives in rural areas and almost all of these persons are engaged in some kind of agriculture. In 1981, rice and wheat ranked first and second in value and land area planted. Potatoes, sugarcane, jute, and oilseeds were the next most valuable crops (Wennergren *et al.* 1984).

Cropping patterns follow the rainfall. This is particularly true for rice which has three distinct crops. The *rabi* season is dry and extends from late October to late March. Irrigated *boro* rice is grown in this season. Non-irrigated crops include wheat, potatoes and oilseeds. About a third of the cultivated land is used in this season. The rainy *bhadoi* season that follows includes the early part of the monsoon and ends in July or August. *Aus* rice and jute are the primary crops. *Bhadoi* is followed by the *aghani* season that lasts until November or December and thus overlaps with the *rabi* season when *aman* rice is the only major crop. *Aus* and *aman* paddy can sometimes be planted on the same land. Draught animals (cattle and water buffalo) are grazed on paddy stubble and are fed crop residues and other fodder when stubble is unavailable (Johnson 1982).

Agriculture and homestead activities are relatively uniform throughout Bangladesh, despite general physiographic zones, because "... (ecological variation is) not dramatic and certainly not of the magnitude found in other nations with a more varied geographical structure" (Wennergen *et al.* 1984). The largest difference is in the hill region where the indigenous population practices slash and burn agriculture.

Location of the major crops varies with soils and other local conditions, but not always according to the major physiographic regions identified above. Generally speaking, *aman* rice is found nationwide, while *aus* is found predominantly in the plains and dryland region, and *boro* in the Mymensingh and Sylhet Districts. Wheat is grown mostly in the north-west and also in the Comilla District, while jute and oilseeds are grown mostly in the plains.

3. System structure

"Trees have always been planted by rural dwellers in Bangladesh, ... on homestead mounds ..." (Douglas 1983). Thus, homestead forests are an existing system in Bangladesh. This is also reflected in the species present (Table 13.1). Homesteads in the plains, delta and dryland regions are built on mounds to raise dwellings above the water level during the annual monsoon floods (Fig. 13.2). The mound area has many uses, including growing plant materials which provide fuelwood, fodder, building and other materials. These plants are grown on the homestead mound, often in relatively small areas, and are collectively called homestead forests.

The typical farm in Bangladesh contains an extended family unit which lives in a *bari*. The *bari* contains several houses for the different subfamilies, vegetable gardens planted and cultivated by female family members, and is surrounded by fences and/or trees and shrubs (Fig. 13.3). We found that the median homestead surveyed was 0.097 ha, the range being 0.020–1.4.4 ha. Only four households did not own their homestead land. Farm size ranged

Table 13.1. Common tree, shrub and bamboo species in the homesteads of Bangladesh.

Species		Homesteads with species*		Districts with species
Common name	Scientific name			
Timber		(No.)	(%)	(No.)
Rendi	*Samanea saman*	71	34	7
Koroi	*Albizia* spp.	72	34	7
Neem	*Azadirachta indica*	54	26	7
Pitraj	*Aanoora rohituka*	26	12	2
Pahari	Unknown	24	11	1
Other[a]		122	<10	
Total		369		
Fuel				
Mander	*Erythrina* spp.	86	41	7
Shimul	*Salmalia malabarica*	60	29	7
Jarul	*Lagerstoremia speciosa*	42	20	5
Hijal	*Barringtonia acutangula*	33	16	5
Tetul	*Tamarindus indica*	31	15	7
Babla	*Acacia nilotica*	30	14	4
Jhiga	*Lannea coromandelica*	29	14	3
Sheora	*Streblus* spp.	27	13	3
Other[a]		123	<10	
Total		461		
Fruit				
Mango	*Mangifera indica*	188	90	7
Jack fruit	*Artocarpus heterophylla*	157	75	7
Betel nut	*Areca catechu*	129	61	7
Coconut	*Cocos nucifera*	98	47	7
Date palm	*Phoenix dactylifera*	70	33	7
Jaam	*Eugenia* spp.	63	30	7
Boroi	*Ziziphus jujuba*	62	30	7
Guava	*Psidium guajava*	57	27	7
Palm	*Palmyra* spp.	36	17	7
Bel	*Aegle marmelos*	35	17	7
Ata	*Anona* spp.	27	13	7
Amra	*Emblica officinalis*	24	11	7
Total		946		
Shrubs				
Bhenna	Unknown	35	17	5
Other[a]		95	<10	
Total		130		
Bamboo				
Barak	*Bambusa vulgaris*	115	55	7
Muli	*Melocanna bambusoidea*	61	29	7
Makla	*Bambusa nutans*	29	14	4
Talla	*Bambusa nutans*	26	12	4
Other[a]		96	<10	
Total		327		

Source: Project design field survey (unpublished).

* No single species on 10% or more of homesteads.

Fig. 13.2. Dwellings and their surrounding homesteads are usually raised above the monsoon flood levels. Vegetables as well as plants that provide fuelwood, fodder and building materials are grown on these homesteads.

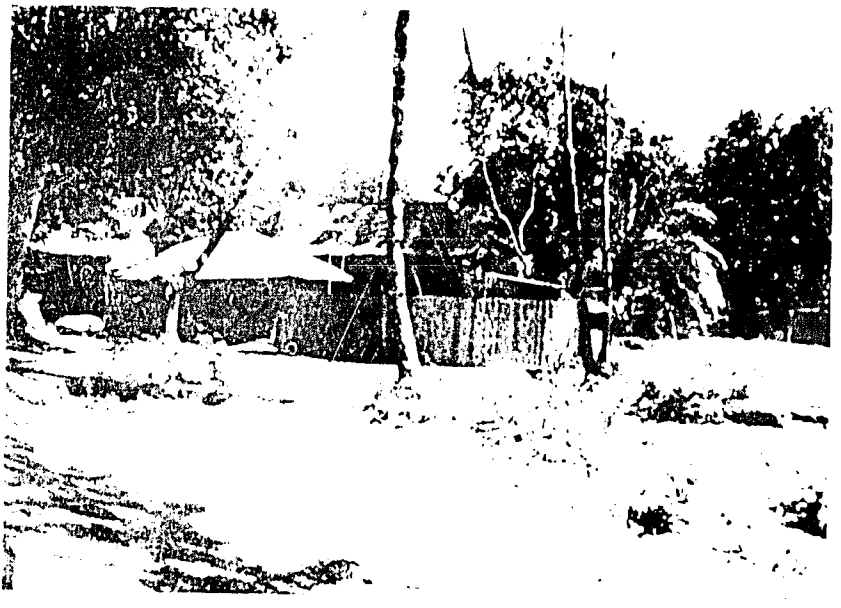

Fig. 13.3. A *bari*, which is the typical farm in Bangladesh. Note the open spaces which could be used for homestead agroforestry.

from 0.040 to 6.465 cultivable ha with a 0.469 ha median. Twenty-two households did not own their farms. The homestead area averaged 17% (0.097/(0.469 + 0.097)) of the useable land area. This relatively large proportion of land in a land-scarce economy makes its full utilization important.

One-third to one-half of all homesteads have at least one timber/fuelwood species and/or bamboo present (Table 13.1). However, 60–90% have mango, jack fruit, and/or betel-nut trees. These percentages, and the absolute numbers of species present, imply that fruit-bearing trees are favoured as much and probably more than the traditional forest species.

The proposed programme hopes to capitalize on the existing system by promoting plantings on unused spaces which still exist and by eventually distributing improved plant materials. The programme would recommend a number of species that are compatible with existing land use. For example, plants which would not overshadow vegetable gardens, or otherwise compete with existing desired vegetation, would be recommended and made available. The programme would begin by promoting indigenous materials but would concurrently develop and test improved native and exotic plants. Improved plants allow increasing yield for a constant number of producing plants.

Several potential benefits are anticipated. The most obvious is the increased production of fuelwood and ancillary products for household consumption and cash income. Another potential benefit is decreased labour expenditure for gathering fuelwood, the distance travelled to collect fuelwood being less as it becomes less scarce. The labour so released might find better rewards in alternative activities, such as craft production for personal use or sale.

4. Functional aspects of the system

The system and the proposed project sound logical and simple, but there are many necessary conditions for it to function properly. Seed and/or seedlings must be grown, the desired improved plants developed, plant materials distributed, farmers informed and convinced of the system's merits, and so on. Many of these conditions will require government intervention because such activities are not carried out by the private sector. Some activities could eventually be performed by the private sector if sufficient demand develops.

The likelihood of fulfilling these conditions should be assessed. One subset of these conditions centres around the farm household and its perceptions. Is collection of fuelwood and fodder time consuming enough to make new plantings worthwhile? Are farmers familiar enough with planting and maintenance of trees, as well as government institutions, for the programme to work?

5. Evaluation

A survey was made of farmers throughout Bangladesh to help answer these questions. A sample was taken from seven Districts which are a cross-section of Bangladesh's agro-ecological zones. The Districts (and regions represented) were Barisal (delta), Chittagong and Sylhet (hills), and Dhaka, Mymensingh, Pabna, and Rangpur (plains and dryland). One village was selected in each District. Only villages near or associated with existing or proposed agricultural demonstration sites were selected. This was done because these would be the first villages where the homestead forestry programme would be implemented.

Thirty households were interviewed in each village. Village leaders and influential persons were included because their attitudes would help shape village opinion. Unreceptive attitudes by these persons could make programme implementation difficult. Male heads of households were generally interviewed because local custom discourages strangers from talking to female household members. However, there were some female respondents.

A schedule of interview questions was used rather than a formal, structured questionnaire. This was necessary because language and customs can differ by locale and because the survey was too small to develop several regional questionnaires. Two hundred and ten households of the total 1,970 households in the seven villages were interviewed.

5.1. *Survey results*

Most families used a combination of cow dung, rice straw, paddy husks, bamboo residues, fuelwood, tree leaves and twigs, jute residues, and other minor fuels to cook their food. Women, or both men and women, collect the fuel (Table 13.2) and spend a median 13.8 hours per week collecting it (Table 13.3). Women usually collect those fuels located within or near the homestead

Table 13.2. Collection of fuel and fodder by men/women in Bangladesh.

Person collecting	Fuel (%)	Fodder (%)
Men	9	46
Women	32	13
Both	54	29
Servants	5	9
None collected	0	3
Total	100	100

Source: Project design field survey (unpublished).

Table 13.3. Average time spent per household for collecting fuel and fodder in Bangladesh.

Hours per week	Fuel %	Fodder %
1–5	3	2
6–10	34	1
11–15	34	20
16–20	10	11
21–25	12	18
26–30	7	16
31–35	0	6
Total	100	100

Source: Project design field survey (unpublished).

and men usually collect fuels located outside the homestead and in agricultural fields (Fig. 13.4).

This pattern is not universal, but is common because Bangladesh is predominantly a Muslim nation and many women live in *purdah*.

Most fuels have alternative uses. Respondents reported that rice straw could have been used for fodder or roof thatching, cow dung for fertilizer, leaves for compost, and twigs and branches for fences. Thus, there is an opportunity cost when these plant materials are used for fuel.

Fig. 13.4. Fuelwood shortage is acute, and, as in most other developing countries, fuelwood collection is mostly a woman's job.

Table 13.4. Average number of trees planted during the five years before the survey and new trees for which there is space on a homestead.

Number of trees	Trees planted in the past five years (%)	Number of new trees that could be planted (%)
0	30	31
1–10	35	24
11–20	16	13
21–30	9	11
31–50	5	8
51–100	5	8
101–200	<1	4
over 200	0	1
Total	100	100

Source: Project design field survey (unpublished).

Grass, rice straw, rice bran, other crop residues, leaves (mainly bamboo), and oil cake are the most common fodders. Here, men collect almost half by themselves and the median collection time increases to 17.6 hours per week. The proportion of men collecting fodder increases, in part because the fodder is located some distance from the homestead.

About 70% of the respondents had planted trees within the previous five years and also believed there was room for additional trees on the homestead (Table 13.4). Forty-five percent believed there was room for 11 more trees on the homestead. In addition, 65% knew that raising a tree was relatively difficult (Table 13.5).

Cultivation practices included fencing, fertilizing with dung or compost, weeding and watering. Most frequently mentioned difficulties related to

Table 13.5. Knowledge of forestry-related techniques and institutions in Bangladesh.

Question	Yes (%)	No. (%)	Total (%)
Is raising a tree difficult?	63	37	100
Know of government nursery?	60	40	100
Purchased seed from government nursery?	40	20	60
Know of agricultural extension officer?	57	43	100
Met agricultural extension officer?	35	22	57
(a) In own village	17	NA	NA
(b) At local market	8	NA	NA
(c) At extension office	10	NA	NA

Source: Project design field survey (unpublished).

NA = Not applicable

growing trees were physical or economic lack of fencing, seedling destruction by livestock, and seedling theft by enemies and/or social rivals.

Both men and women plant trees in about three-quarters of the households, men only in 20%, and women only in 6%. Men usually plant and tend trees which are distant from the residence while women perform these tasks near the residence. However, cultivating and protecting trees is generally the responsibility of all family members. The tree species and planting location are decided by men; however, we do not know the extent of the influence women may have on the discussion and pre-decision process. There seems to be sufficient female involvement throughout the decision-making, as well as in the planting, cultivating and harvesting processes, to indicate that an agroforestry project should have elements designed to include women.

Almost two-thirds of the respondents know about government nurseries and 40% of all respondents had purchased seedlings from them (Table 13.5). Fifty-seven percent of the respondents know of the local agricultural extension officer, but only 35% had met the officer during his visit to the village, 8% at the local market, and 10% during a visit to the agricultural office.

5.2. *Interpretation of results*

The survey showed that most farmers owned their homestead site, even if they did not own the land they farmed. Land ownership is important in fostering fuelwood plantings because these plantings take two to four years before a first harvest, and often longer. There is little incentive to plant and cultivate such species on another persons' land because the planter may not be able to harvest the crop. The large number of owned homesteads and farms is a positive influence on a homestead agroforestry system.

The presence of fruit trees on homesteads, as well as informal conversation with farmers during the interviews, indicated the farmers' preference for fruit trees and species other than those traditionally managed by foresters. New plantings will not be limited to these plants but the strong implication is that foresters interested in social forestry and agroforestry must have expertise in managing non-traditional forestry tree species. Foresters who might be required to supervise or advise on such tree plantings must also have expertise in managing individual or small groups of trees which will fit on the limited land areas available on small homesteads and farms.

Several conclusions can be drawn from the responses about fuel type, collection patterns and alternative uses. First, a great deal of time is spent collecting fuel and fodder – an average of over 30 hours per week by a household. Respondents report agricultural residues may be carried from distances as great as 6.4 km. There is a great potential for freeing labour for other uses if fuel and fodder sources can be located closer to the residence.

Secondly, there are other uses for non-wood fuels. Availability of fuelwood would free these materials for other uses and thus increase farm productivity. Finally, the large proportion of women collecting fuel supports the general concept that improved techniques and practices must be communicated to women because they are the persons implementing them.

Experience in planting trees, knowledge of cultural practices, and the belief that there is room on the homesteads for additional plantings were widespread among farmers. These factors are important if a successful agroforestry programme is to be initiated. Thus, the prospects seem favourable for improving agroforestry on Bangladeshi homesteads.

Government nurseries have an important role in such a programme because those nurseries are likely to supply the planting stocks. These stocks would initially be existing plant materials and might eventually include improved ones. Successful project implementation requires distributing these plant materials. Government nurseries are a likely distribution channel, particularly early in a project's life. Knowledge of and purchases from a government nursery by many of the farmers improve the chances of planting stocks reaching the farmers.

Private nurseries and sellers could take over from the government once improved planting materials and adequate seed sources have been developed and if demand is adequate. This may be desirable if there are sufficient public-sector funds to develop enough nurseries and because it could create additional small-scale investment opportunities and employment.

Knowledge of and contact with the extension workers may also be important for successful project implementation because they often provide information about cultivation techniques and new plant materials. One-third of the households have a personal acquaintance with the extension personnel despite the general transportation and communication difficulties. The conditions thus seem favourable for extension activities. However, this link in the implementation chain needs to be further strengthened.

6. Conclusions

The conditions in Bangladesh seem favourable for the successful implementation of a homestead agroforestry system. Many persons there own their own homesteads and farms, thereby eliminating the disincentive of planting trees which someone else will harvest. Moreover the farmers are familiar with trees and their cultivation, and they believe that they have room to plant more trees. Thus the level of basic knowledge and perception of opportunity among the farmers is satisfactory.

However, these conditions alone may not be sufficient for a successful programme. Channels of distribution for planting stocks must exist or be

built. Plant varieties better adapted to local growing conditions, generally improved growing stock and exotic species can enhance programme success, although management practices for these plants must often be taught. Existing government nurseries and extension services are appropriate institutions for distribution and teaching to start with. The many respondents familiar with government nurseries and extension workers is another positive influence.

Another condition is that the species selected must be those desired by the people, otherwise they will not plant them. The ubiquitous mango and jack fruit trees, plus respondents' free responses, indicate that multipurpose trees are desired. Forest services have traditionally managed only trees grown in large forested areas. Many foresters consider working with other species unprofessional or demeaning. Foresters must shift part of their emphasis from the traditional forest trees to multipurpose trees which people desire. In addition, management practices for multipurpose and other species are important. These should include practices for individual and small groups of trees, as well as large planted areas.

Finally, the study showed that women play an important role in collecting fuel and in planting and cultivating trees. This implies that programmes should strongly consider modules to inform women of the new plant materials and to teach them new cultural and management practices.

Acknowledgement

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14. Forest villages: an agroforestry approach to rehabilitating forest land degraded by shifting cultivation in Thailand*

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Abstract. The Forest Village scheme was introduced by the Forest Industries Organization (FIO) of Thailand in 1967 in an attempt to stop further spread of the rapidly increasing shifting cultivation and deforestation in the country. The underlying principle of the scheme is to relate reforestation to the social welfare of the people involved. It is essentially a modification of the traditional taungya method of plantation establishment.

The main aim of the scheme is to induce the shifting cultivators to settle down in villages where each family is given tenure over a plot of land to construct a house and develop a homegarden around it. The farmers are required to help establish and maintain forest plantations in which they are permitted to raise agricultural crops during the first three years of their establishment. The farmers are also given free medical and educational facilities and technical advice on crop and livestock husbandry, and they can earn cash rewards for successful plantation establishment.

Although the scheme has not achieved its full target in terms of area covered and number of families settled, it is proving to be a successful method of luring people away from destructive shifting cultivation. The approach is applicable to other countries and regions with similar land-use problems and socio-cultural background.

The paper also examines the constraints to the effective working of the scheme, provides some simple suggestions for improving its functioning and identifies some of the issues that can easily be tackled by research.

1. Introduction

The number of people engaged in shifting cultivation in Thailand is estimated to have risen from 300,000 to well over 700,000 during the period from 1965 to 1980 (McDowell 1982). This phenomenal increase has been caused mainly

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by migration from neighbouring Laos and Burma as well as within the country from the lowland agricultural lands into the forests. Consequently, the forests in the country are under severe pressure. Moreover, the length of the fallow periods in shifting cultivation cycles is drastically shortened, and as a result the land is rendered unsuitable for sustaining repeated croppings and hence abandoned. Subsequent regeneration of forest species is very slow and poor on such abandoned sites. Shifting cultivation is thus causing large scale forest destruction and land degradation in Thailand. It has been estimated that the country had over 700,000 ha of land under shifting cultivation in 1980, and that increasing encroachment into the forest was causing forest destruction in over 400,000 ha each year (FAO/UNEP 1981).

With a view to arresting deforestation and reclaiming the degraded forest areas, the Government of Thailand introduced and encouraged the taungya plantation system (King 1968). The results were, however, not satisfactory, primarily because the scheme had no provisions for the social welfare of the people involved (Boonkird 1978).

In 1967, the Forest Industry Organization (FIO) launched the Forest Village system in the northern highlands in an effort to rehabilitate the degraded forest land. It is essentially a modification of the taungya system, and its main objectives are: (1) to attract shifting cultivators and landless people to establish themselves in Forest Villages which offer improved facilities and greater stability than nomadic life; and (2) to encourage village people to establish taungya plantations in order to reforest areas degraded by shifting cultivation. This could also result in opportunities for long-term forest employment (FAO 1978).

The scheme, though originally designed for the hilly areas of northern Thailand, where shifting cultivation has been most common, now extends all over Thailand. In 1981 there were 26 Forest Villages spread over the country, and they undertook plantation establishment in a total of 4,000 ha annually.

Encouraged by the success of the FIO Forest Village system, the royal family of Thailand and the Royal Forest Department (RFD) have also set up Forest Villages similar to those developed by the FIO. The underlying approach in all of them is to promote rural development and sound land use by relating forestry work with social welfare for the people involved.

This paper examines the working of the FIO Forest Village system. Since the scheme encompasses the whole of the country, it is relevant to give a general account of the biophysical and land-use aspects of the country in order to understand the system in its proper perspective.

2. General description of the area

Figure 14.1 shows the salient aspects of the geographic location and land-use systems of Thailand.

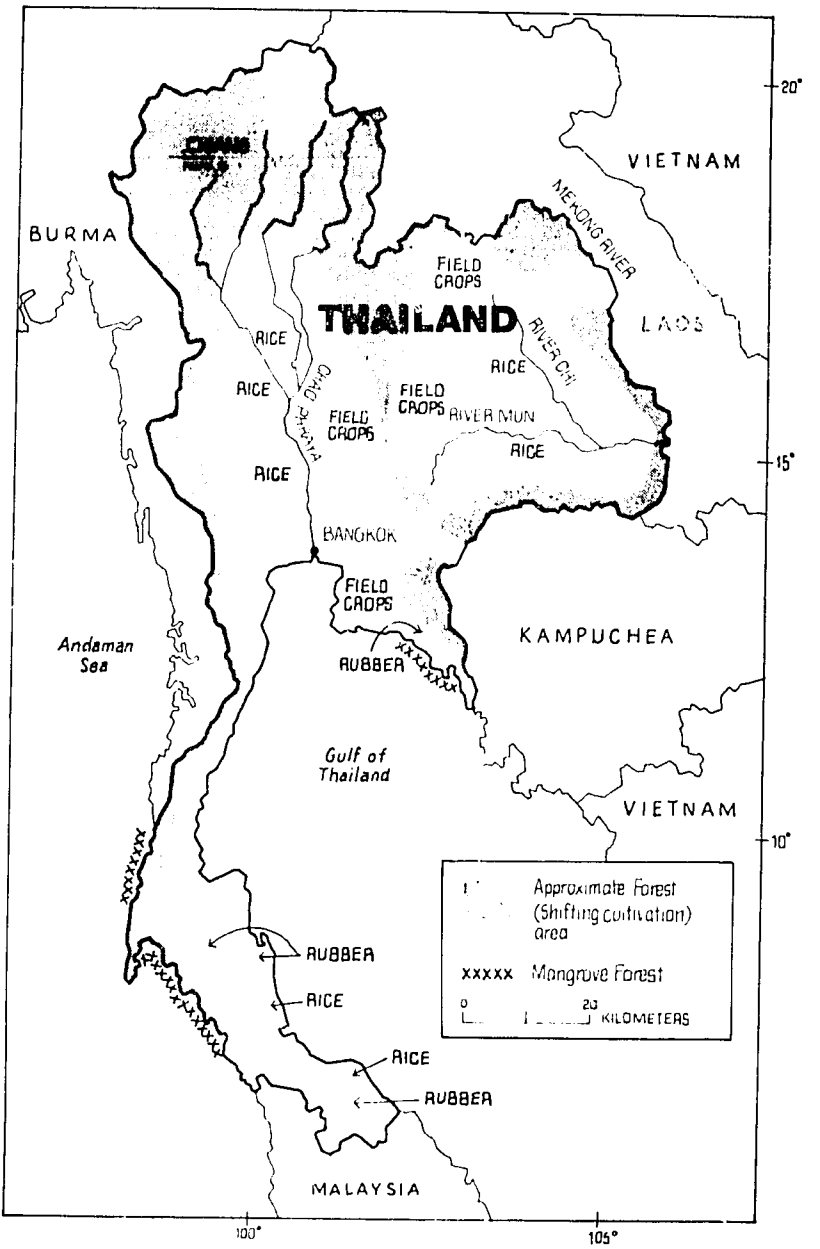

Fig. 14.1. A rough land-use map of Thailand.

2.1. *Geographic location*

The Kingdom of Thailand is located on the Malay peninsula (5° 45′–20° 30′ N and 97° 30′–105° 45′ E). It has an area of approximately 514,000 km^2 and has four main geographic regions.

The northern region (16.96 million ha) comprises a range of fold mountains which extend along the western border through the peninsula to Malaysia. These mountains have an average elevation of 1,600 m and are interspersed with fertile valleys through which flow the four tributaries of Thailand's major river – the Chao Phraya.

The north-eastern region, which includes the Khorat plateau, covers approximately 16.86 million ha. The elevation of the plateau is 200 m while the mountains to the west average between 800 and 1,300 m. This region is characterized by saline soils and is quite dry and windy in the summer.

The central plain has a total area of 10.39 million ha and is the rice bowl of Thailand. In the north, three tributaries flow together into the Chao Phraya river and in the south is the Chao Phraya Delta.

The southern region (7.07 million ha) is the peninsula which in the west is composed of mountains with an average elevation of 1,000–5,000 m. Most of the rivers and streams here flow eastwards into the Gulf of Thailand.

2.2. *Biophysical environment*

Climate. Thailand receives 90% of its annual rainfall from the south-west monsoon which lasts from May to September. During the period from October to April, the south-eastern Asiatic cyclonic storms bring irregular amounts of additional rain to the southern regions, while most of the north and north-eastern areas have a long dry season.

Annual rainfall is highest in the southern and western parts of the peninsula and in the south-eastern region and ranges from 2,000–4,000 mm. The central plain, which lies in the rainshadow of the western mountains, receives between 1,000 and 1,400 mm, while the north-east gets between 1,000 and 2,000 mm.

Temperatures are relatively steady throughout the year, averaging between 24 C and 30 C. In the north, frost may occur at higher elevations in December, while in the south climate is moderated by the maritime influence. The cold dry winter air produces frequent morning fogs, especially in the north.

Soils (see UNESCO/FAO Soils Map of the World–sheet IX). The predominant soils are Acrisols with a lithic phase, i.e., the presence of continuous coherent or hard rock within 50 cm of the surface. In general, the soils are podsolized and have low base saturation and cation-exchange capacity. Soils in the north-east are saline.

Vegetation. Thailand has a wide variety of vegetation types reflecting the wide range of ecological and climatic conditions. The major vegetation types include:

- Evergreen and semi-evergreen forests;
- Dry and moist deciduous forests;
- Dry dipterocarp forests;
- Fresh-water swamp forests;
- Mangrove forests;
- Savanna forests;
- Bamboo forests;
- Beach forests;
- Coniferous forests;
- Scrub forests.

2.3. *Land-use systems*

Agriculture. The alluvial soils of the intermontane basins of northern Thailand are very suitable for the cultivation of rice, tobacco, fruit trees and vegetables. In addition, maize, peanuts, beans, garlic and onions are also produced. On the upper slopes, tea is grown both by large estates and by smallholders. The former produce tea for drinking, while the latter ferment the tea leaves to produce a product for chewing (*miang*) (Kunstadter *et al.* 1972). In addition, the Hmong Hill tribe cultivate opium (at elevations between 1,000 and 1,500 m) as a cash crop and maize as a subsistence crop. There is a United Nations-supported crop-substitution project to encourage these farmers to give up opium cultivation in favour of agricultural crops such as coffee, maize and beans, and flowers such as tulips (McDowell 1982).

The fertile Choo Phraya Delta region of the central plain is intensively cultivated. The main crop is rice, although sugarcane is also produced. The alluvial deposits of the streams on the south-eastern part of the central plain are also used for rice cultivation, while the higher well-drained areas are used for rubber plantations, fruit or orchards, sugarcane, cassava and pineapples. In 1979, Thailand's rice production was estimated at 15.6 million tonnes. Only 10% of the total rice area receives controlled irrigation. The alluvial deposits of the rivers Mun and Chi in the north-eastern region, although not very fertile, are extensively used for rice. The production per unit area is low and increasing soil salinity is a problem. Streams flowing off the peninsula into the Gulf of Thailand often have built-up deltas which are utilized for wet rice cultivation.

Forestry. At the end of 1980, it was estimated that the natural forest area of Thailand amounted to 16.17 million ha, or about 31% of the country's total area (FAO/UNDP 1981). This contrasts dramatically with a forest area of 57% in 1961 (Boonkird 1979).

There are numerous types of forest, as indicated above. The main timber species from Thailand's natural forests are:

- *Tectona grandis*
- *Dipterocarpus alatus*
- *Shorea* spp.
- *Pterocarpus* spp.
- *Toona ciliata*
- *Intsia palembanica*
- *Parashorea stellata*
- *Dalbergia cochinchinensis.*

FAO estimated that in 1980 the annual value of all non-timber forest products from Thailand such as Dipterocarp oil, gum damar, bamboo pulp, edible bamboo shoots, canes, resin, honey, camphor, etc. was about US$ 30 million (FAO/UNEP 1981).

In addition to natural forests, there were around 0.43 million ha of successfully established hard and softwood plantations in 1983. The main hardwood species used include *Tectona grandis*, *Pterocarpus macrocarpus* and *Dipterocarpus* spp. Other species that have been successfully established are *Areca catechu*, *Casuarina junghuhniana*, *Casuarina equisetifolia* and *Eucalyptus* spp. The softwood species used are *Pinus kesiya* and *Pinus merkusii*. Rubber is one of the main tree crops with 1.35 million ha planted in 1979.

Agroforestry. Various agroforestry systems/practices can be identified in Thailand.

- Swidden/shifting cultivation for growing rice as the main crop with a variety of other food and cash crops (Kunstadter *et al.* 1978; Kyuma and Pairinta 1983). In some areas, the woody vegetation of the long fallow period is deliberately managed for a variety of products, e.g., fruit, honey, fodder, etc. (Kunstdter *et al.* 1978);
- Homegardens dominated by a wide variety of fruit trees;
- Sericulture, where various species of silkworm moths are reared on the foliage of mulberry trees;
- Aquaculture in mangrove forests;
- Intercropping of coconut with cacao (*Theobroma cacao*);
- Grazing of cattle in coconut plantations, or in forest plantations;
- Forest Villages.

3. Organization and structure of the Forest Village system

3.1. *Organization*

The FIO selects the degraded land where a Forest Village is to be set up for reforesting the land. The benefits and features of the scheme are publicized widely within the locality through extensive media coverage and other extension methods. The services of religious and other leaders are also solicited to disseminate such information and to allay any suspicion among the villagers. Families who come forward and agree to give up shifting cultivation in favour of settled land use are provided with a piece of land within the selected village unit for building and setting up a homestead garden around it (see below for details). Moreover, they are also permitted to grow crops between the young trees in the forest plantation that they will have to help in establishing according to the plan already prepared by the FIO.

The FIO has set up "Development Teams" having multidisciplinary expertise for each Forest Village. These teams provide agricultural, educational and medical services to the people covered by the scheme. The objective is to encourage farmers to develop permanent bases in the Forest Village.

3.2. *Components*

Crops. Both subsistence and cash crops are grown. In the forest plantations, the major crops grown are dryland rice, maize (*Zea mays*), sesame (*Sesamum indicum*), sweet potatoes (*Ipomoea batatas*), cassava (*Manihot esculenta*), and water melons (*Citrullus lanatus*). Tobacco (*Nicotiana tabacum*), and kenaf (*Hibiscus cannabinus*) are also grown in some areas.

The main crops in the homegardens are maize, cassava, pumpkins (*Cucurbita* spp.) and chilli pepper (*Capsicum frutescens*). A large number of common agricultural crops are also grown. These include legumes such as beans (*Phaseolus* spp.), lablab bean (*Dolichos lablab*), soya bean (*Glycine max*) and winged bean (*Psophocarpus tetragonolobus*); tuber crops such as sweet potato (*Ipomoea batatas*), taro (*Colocasia antiquorum*), and yams (*Dioscorea* spp.); cucurbitaceous crops such as cucumber (*Cucumis sativus*), loofah (*Lufa acutangula*) and snake gourd (*Trichosanthes cucumeria*); other vegetables such as egg plant (*Solanum melongena*), and tomato (*Lycopersicon esculentum*); minor millets such as Italian millet (*Setaria italica*) and finger millet (*Eleusine coracana*); and spices and medicinal plants such as coriander (*Foeniculum vulgare*), garlic (*Allium sativus*), lemon grass (*Cymbopogon citratus*), mint (*Mentha arvensis*) and onion (*Allium cepa*).

Trees. Teak (*Tectona grandis*), which is native to Thailand, is the major FIO plantation species. In 1983, there were about 30,000 ha of FIO teak plantations. Other major plantation species include *Eucalyptus camaldulensis* (6,500 ha in 1983) and *Melia azedarach* (2,045 ha in 1983).

In addition to growing crops between the trees in the forest plantation the forest villagers also grow fruit trees, e.g., *Parkia speciosa*, *P. javanica* and *Anacardium occidentale*. In some areas rubber trees (*Hevea brasiliensis*) are also grown between plantation trees and the proceeds from the latex sales are divided on a 70:30 basis between the forest villagers and the FIO. The 30% share retained by the FIO covers the cost of fertilizer and tools advanced to the forest villagers.

Other plant species maintained by the forest villagers in their homegardens (and their functions/uses) are listed in Table 14.1.

Animals. Forest villagers keep a variety of domestic animals in the homegardens for food, ritual/religious sacrifices and prestige. Common animals include cows, pigs, chickens and ducks.

Management aspects. Degraded forest is cleared and burned and trees planted in holes (20 × 20 × 20 cm). Teak was originally grown at a spacing of 4 × 4 m on a 60-year rotation. Recently, however, a spacing of 2 × 8 m and 40-year rotation has been adopted.

Where soils are poor and dry, *Eucalyptus camaldulensis* (four-month-old seedlings) and *Melia azedarach* (one-year-old plants) are planted at 2 × 8 m spacing. Eucalyptus plantations are grown on a 10–15-year rotation for fuel or a 20-year rotation for timber.

Table 14.1. Plant species other than the common agricultural species found in forest villagers' homegardens and their functions/uses.

Species	Functions/uses
Areca catechu	Masticatory nut
Artocarpus spp.	Fruit, vegetable
Bambusa spp.	Construction, mats, furniture
Calamus spp.	Furniture, baskets, mats
Citrus spp.	Fruit
Cocos nucifera	Food, oil, thatching, fuel
Dendrocalamus spp.	Construction, mats, furniture
Desmodium pulchellum	Insect repellent
Imperata cylindrica	Roofing grass
Mangifera indica	Fruit, shade
Moghania strobilifera	Insect repellent
Morus spp.	Sericulture, fuel
Musa spp.	Fruit, mulch
Psidium guajava	Fruit
Saccharum spp.	Food
Thyrsostachys spp.	Construction, furniture, mats

After planting the trees, the forest villager plants his crops in the inter-rows. Cropping occurs for the first three years and the villager then moves on to another area. It is the responsibility of the villager to weed and tend the trees while tending the agricultural crops.

Some villagers have a herding co-operative for their cattle. The owners of the cattle take turns to herd the village cattle within the plantations where grazing is permitted.

4. Functional aspects of the system

4.1. *Resource input and utilization*

Each family in the Forest Village is allocated 1.6 ha annually for clearing and planting with plantation trees and food/cash crops. In addition, 0.16 ha is allocated for house building and the homegarden. Figure 14.2 depicts a typical Forest Village scene with houses of the farmers in the midst of the individual homegardens. Cropping in the forest plantation occurs for up to three years and hence a villager can have up to 4.8 ha/year on which to grow his crops. Since the intended number of families per Forest Village is 100, up to 160 ha of land may be cleared and planted with trees and crops each year. In 1981, however, there was an average of nearly 59 families per Forest Village with

Fig. 14.2. Photograph showing the houses and the homesteads surrounding them in a Forest Village in Northern Thailand (Photo: P.K.R. Nair)

each family cultivating 2.61 ha/year, i.e., a total of 153.63 ha annually per Forest Village.

In 1981 the average size of Forest Village families was 5.56 members. In addition to their annual responsibilities of establishing the forest plantation (on a minimum of 1.6 ha) and growing of crops in the plantation and homegardens, it was estimated that each Forest Village needed labour equal to 200 man days per year. This would be required for various plantation operations, e.g., weeding, pruning, thinning, fire prevention, road and rail maintenance, etc. If a nursery was attached to the village an additional 50 man days per year would be required. Thus, depending on the number of families in the village, at least two members per family are guaranteed work on a continuous basis within the forest plantation. They are paid according to the prevailing minimum agricultural wage. Such labour is recruited exclusively from within the Forest Village.

4.2. *Other facilities*

In addition to providing land, the FIO provides numerous other inputs and facilities. These include:

- Provision of drinking water and electricity free of charge to each house in the Forest Village;
- FIO medical team dispensing free medicines and advice to villagers on health, family planning, sanitation, etc.;
- Forest Village primary school in accordance with the Ministry of Education regulations, textbooks and uniforms being provided free of charge;
- Monetary incentives for successful establishment of forest plantation trees;
- Payment of a bonus of about US $ 60 for clearing, planting and two weedings of each hectare of allocated land;
- A reward of about US $ 27/ha if tree survival is 100% after harvesting of agricultural crops and the third weeding (this reward may be graded and related to percentage survival over 75%);
- A bonus of US $ 75 for successfully tending 4.8 ha of forest plantation over three years at the end of the third year; if tending continues, the village receives US $ 25/ha per year for each successful 1.6 ha;
- Transport is provided for:
  Taking workers to the plantation site;
  Moving construction materials of forest villagers' houses;
  Taking forest villagers' agricultural produce to market.
- Advice on the market performance of various agricultural crops.

Table 14.2 provides a comparison of cost per hectare to FIO for establishing forest plantations with and without Forest Villages.

Table 14.2. Cost (US $ per hectare) of establishing FIO forest plantation in Thailand with and without the Forest Village scheme.[1]

	Without Forest Village		With Forest Village	
	Teak	Non-teak	Teak	Non-teak
First year				
Labour	205.60	235.05	71.20	82.07
Administrative cost	287.28	287.28	287.28	287.28
Fixed cost (house, machinery, etc.)	74.00	74.00	74.00	74.00
Stump or seedling and replanting charges[2]	19.57	32.61	17.93	29.89
Forest Village expenses	—	—	168.29	168.29
Total	586.45	628.94	618.70	641.53
Second year				
Labour and/or reward	74.46	95.92	74.46	95.92
Stump/seedling	3.26	8.15	1.63	4.08
Total	77.72	104.07	76.09	100.00
Third year				
Labour and/or reward	56.79	66.86	56.79	68.86
Stump/seedling	1.63	4.08	0.82	2.04
Total	58.42	72.94	57.61	70.90
Fourth and fifth years				
Maintenance and protection per year	52.45	52.45	52.45	52.45
Total for two years	104.90	104.90	104.90	104.90
Sixth to tenth years				
Maintenance and protection per year[3]	20.65	20.65	20.65	20.65
Total for five years	103.25	103.25	103.25	103.25
Grand total for ten years	930.74	1,014.10	960.55	1,020.58

[1] Daily wage rate per labourer = B38; 1US $ = B23.
[2] Cost per teak stump = US $ 0.03; cost per non-teak seedling = US $ 0.04; replanting at the rate of 20% in "Without Forest Village" and 10% in "With Forest Village".
[3] Thinning cost is not included as the output from thinning will cover the expenses involved.

4.3. *Production*

Data on the production and income from maize, cassava and kenaf grown in forest plantations in 1981 are given in Table 14.3.

The soils, especially in the dry north-eastern region, are generally poor. This tends to exaggerate the competitive interaction between the trees and crops. Thus, often, yields of dryland rice intercropped between the plantation trees

Fig. 14.3 (top) First year of establishment of teak plantation in the Forest Village with rice as the inter-agricultural crop

Fig. 14.3 (bottom) The second year of establishment of teak and eucalyptus in the Forest Village with rice as the agricultural crop. The decline in soil productivity is already evident from the relatively low vigour of the rice crop in comparison to that of the first-year rice crop shown in Fig. 14.3 (top) (Photos: P.K.R. Nair)

Table 14.3. Area and total value of produce of the three agricultural crops grown in the forest scheme in Thailand in 1981.

Crop	Area of cultivation in plantation (ha)	Income (US $)
Maize	1,661	163,568
Cassava	1,782	75,874
Kenaf	380	49,348

tend to be best in the first year. Yields decline markedly in successive years. Photographs of a teak + rice plot during the first and second year of cropping, given as Fig. 14.3A and 14.3B, respectively, illustrate this point.

Production of upland rice is typically of the order of 0.5–1.5 tons $ha^{-1}yr^{-1}$. Generally, the rice produced is used for home consumption, although occasionally some of it may be sold to raise cash. This is also the case with pigs and chickens. In 1981, the Forest Villages earned an average of US $ 266 per family from the sale of agricultural crops grown in forest plantations and in their homegardens. Added income from rewards, bonuses and daily wages from forest plantation operations gave a total income of US $ 693 per family per year (Table 14.4) or US $ 10.38 per person per month.

Estimates of timber production from the plantations, based on local experience, are 75 m^3 per ha in a 40-year rotation of teak and 75 m^3 from a 15-year rotation of eucalyptus.

5. System evaluation

5.1. *Rate of growth*

The original target was to start with 2,000 Forest Villages covering 32,000 ha (1.6 ha per family per year, and 100 families in each village), increasing progressively to 4,500 villages undertaking plantation establishment in 73,000 ha annually by the year 2000. However, by 1981, there were only 26 such villages which undertook planting in a total of about 4,000 ha/year. Thus, the scheme has not reached the planned target.

5.2. *Advantages*

1. The Forest Village system is proving to be a successful but slow method of ensuring the long-term improvement of national and export wood sources.
2. The rehabilitation of the country's forest resource is being achieved by people who would normally be engaged in destructive shifting cultivation.

Table 14.4. Income from the FIO Forest Village scheme in different regions of Thailand.*

Region	No. of villages	Mean no. of families per village	Mean area of (ha) cultivated per village	Mean area (ha) cultivated per family	Mean Village income (US $) for 1981					
					From agricultural crops	Reward	Bonus	Daily	Total	Income per family
North	16	60.94	109.03	1.79	15,493	5,618	1,767	24,865	47,743	783.44
North-east	6	64.67	315.05	4.87	20,888	2,948	1,696	19,634	45,166	698.41
South	4	41.75	98.87	2.15	8,246	4,526	652	21,489	34,913	321.54
Weighted means	—	58.85	153.63	2.56	15,623	4,909	1,697	23,139	41,868	692.76

* In 1981 there were a total of 1,530 families cultivating a total of 3,994 ha in different regions of Thailand.

3. Opportunities are provided for landless people to form settled communities. Long-term employment, raising food and cash crops, and better health and education facilities result in a higher standard of living for the forest villagers. This is especially important in the strategic border areas that are prone to destabilizing insurgency activities.

5.3. *Weaknesses/constraints*

1. Enforcing the policy of forest reserves becomes difficult and expensive where forest land is still plentiful. Shifting cultivators are still able to operate illegally and it is difficult to induce them to settle in a Forest Village.
2. The initial years in a Forest Village can be hard and frictions can arise with other families in the village (King 1968). This is often compounded by a cash-flow problem since payments of rewards, bonuses, etc. are not made till the end of the first year of participation.
3. Some forest villagers find the pay and other financial incentives low, resulting in their deserting the Forest Village and seeking employment elsewhere.
4. Setting up large numbers of Forest Villages with free electricity, water, schools, medical facilities and other financial incentives requires a significant amount of capital expenditure.
5. Often funds are not available because of misunderstanding about the inclusion of social-welfare expenditures in reforestation projects.
6. Some selfish politicians and unscrupulous businessmen undermine the concept of Forest Villages in order to ensure the availability of cheap labour for themselves.
7. Some reforestation sites are on steep slopes and the forest villagers find it difficult to cultivate and harvest their crops. Also some soils are very poor and this results in minimal yields of agricultural crops.
8. There is a scarcity of capable managers (conversant with forestry, agriculture, administration and sociology) to take charge of Forest Villages.

5.4. *Potential*

The concept and philosophy of Forest Villages represent a sound approach to tackling the problems of shifting cultivation *vis-à-vis* land degradation. The benefits accrued from the scheme can, however, be enhanced by removing the observed bottlenecks and constraints as far as possible and improving the efficiency of working through appropriate technological interventions and social improvements. Some examples are providing forest villagers with

improved varieties of seeds, appropriate types of fertilizers and sound advice on their proper use, credit facilities, social facilities such as realistic rates of pay, bonuses and rewards, and so on, increasing the area of homegardens from the present 0.16 ha per family to a more acceptable size, etc.

Today the Forest Village system has proved to be a sustainable system, although its growth has been slow due to the various problems mentioned earlier. Suggested improvements in the system should assure the system's sustainability, i.e., attracting cultivators to settle down and help rehabilitate the degraded forest lands. This provides long-term employment and better living standards, and thus the shifting cultivators are prompted to stay within the ambit of the system. The system should be thought of as a multi-product enterprise rather than a system that provides supplementary income through forest-land tenancy.

The Forest Village system has been tried successfully in various countries, e.g., Kenya, Gabon, Uganda, India, Nigeria and Cambodia. Although it is more expensive than the traditional taungya system it is particularly suitable for countries with a large natural forest resource and high numbers of shifting cultivators and other landless people. The system envisages the sustainable use of forest land for food production by landless people who would otherwise be engaged in forest destruction. This agroforestry approach is a viable alternative to resource-depleting and environmentally degrading shifting cultivation (Nair 1986; Nair and Fernandes 1984). With appropriate technological back-up and infrastructural improvement, the system can prove itself to be quite acceptable and adoptable under other situations with comparable land-use problems and socio-cultural constraints.

5.5. *Research needs*

The foregoing analysis of the functioning of the system reveals that the major constraints to its effective functioning are both biological (technological) and socio-cultural. Whereas some of the socio-cultural problems are intimately tied up with the general situation in the country, and hence cannot easily be overcome, there are certain biological constraints that can be tackled effectively through research efforts. In fact it is a serious drawback of the scheme that research input has not been built into its operational framework so that the management techniques are based on the knowledge that was available at the time of project formulation. Moreover, no effective system exists for mitigating some of the simple problems through research-supported "mid-term corrections". Some of the issues that can be tackled through simple research are:

- The role of fast-growing nitrogen-fixing multipurpose wood species in association with plantation trees;
- Use of manures and fertilizers, at least on a limited scale, for ameliorating the decline in soil fertility that occurs after the first year of cropping;
- Adjustment of planting patterns and management schedules of the plantation (forestry) species in relation to agricultural crops so as to facilitate profitable cultivation of agricultural species for as long a time as possible;
- Use of appropriate varieties of crop species adapted to specific situations, such as low light availability, soil reaction (acidity, salinity), soil conditions (poor drainage, low fertility), and so on;
- Monitoring the visual interaction effects between the tree and the herbaceous components in order to devise appropriate ways of overcoming some of the negative interaction effects to the extent possible even during the life of the project.

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15. Integration of animals in rubber plantations*

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Abstract. This paper describes a unique agroforestry approach of integrating animals (sheep, poultry and bees) in smallholder rubber plantations. The approach is based on the existence of surplus family labour, utilization of interspaces between the rows of rubber, availability of cheap and nutritious animal feed and the presence of a favourable microclimate for animal growth under rubber. Results of trials carried out by the Rubber Research Institute of Malaysia since the 1970s are presented.

A rotational system of broiler production under rubber was found to be technically, socially and economically feasible, providing a net return on family labour of M$ 370–M$ 825 per consignment of 500 birds. Sheep rearing under rubber also appeared to be very attractive and practical; apart from producing meat for sale it also served as a "biological weed control" measure. The cost of controlling the weeds commonly found in rubber plantations could be reduced by about 21% over the usual method by using sheep grazing for weed control. The internal rate of return (IRR) from sheep rearing can be as high as 44%. Details of operation and management aspects of sheep integration under rubber are given.

Bees kept under rubber feed on nectar produced by the inflorescence and the tips of young rubber shoots and also on flowers of intercrops and weeds. The *Apis cerana* species was found to be suitable, producing about 3 kg of honey per colony per harvest.

1. Introduction

Rubber (*Hevea brasiliensis*) is the most important commercial crop in Malaysia, and Malaysia is the biggest producer of natural rubber in the world. The country has 1.96 million ha under rubber and it provides 1.6 million tons of rubber accounting for 39% of total world production. The size of the rubber production units range from very small holdings of an average of 1.4 ha to large estates of hundreds of hectares. The Government of Malaysia has designated rubber production units of less than 40.4 ha as "smallholdings" and the rest as "estates". The smallholdings account for 1.5 million ha (76%

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of the total area of the country under rubber) and 0.9 million tons of rubber per annum (56% of total national production) and involve an estimated 0.5 million families (Government of Malaysia 1982; Leong, unpublished).

Although the rubber-production strategy in both the smallholdings and the estates aims at maximum output of rubber, various types of intercropping and other plant associations are common in smallholdings but not in estates. The rationale for intercropping is that in a monocrop of rubber, which is usually planted at 7.3 × 2.4 m spacing (570 trees/ha), about 75% of the total land area is not effectively occupied by the roots of the main crop when the rubber trees are under three years old (Tan *et al.* 1980), and in smallholdings the farmers take advantage of this using the surplus family labour that they usually have. It is also recommended by government authorities to plant intercrops such as banana, maize, groundnut and vegetables in the smallholdings during the immature growth phase of rubber (see Fig. 15.1), whereas leguminous cover

Fig. 15.1. Banana and pineapple intercropped with eight-month-old bud-grafted rubber.

crops are recommended if intercropping is not practised. Leguminous cover is a regular aspect of plantation management in estates. However, most intercrops cannot be grown when the rubber canopy closes about three years after planting, and the leguminous cover (except for shade-tolerant species such as *Calopogonium caeruleum*) fades away progressively as the rubber trees grow. Consequently, the inter-row spaces in rubber plantations are infested by weeds. Since these weeds compete with rubber trees, they have to be controlled, which is usually done by the use of herbicides. It is estimated that the Malaysian rubber industry spends about M$ (ringgit) 100 million (1 US$ = 2.5 ringgit in May 1985) annually on weed control.

Recently some efforts have been made to integrate animal production in rubber plantations, whereby the interspaces in the plantations are utilized to rear animals such as poultry and for bee keeping, while the weeds are used as feed for sheep. This approach to maximizing land use and diversifying agricultural production in rubber areas seems a sound one. The paper discusses the salient aspects of this new agroforestry approach.

2. The concept of animal integration in rubber plantations

The main objectives of integration of animals with rubber are:

To increase the production of meat protein economically without having to open large new areas of land for animal production;
To reduce weeding costs through controlled grazing of palatable species and/or treading and trampling of non-palatable species under rubber;
To reduce surface erosion through controlled grazing – complete eradication of weeds is not recommended so that a continuous supply of feed for the animals can be maintained;
To use organic manure to fertilize the rubber trees and intercrops, and thus reduce the cost of inorganic fertilizer on the one hand and improve soil fertility on the other;
To provide additional income to rubber growers, particularly smallholders, through increased productivity from a unit of land.

Basically the concept is the same as that of integrated farming in rubber, discussed by Wan Mohamed (1978), with appropriate modifications. It is based on and motivated by the following factors.

2.1. *Revenue utilization*

Surplus labour. In individual rubber smallholdings, with an average size of 1.2–1.6 ha, surplus labour is available, especially during the unproductive immature phase of rubber growth (Selvadurai 1970).

Planting of intercrops (Wan Mohamed and Chee 1976) or rearing of poultry (Wan Mohamed and Abraham 1976; Wan Mohamed and Chee 1976), bees (Mohd Ali *et al.* 1984) and/or sheep/goats (Wan Mohamed 1978; Lee *et al.* 1978 and Wan Mohamed 1982) are some of the possible ways of utilizing excess family labour profitably. For the estates sector, although the possibility of excess labour usually does not occur, a part of the existing labour assigned to do normal weeding can be mobilized to manage sheep which perform the weeding work by grazing on the weeds.

Land. No additional land is required to carry out integration of animals under rubber. The interspaces between the rows of rubber can be utilized to grow the supplementary feeds such as cultivated grass and legumes required by sheep, as well as to build shelter for the animals (poultry, bees and sheep) and also for grazing. However, before letting the animals (sheep) in, the rubber trees must be not less than 1.5 years old and the plants at least 2 m tall because the animals tend to feed on the lower whorls of the rubber plants.

2.2. *Availability of cheap and nutritious animal feed*

The ground vegetation that succeeds after the cultivation of intercrops, or after the leguminous cover fades away, grows naturally and thus constitutes a free source of feed for sheep. Wan Mohamed (1977) reported that the total dry matter yield of such undergrowth species found under rubber was between 500 and 600 kg ha^{-1}, and most of the species were palatable to sheep or goats. Table 15.1 lists the palatable and non-palatable undergrowth species found

Table 15.1. Species composition of undergrowth in rubber plantations.

Palatable (to sheep)	Non-palatable (to sheep)
Asystasia nemorosa	*Ageratum conyzoides*
Axonopus compressus	*Boreria* spp.
Imperata cylindrica (very young)	*Bridelia tomentosa*
Ischemum muticum	*Cyperus* spp.
Mikinia cordata	*Eupatorium odoratum*
Ottochloa nodosa	*Hyptis brevipes*
Paspalum conjugatum	*Imperata cylindrica* (mature)
Paspalum orbiculare	*Lantana camara*
Rhynchaltrum repens	*Melastoma malabatrichum*
Ferns (some species only)	*Mimosa pudica* (mature)
Rubber seedlings	*Mimosa invisa*
Planted legume covers	
Calopogonium mucunoides	
Centrosema pubescens	
Desmodium spp.	
Flemingia congesta	

Source: Wan Mohamed (1977).

Table 15.2. Chemical composition of ground vegetation in smallholdings and estates.

Location	Plants	Chemical composition (%)		
		Crude protein	Crude fat	Crude fibre
Smallholdings	Grasses	9.4	1.5	33.3
	Broadleaves	13.2	1.9	32.9
	Ferns	11.4	1.8	1.9
	Mixed	11.4	2.1	28.0
Estates	Grasses	11.4	1.9	33.1
	Broadleaves	14.1	1.8	33.1
	Ferns	13.9	1.9	27.2

Source: Wan Mohamed (1977).

under rubber. Table 15.2, which gives the chemical composition of grasses, broad-leaved plants and ferns in smallholdings and estates, indicates that these undergrowth species are quite nutritious. Moreover, it has also been observed that sheep feed on rubber seeds, young self-sown seedlings and also fresh leaves of fallen rubber branches. In the case of bee-keeping, the bees feed on nectar produced by the inflorescence and tips of young shoots of rubber trees. Other sources of nectar for the bees are flowers of intecrops planted in the inter-rows, weeds and other plants around the rubber areas.

2.3. *Favourable microclimate under rubber*

The temperature inside a stand of rubber is 1–5° C lower than in the open (Ani *et al.* 1985), which can be one of the factors contributing to better growth and productivity of sheep reared under rubber (Lowe 1968). Under immature rubber where the canopy does not provide total shade for the sheep, the sheep have been observed to rest for a few minutes under the shade of the young trees, probably to cool off their bodies. Partial shade provided by the rubber canopies offers a conducive environment for poultry rearing and bee-keeping too.

3. Trials at the rubber research institute of Malaysia (RRIM)

The RRIM initiated trials on animal integration with rubber in the 1970s. The emphasis has mainly been on those animals which do not adversely affect or interfere with normal growth, productivity and management of rubber. The animals found suitable so far are poultry, sheep and bees, and summary

accounts of the results obtained so far are given in the following sections. Goats were found to cause damage to the bark of young rubber (Tan *et al.* 1980), while buffaloes did not thrive well in most rubber-growing areas which are mostly gently sloping and undulating. Buffaloes also cause bark damage to rubber trees when they rub their horns on them. Cattle were not tested as they were known to drink and spill latex from the latex cups on the trees, in addition to causing root damage and soil compaction due to trampling.

4. Poultry-production in smallholdings

Two systems of broiler poultry production have been tested. In the first system, the chickens were given shelter at night and were allowed to go free in a fenced area in the smallholdings during the day, feeding on insects, worms, weed seeds, tender underground vegetation, etc. Concentrate feed, consisting of grain and agricultural by-products, was also given. In the second system, an intensive management of broiler production was adopted where the birds were kept housed at all times and fed with feed concentrates (Fig. 15.2). It was found that the second system was more acceptable to smallholders. In 1983, the rotational broiler production system was introduced where groups of 5–10 smallholders in one area rear 500-bird batches continuously in a rotational system. The advantage of this system is that it allows agreements to be made between the smallholders and the suppliers of day-old chicks, feeds and other

Fig. 15.2. Rearing of broiler chickens in the inter-rows of five-year-old rubber trees.

materials on the quality, supply and price of supplies on the one hand, and between smallholders and wholesale buyers of the chickens produced on the other. These arrangements allow for better planning and give more confidence to the smallholders. Further, technical guidance and assistance by government agencies can be carried out more efficiently on a group basis.

The average cost of producing broilers was M$ 3.27 per bird in 1976 (Wan Mohamed and Chee 1976). It went up to M$ 4.83 in 1982 (Wan Mohamed 1982) and to about M$ 5.30 in 1984 due to the increase in the cost of day-old chicks and feeds. Wan Mohamed (1982) estimated that in a rubber smallholding rearing poultry, 85% of family labour was utilized to provide feed, water and general cleaning of the shed, and feed and water utensils. The daily labour input was 3–4 man-hours to raise 500–1,000 birds per consignment.

Results of studies carried out on individual smallholdings and recent observations on the rotational system of broiler production showed that broiler production is technically, socially and economically feasible (Wan Mohamed and Chee 1976; Lee *et al.* 1978). The net return on family labour had earlier been calculated at M$ 370–835 per consignment for raising 500 birds (Wan Mohamed 1982), but recently the figure has dropped much lower mainly due to a very poor selling price. In fact, some smallholders experienced losses in some of the batches in the rotation. However, on the average, the smallholders received positive net family returns. The most important factors that influence income from broiler production, as put forward by Wan Mohamed and Abraham (1976) and Lee *et al.* (1978), are:

- Supply of high-quality day-old chicks when needed;
- Supply of unadulterated high-quality feed;
- Availability of markets and suitable market price; and
- Cost of day-old chicks and feed.

Smallholders' efforts and their willingness to follow the recommended system are also major factors that determine the level of income and profit earned (Wan Mohamed 1982).

5. Sheep rearing under rubber

The RRIM has been conducting investigations on sheep rearing under rubber since 1975 (see Fig. 15.3). The technical, social and economic aspects have been discussed in detail by Wan Mohamed (1977, 1978, 1982), Tan and Abraham (1981), Wan Mansor and Tan (1980) and Wan Mohamed and Ahmad Hamidy (1983). The salient aspects are as follows:

Fig. 15.3. Sheep grazing under 12-year-old rubber trees.

5.1. *Operational aspects*

Sheep can be reared in both immature and mature rubber areas. In immature rubber, the rubber plants must be over 2 m high and at least 1.5 years old, as mentioned earlier, and the field must have palatable undergrowth species (Table 15.1). The number of sheep per unit area of holding or estate is determined mainly by the amount and growth rate of palatable undergrowth available. The present recommendation is 6–8 animals per hectare for immature areas and 3–5 animals per hectare for mature areas. Understocking leads to inefficient utilization of undergrowth vegetation, but high stocking rates may lead to depletion of palatable species and even erosion. Therefore, understocking at the start of the project is recommended to ensure that enough feed is available as the number of animals increases progressively.

Sheep rearing is not recommended in smallholdings of less than 2.5 ha that have no adjacent grazing ground because in such cases the direct and indirect returns will be too low. However, there is no upper limit of area for sheep rearing (in estates). Security of animals is one of the major problems in rearing sheep under rubber. Casualties due to attack by wild dogs as well as thefts have been experienced in the past. Regular shooting of wild dogs is necessary, and animal sheds should not be too isolated. The security problem has been a major reason for not initiating the large-scale free-ranch system of sheep rearing under rubber. In this context, the use of solar-powered electric

fencing with an alarm system seems advantageous and the feasibility of using it needs to be looked into.

Sheep rearing for weed control in plantations

One of the main objectives of rearing sheep under rubber is to use the sheep as an agent of biological weed control. Since sheep can consume up to 70% of weed species (Wan Mohamed 1977), the cost of weeding with herbicides and labour can be reduced. Wan Mansor and Tan (1980) reported that 75% of the available weeds in their trial area were edible by sheep so that the cost of weed control was reduced by M$ 7.26 ha^{-1}, amounting to a 21.7% saving during the study period of four years (1976–1979). In another study by Lim *et al.* (1983), savings in cost of weeding were M$ 15.00 ha^{-1} yr^{-1}. These differences in weeding costs were due to different stocking rates and weed conditions.

Efficiency of weeding by sheep grazing can be further improved by the use of solar-powered electric fencing. This system of controlled grazing also reduces the requirement of labour for handling large flock sizes (300 to 400 sheep) from three to only one worker. Since the fencing system used was of the portable type, grazing patterns could be conveniently programmed according to weeding requirement in the plantations (T. Ismail and D.T. Chong, unpublished).

Management aspects

Appropriate management of the grazing area is important. It is essential to constantly monitor the effect of grazing by sheep. Overgrazing leads to depletion of palatable weed species and can cause soil erosion. Non-palatable weeds will compete with the palatable species which might later lead to feed insufficiency (Wan Mohamed 1982). Therefore, those weeds that are not "taken" by sheep should be removed manually by slashing or digging, or chemically by herbicide application.

Sheep manure can be used as a source of manure for rubber. An adult sheep excretes an average of 186 g of droppings (on a dry-matter basis) daily, so that at a stocking rate of 6 animals per hectare an average of about 400 kg ha^{-1} of sheep manure can be obtained per annum. The droppings contain 2.40% N, 0.49% P, 2.89% K, 1.84% Ca and 0.54% Mg (Wan Mohamed 1977). Thus the average annual nutrient addition could be about 10 kg N, 2 kg P, 11.5 kg K, 7 kg Ca and 2 kg Mg per hectare. While the sheep graze in the field, they deposit the droppings on the soil. The excreted droppings that accumulate in the shed have to be removed two or three times a month and can be applied to the rubber trees in the field. It has been observed on a field with sandy alluvial soil that the growth of rubber trees improved after constant grazing at 6–8 week intervals over a period of two years.

Performance evaluation

Studies carried out by the RRIM since 1975 have shown that both local and Dorset Horn (DH) crossbred sheep adapted well in smallholdings and in estates. However, in terms of growth and productivity, the DH crossbreds (especially 50% DH) perfomed better. In terms of grazing performance, it was observed that the DH crossbreds consumed more palatable weeds (on a per-animal basis) than local sheep because of the heavier body weight of the former. Tan and Abraham (1981) reported that sheep performed better at the RRIM Experiment Station than on farmers' smallholdings. The comparative data are given in Table 15.3. Obviously, the differences in environmental and management conditions explain these different results.

It has generally been observed that growth of rubber is better in grazed areas compared to non-grazed areas. In a one-year study reported by Tan and Abraham (1981) it was observed that girth increment on trees in fields where the undergrowth was grazed by sheep on either a rotational or free-range

Table 15.3. Performance of sheep under rubber.

Item	RRIM Experiment Station[a]	Smallholdings[b]
Average number of offspring (lamb ram year)	1.5	1.3
Productivity (%)	142	127
Lambing interval (days)	207	259
Age at first lambing (days)[c]	355	482
Single lambing (%)	94	100
Twin lambing (%)	6	0
Triple lambing (%)	0	0
Average lamb birthweight (kg)		
Male	1.63	0.99
Female	1.57	1.02
Mean	1.60	1.01
Average daily weight gain (g) to nine months of age		
Male	49.5	32
Female	43.0	30
Mean	46.5	31
Weight of adult ram (kg)	26.0	—
Dressing (%)	46.0	—
Lamb mortality (%)	18.0	—
Mortality rate from		
Single lambing (%)	15.0	23.1
Twin lambing (%)	50.0	0
Triple lambing (%)	0	0

[a] Wan Mohamed (1978)
[b] Lee *et al.* (1978)
[c] Wan Mohamed (1982)

grazing system was better by 25 and 33%, respectively, than that in the field where the undergrowth was not grazed. They attributed the differences to the reduction in weed competition as well as return of organic manure to the grazed fields. Recently it has been postulated that the better growth of rubber trees with sheep under the controlled-grazing system, and using solar-powered electric fencing as compared with the free-range grazing system, is a result of better weed control with the former.

Economics

Income from sheep rearing can be derived directly from the sale of sheep, either as breeding stock or for slaughter. Indirect returns are in the form of savings in costs of weeding and fertilizer. From an economic analysis of the practice, Wan Mansor and Tan (1980) reported that rearing an original stock of 21 animals for a duration of 25 months resulted in a profit of M$ 2,970.15, amounting to a 107.5% increase of the total investment of M$ 1,724.30. The net present value (NPV) and internal rate of return (IRR) were found to be M$ 1,975.24 and 44.06%, respectively. Lim *et al.* (1983) reported that from an original stock of six animals an average income of M$ 60.90 per month was obtained after rearing the sheep for four years.

Research needs

In view of the potential for future development of sheep rearing under rubber in Malaysia, it is essential to carry out more research on various aspects in order to perfect the system. Tan and Abraham (1981) and Wan Mohamed and Ahmad Hamidy (1983) suggested several aspects be studied. Some of their suggestions, along with a few additional ones, are given here:

- Ecological succession of undergrowth vegetation of palatable and non-palatable weed species as a result of grazing;
- Methods of encouraging growth and persistence of palatable species in the natural undergrowth;
- Introduction of new species of legumes and grasses that can grow under shade and withstand grazing;
- Systematic grazing schemes that will lead to more efficient weed control;
- Breeding for better crossbreds adaptable to local environments and feeds;
- A large-scale sheep rearing and management system with lower costs of initial inputs and management;
- Supplementary feeding of agricultural by-products, e.g., oil-palm sludge, palm-kernel cake, rice bran, etc.;
- Ways of utilizing sheep by-products such as wool and skin that could provide additional income;

- Replacing the expensive forms of mineral licks (salt plus macro- and micro-elements) with cheaper materials;
- Conversion of sheep dung into nutrient-enriched animal manure or compost.

6. Bee-keeping under rubber

Work on bee-keeping under rubber by the RRIM started in the early 1980s, mainly in rubber smallholdings. The *Apis cerana* species of bee has been found to be suitable under smallholder conditions. The main harvesting season for honey kept under rubber is in February/March, i.e., during the flowering season of the rubber trees. Currently, there are only a few smallholders participating in a pilot project with the RRIM. Preliminary observations indicate that an average of 3 kg of honey could be collected from one colony during the February/March flowering season (Mohd Ali *et al.* 1984).

Smallholders are encouraged to rear bees because the establishment cost of bee keeping is low and the technique can quite easily be acquired by them. In return the farmers can obtain additional income from the sale of honey.

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16. Multistoreyed agroforestry garden system in West Sumatra, Indonesia*

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Abstract. The agroforestry garden system in Maninjau in West Sumatra is characterized by an intensive integration of forest species and commercial crops forming a forest-like system. The intimate association of different species provides both subsistence and commercial products which supplement rice production. This complex agroforest is managed by a combination of cultural practices and respect for natural processes of vegetation production and reproduction. It represents a profitable production system and constitutes an efficient buffer between villages and protected forest. The system represents a sustainable and flexible association between forest resources and cultivation of cash crops.

1. Introduction

The Minangkabau area in the province of West Sumatra of Indonesia is characterized by an ancient culture and a diversified agriculture that combines irrigated rice with perennial crops. Tropical forest that once dominated the area is now restricted to protected stations only. The District of Maninjau has developed impressive tree gardens which combine commercial tree crops and managed forest species and dominate the agricultural landscape. These gardens originated a long time ago, probably from managed – or re-established forests associated with forest clearing for rice growing.

The Maninjau agroforestry system was studied intensively during 1983/84 by a multidisciplinary team having special interest in forest botany and ecology, socio-economics and agronomy. Some detailed reports from this study have been prepared on different aspects such as the structure, architecture, botanic composition, use of plants and management practices of the system (Michon 1985) and their socio-economic characteristics, production, relation with the other components of the production system, and place and role in the peasant economy (Mary 1986).

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This paper summarizes the salient functional aspects of this interesting multistoreyed agroforestry system and evaluates its research needs and extrapolatability.

2. General description of the area

2.1. *Geographic location*

The area of Maninjau is located in the central part of the Province of West Sumatra (0 1 S, 100 E) and belongs to the Minangkabau country. The location of the study area is indicated in Fig. 16.1.

The area covers about 300 km^2, about a third of which consists of Maninjau lake, occupying the bottom of the ancient crater of Maninjau. It is bordered to the east by the rice-growing plateau of Bukittinggi (the heartland of Minangkabau country) and to the north by a remote mountain area. The crater opens to the west by a narrow rift towards the coastal plain of Padang.

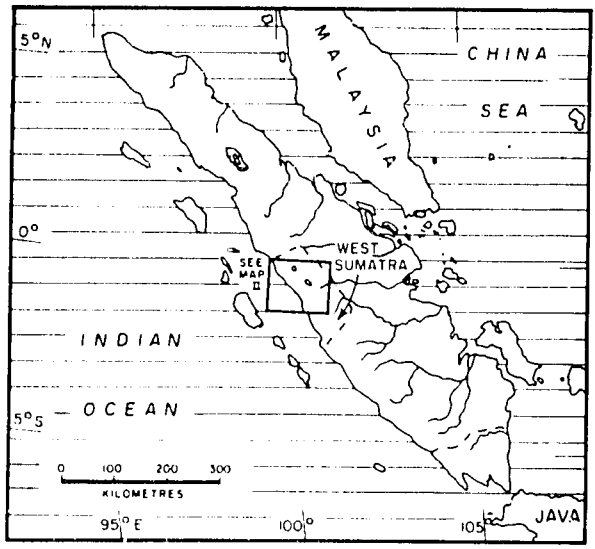
2.2. *Biophysical environment*

Climate. The area receives 3,000 4,500 mm of rain per year: the eastern part is the driest. The rainfall peak occurs in October–March, with sometimes a short "dry season" in February; the usual dry season (with less than 200 mm rainfall per month) is in July August. The rainfall pattern is characterized by violent storms in the afternoons. The average temperature remains steady throughout the year at about 25 C at the lake level.

Topography and soils. Topography is characterized by the predominance of steep slopes. To the south and to the west, the lake is directly surrounded by very steep slopes (more than 40) ending in a ridge up to the border of the crater; the lake terrace is less than 100 m wide. To the north and to the east, the terrace forms a wider plain undulating at 500 2,000 m up to the bottom of the crater slopes. The lake is at an altitude of 450 m, and the crater ridges reach 1,200 1,500 m a.s.l.

Soils are young and loose volcanic soils (Andosols) that are rich in nutrients but very unstable in structure and therefore prone to erosion and sliding. Numerous landslides occur during the rainy season and the soils on the lower parts of the slopes are rocky and stony and poorly compacted on the upper parts of the crater. Peasants maintain a permanent and efficiently protective tree cover on the slopes to avoid serious landslides.

Vegetation. The natural vegetation is tropical rain forest (Ogino *et al.* 1984). It still covers 30 79% of the total land area in different villages, and remains quite undisturbed from 900 m altitude up to the crater ridge. Above 800 m



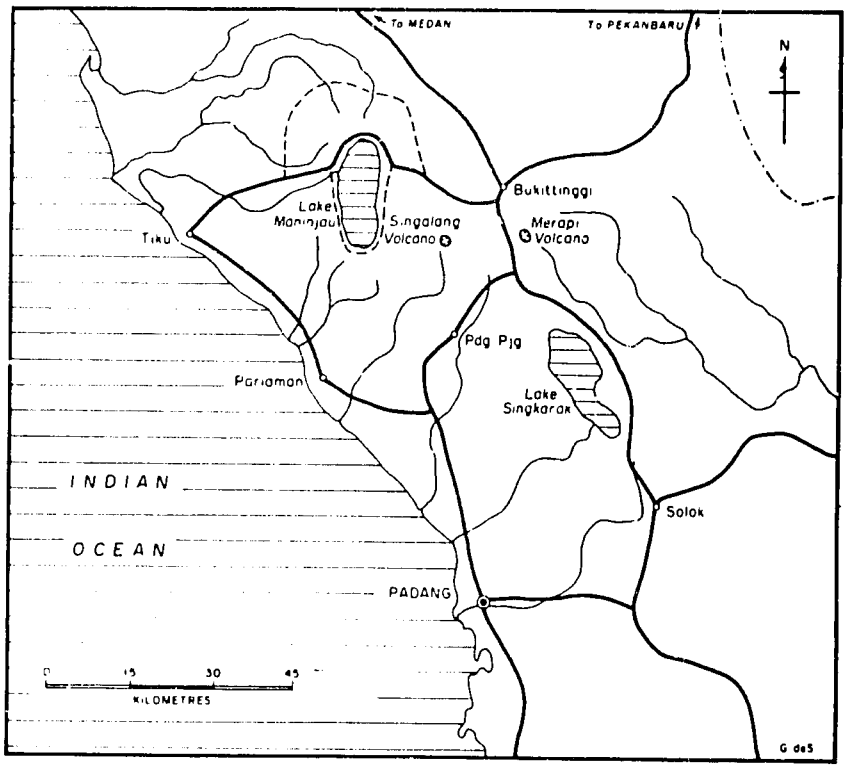


Fig 16.1. The location of the study area in West Sumatra.

a.s.l. it is a typical mountain forest with Fagaceae (*Quercus* and *Castanopsis*), Lauraceae and Myrtaceae as canopy trees, and Anacardiaceae (*Mangifera* and *Swintonia*) or *Shorea platyclados* (Dipterocarpaceae) as emergents. Due to the violent winds and landslides, this natural forest is highly perturbed: lianas are numerous (among which are rattans) and big *Ficus* appear to be efficient soil stabilizers with their abundant roots. On the steepest slopes, forest is replaced by a bushy formation with *Pandanus*, ferns and herbs. Below 800 m a.s.l., what remains of the original forest is characterized by overstorey species of Burseraceae (*Canarium*, *Santiria*, *Dacryodes*), Fagaceae (*Lithocarpus*, *Quercus*), some spared Dipterocarpaceae (*Shorea sumatrana*, *S. sororia*, *Hopea mengarawan*, *Parashorea lucida*), and *Acrocarpus fraxinifolius*. The understorey vegetation consists of Meliaceae (*Aglaia argentea*, *A. gango*, *Chisocheton* spp., *Disoxylon macrocarpum*, *D. cauliforum*, *Toona sinensis*), Lauraceae (*Cinnamomum parthenoxylon*, *Litsea* spp., *Actinodaphne* sp.), Annonaceae, Euphorbiaceae and Myristicaceae. Tree species of earlier successional formations are very common: *Octomeles sumatrana* (Datiscaceae), *Alstonia angustiloba* (Apocynaceae), *Terminalia* spp. (Combretaceae), *Pisonia umbellifera* (Nyctaginaceae), and *Artocarpus* spp. (Moraceae). Most of these forest species are also frequently found in the agroforestry system and are retained and managed by peasants for various purposes.

2.3. *Land-use systems*

Agriculture. The area of Maninjau is characterized by a settled, smallholder agriculture with two major components:

Rice cultivation on permament irrigated ricefields located on the lake terraces and at the bottom of the slopes, covering 13–75% of the total agricultural land of villages (or 3.5–30% of the total land of villages). Rice production is mainly for home consumption, but surpluses are sold in some villages. From one to three harvests per year are obtained depending on the availability of water and labour opportunities; rice fields are also planted with vegetable crops such as chillies, egg plant and cucumber between two rice crops.

Mixed tree-gardens (the "agroforest") for both commercial (spices, coffee, fruits) and subsistence purposes (wood, fruits, vegetables, etc.) are the other major agricultural system. This is described later.

A schematic presentation of the structural configuration and arrangement of these land-use systems is presented in Fig. 16.2.

Livestock consists usually of chickens and some sheep or goats; in some villages, water buffaloes are also kept, mainly as draught animals for work in rice fields.

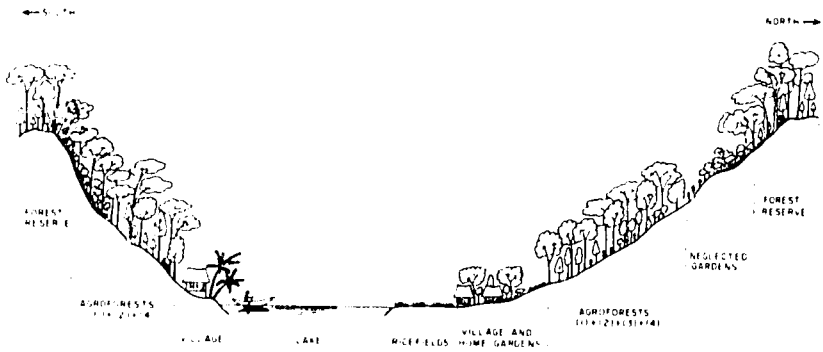


Fig. 16.2. Schematic presentation of the agroforestry and land-use pattern in Maninjau. (1) durian + timber species + cinnamon + nutmeg + coffee; (2) timber species + nutmeg + cinnamon; (3) rejuvenated coffee garden with two-three overstorey timber/fruit trees; (4) neglected garden with some fruit trees + timber species and occasional agricultural species.

Forestry. There are no planted forests; wood for construction and other common uses is obtained from mixed tree gardens. Most of the natural forest above 900 m a.s.l. (on the steepest parts of the slopes) comes under the status of "Forest Reserve", which is State managed. This status dates from the colonial period, but the boundaries of the reserve have been slighly extended for several years by the Indonesian Forestry Services for protection purposes. Wood and rattan collection is strictly forbidden by law.

Agroforestry. The main agroforestry system consists of the tree gardens located on the slopes between the villages and the forest reserve. A typical unit is shown in Fig. 16.3. These gardens, known as *parak*, make up 50–88% of the agricultural land in different villages (13–33% of the total land). They are characterized by high species diversity, high density of trees and a complex and layered vertical structure. They provide both commercial and subsistance wood products, including typical minor forest products such as wild forest fruits and vegetables, forest medicines, etc. Agricultural tree crops such as cinnamon, nutmeg and coffee and cultivated fruits, and short-duration crops such as chilli, tubers and beans are also obtained. Patterns of production and reproduction of the species are close to those in natural forest ecosystems; man's intervention is restricted to the harvest of products and some planting of a few species.

Apart from these mixed-tree gardens, there are also the homegardens of the villages as a minor component of the farms, but they are not developed around all houses. They include ornamental plants (in front of the house), and valuable fruit species that peasants are reluctant to grow in the slope gardens for security reasons.

Others. The lake is used for important fishing activities, especially in the southern and western parts of the crater. Fish are caught for home consumption and for sale on the crater markets. A particular kind of very small fish

Fig. 10.3 The transitional zone between the agricultural fields and agroforestry gardens (Photo: G. Michon).

typical of Maninjau lake — the *palai rinuak* — and a species of small mussel (the *pensi*) are exported to more important markets outside the crater.

2.4. *Socio-economic characteristics*

Demographic patterns and land tenure. The general features and customs of the Maninjau population are typical of Minangkabau society. The population density in different villages varies from 150 to 350 per km². But during the past two decades (1960–1980) the increase in population was only 10.5% as compared to 52% for the whole of Indonesia. This apparent low rate is due to a particular tradition of Minang people, namely, the voluntary migration of young men to neighbouring areas, or *rantau*, which in the past used to be only a temporary habit but now tends to be a more definite part of their culture. In Maninjau, 40–70% of the "original" population live outside the province, and young out-migrants and their wives and children do not wish to go back. This results in a loss of young workers and a general shortage of labour for agricultural work, but it also reduces population pressure on land resources (Naim 1973).

Minang society is matrilinear. The social unit is the enlarged family. Land and trees are owned communally by the clan. Usually rice-field land is temporarily shared among married daughters, but for the tree-garden land, sharing may apply only to trees, or their produce, depending on several factors such as the nature of the trees, their pattern of production, the person

Table 16.1. Socio-economic characteristics of some typical farms and villages in Maninjau, Western Sumatra.

Characteristics	Village 1		Village 2		Village 3	
	Total area (ha)	% of agricultural area	Total area (ha)	% of agricultural area	Total area (ha)	% of agricultural area
Total village land	1,800		1,000		750	
Total agricultural area	1,250	100	640	100	160	100
Total area of rice fields	540	43	220	34	20	12
Total area of "agroforest" (mixed gardens)	280	22	342	53	100	63
Total area of other agric. land – homegardens, abandoned fields	434	35	80	13	40	23
Ratio agroforest area/rice field area	0.5		1.6		5	
Total population living in village	2,302		3,453		1,200	
Number of households in village	416		540		204	
% of original village population living outside the province	50		60		70	
Population density/km^2	128		345		160	
Population density reported to the area of cultivated land	185		540		750	
% of household with non-farming main activity	1		16		11	
Mean (M) and range (R) of rice field unit (ha)	M:1.3 R:0.5 to 2		M:0.4 R:0.1 to 0.7		M:0.1 R:0.01 to 0.3	
M and R of agroforest size (ha)	M:0.67 R:0.1 to		M:0.63 R:0.05 to 2		M:0.5 unit R:0.01 to 2	
M and R of agricultural land per household (ha)	M:3 R: no data		M::1.18 R: no data		M:0.8 R: no data	

who had planted them, and so on. In Maninjau, the upkeep of a garden – but not the control over land or tree produce – is handled by one person who has the right to plant new trees or annual crops and harvest what he has planted for himself (the trees concerned are mainly coffee, cinnamon and wood species). But the produce of other trees (fruit of long-lived wood species and nutmeg) is shared among all the members of the clan, and decisions concerning the sale or mortgaging of a piece of land have to be taken communally. This land-tenure system is a good warranty against the excessive subdivision and fragmentation of productive land and against the accumulation of ownership by rich people; it also reduces the chances of any sudden transformation of the agricultural system: land cannot be sold or transformed, a tree cannot be cut down by the individual decision of a single owner (Ok Kung Pak 1982). However, this may have good as well as bad consequences.

Characteristics of farms and villages. The size and the form of the management units are not uniform. Three situations from three different villages are presented in Table 16.1, which reflect the heterogeneity among the villages (Mary 1986).

- Village 1: large extension of agricultural land and rice fields;
- Village 2: irrigated rice fields and total agricultural land not so extended, but intensively managed; tree gardens well developed;
- Village 3: scarcity of agricultural land, particularly of rice fields; tree gardens dominate.

Road and market facilities. Maninjau is presently well related to the neighbouring areas: a car can reach the international harbour of Padang (100 km) by a new road (about three hours), and the main regional market centre of Bukittinggi (40 km) in two hours. There are regular public transport services from villages in the northern and eastern parts of the crater. However, the villages in the south and west have no roads suitable for vehicles, and the main mode of traffic is small boats crossing the lake to the district centre or to the western road out of the crater.

There are co-operatives for rice cultivation and processing or sale in each part of the crater, and a co-operative dealing with cultivation and marketing of spices and coffee for the south-eastern part. In other areas, marketing of products occurs through local traders. Credit facilities are developed only for rice.

3. Structure of the system

Agroforests in Maninjau are not homogeneous either in composition or in structure. The different combinations of crops, and of cultivated and

spontaneous components, result from historic and economic criteria. However, they form a dense, forest-like cover on the slopes (Michon 1985).

3.1. *Components of the agroforest*

Cultivated annual crops. Annual – or short-cycle – crops are by no means dominant in the agroforest; they form a temporary, occasional component which appears at the time of re-emergence of the undergrowth of gardens, often in association with cinnamon, coffee or nutmeg. These are the same crops which can be grown in rice fields between two rice harvests: chilli (*Capsicum annuum*), egg plant (*Solanum melongena*), maize (*Zea mays*), beans (*Vigna* spp., *Phaseolus* spp.), cucumber (*Cucumis sativus*), bananas (*Musa paradisiaca*), papaya (*Carica papaya*), etc. Tuber crops are avoided because of the high degree of depredation by wild pigs.

Tree crops. These include only planted trees which receive care and attention and are systematically harvested. Agroforests usually have only six common cultivated tree crops:

Durio zibethinus (Bombacaceae), durian. A large tree up to 40 m high, producing large fruits, is the main component of the agroforest canopy and the main tree species of Maninjau. It originates from the natural forest of Western Indonesia, bears fruit in July–August from the age of seven years to more than 100 years. The fruits are both sold to local traders and abundantly consumed; in peak seasons, durian is consumed in even greater quantities than rice. Durian is propagated from seeds collected from the best fruits and planted in chosen places in the gardens. The trees receive no special care, but before the fruiting season the undergrowth is cleared in order to facilitate better collection of the fallen fruit. The trees are allowed to die naturally and often fall down during big storms. Wood is collected for construction purposes; it yields a valuable red wood suitable for partition panels (walls).

Pterospermum javanicum (Sterculiaceae). This large-canopy tree, up to 35–40 m high, is common in coastal and low-mountain forest of Sumatra. In the gardens it is found in association with durian. It is a fast growing tree grown for construction wood and yields a red wood suitable for flooring and walls. It is propagated from spontaneous seedlings occurring in the gardens and can be harvested after 15–20 years; it can yield 30–50 boards (300–400 cm × 22 cm × 3–4 cm), for a diameter (dbh) of 35–50 cm.

Toona sinensis (Meliaceae). A medium-sized tree native of local forests, growing up to 35 m high, is a valuable shade tree for coffee and nutmeg. It yields a good timber which is used for flooring or walls and for furniture. It is propagated from seedlings that are collected from clearings under mature trees (the seed needs a certain amount of light to germinate), and is harvested from the age of 30 years. A tree of 30 cm in diameter can yield about 25 boards (400 × 22 × 4 cm).

Cinnamomum burmani (Lauraceae), cinnamon. It is one of the major export crops of West Sumatra, and for centuries has been cultivated in Maninjau. In the agroforests, it is one of the three major understorey species; is grown under a dense stand of durian, *Pterospermum* and other species, from seedlings collected in the gardens and kept in a nursery for one year, or preferably from coppice shoots occurring after harvest. Bark can be harvested when the tree is 8–10 years old (dbh above 10 cm; total height up to 15 m). For harvesting, the tree is cut and the bark of trunk and branches collected. The average yield is 8 kg of dry bark per tree. Wood, from which the bark has been peeled off, is also collected as fuelwood for home consumption or sale.

The average density of a cinnamon stand in the gardens varies between 800 and 1,500 trees/ha, depending on the type of association with overstorey trees and with nutmeg, and on the strategy chosen for harvest. The stand can be harvested at once, and then replanted totally, or regularly collected (10–20 trees cut every year, which are allowed to regenerate to produce coppice shoots). Yields are better in dense stands and upper parts of the slopes (*C. burmani* is a tree native to the mountain forests – over 900 m a.s.l. – in Sumatra and it can be grown at lower altitudes only under a dense canopy of shade trees which maintain a humid and cool microclimate).

Myristica fragrans (Myristicaceae), nutmeg. This medium-sized tree, up to 20 m high, is a native of the eastern parts of the Indonesian archipelago. Nutmeg is grown from seeds collected from mature trees and kept in nurseries for one year. Seedlings are established under a light canopy of durian and *Toona*, and can be associated with a cinnamon stand. Densities for nutmeg vary from 300 to 500 trees/ha. The tree bears fruits after six years, and can produce for 50–70 years. There is no proper fruiting season, but peaks are in July and January. Average yields vary from 10 to 30 kg of dry nuts per tree; macis is also collected and dried.

Coffea canephora (= C. robusta) (Rubiaceae), coffee. Coffee had been a dominant component of agroforestry systems until about 1940, when cultivation was abandoned. But it has recently been re-established. Coffee is planted from seedlings collected from neglected plantations on the upper parts of the slope, under a light canopy of durian. During the early years of establishment, young coffee trees are associated with banana and papaya trees; at the same time young *Toona* trees as well as some *Pterospermum*, *Alangium*, *Leucaena* and *Actinodaphne* are planted within the coffee stand. The stand is manured with decomposed pericarp of durian fruits. Pruning of coffee trees is not a common practice. The level of production is generally low: an average of 120 kg of dry fruit per hectare. The peak of production is in July–August, although there is some fruiting throughout the year. There is no sole-crop stand of coffee in these agroforests. After the dramatic decline in the coffee economy in the 1930s, peasants have become careful to associate coffee (and commercial crops in general) with fruit trees and wood species that have a

long and proven history in the socio-cultural set up of the villages, so that these trees act as shade trees for coffee and improve the total output from the garden land.

Other tree and shrub species. Many other species are important in the agroforest. There are planted species and species which reproduce naturally without any human intervention, but which are retained, managed and harvested for various purposes. These are species originating from the native forest as well as pioneer species from secondary formation or species from the "cultivated" world. A list of such species is given in Table 16.2.

In addition, many plants are collected as medicinals or for traditional uses. Other species with no particular use are considered soil improvers: these include *Eupatorium odoratum*, a common weed, *Pisonia umbellifera*, a large tree with smooth wood, *Laportea stimulans*, a dangerous Urticaceae, etc.

Animals. Some buffaloes are kept for grazing in the agroforest, but the main animal component is the wild fauna: its role in pollination and seed dispersion is important, but it represents a major danger for fruit and tuber crops. Main depredators are monkeys (*Presbytis rubiconda*, the leaf monkey; *Macaca nemestrina* and *M. fascicularis*, the macaques; some gibbons: *Hylobates syndactylus*), civets, squirrels and wild pigs. The Malay sunbear (*Helarctos malayanus*), the "binturong" (*Arctictis binturong*), some tigers and wild cats, wild goats (*Capricornis sumatraensis*), may represent, to a lesser extent, some danger for crops or people.

3.2. *Arrangement of components*

One of the distinguishing features of the mixed gardens is their species diversity; there is no single perennial species that dominates the gardens. Factors influencing the composition and the architecture of the gardens include the size of the agroforest plot in relation to that of the rice-field plot managed by the family, the degree of clearing carried out, cash vs. consumption needs of the family, and location of the plot (in altitude as well as its location in the crater). However, all the plots are characterized by an intimate arrangement between overstorey and understorey species, which can be analysed by using the terms of forst-ecosystem analysis: vegetation structure and architecture are characterized by different layers of mature productive trees which are defined as "structural ensembles" or "producing ensembles" (Michon *et al.* 1983).

Depending on the dominant tree crops in the plot, two schematic types of gardens can be described as follows:

Durian + wood species + cinnamon/nutmeg combination. In this first type of garden, two structural ensembles of productive trees are dominant: the canopy ensemble, comprising *Durio* and *Pterospermum*, occupies the upper strata (up

Table 16.2. "Non-cultivated" but useful tree species in Maninjau agroforestry systems.

Main use	Growth form	*Origin	Secondary use
Construction wood			
Acrocarpus fraxinifolius (Mimos.)	Tree	FI	All species also used as fuelwood
Actinodaphne sp. (Laurac.)	Tree	FI	
Aglaia spp. (Meliac.)	Tree	FI	
Alangium kurzii (Alang.)	Tree	FI and FII	
Alstonia angustiloba (Apoc.)	Tree	FI and FII	
Antidesma sp. (Euphorb.)	Small tree	FII	
Bishofia javanica (Euphorb.)	Tree	FII	
Carallia brachyata (Rhizoph.)	Tree	FI	
Dysoxylon spp. (Meliac.)	Tree	FI	
Litsea spp. (Laurac.)	Tree	FI	
Macaranga tanarius (Euphorb.)	Small tree	FII	
Mallotus spp. (Euphorb.)	Small tree	FI and FII	
Morus macroura (Euphorb.)	Tree	FII	
Nauclea spp. (Rubiac.)	Treelet	FII	
Parashorea lucida (Diptero.)	Tree	FI	
Shorea sumatrana (Diptero.)	Tree	FI	
Shorea platyclados (Diptero.)	Tree	FI	
Shorea spp. (Diptero.)	Tree	FI	
Toona surenii (Meliac.)	Tree	FI	
Trema orientalis (Ulmac.)	Tree	FII	
Fruits			
Annona muricata (Anon.)	Treelet	HG	
Artocarpus integer (Morac.)	Tree	FI, HG	Wood for houses and tools
Art. heterophyllus (Morac.)	Tree	HG	
Averrhoa bilimbi (Oxalid.)	Treelet	HG	Construction wood
Averrhoa carembola (Oxalid.)	Treelet	HG	
Baccaurea spp. (Euphorb.)	Trees	FI and HG	Very good timber (hardwood)
Citrus grandis, *C. hystrix*, *C. aurantifolia*, *C. microcarpa*, *C. medica*, *C. sinensis* (Rutac.)	Trees	FI and HG	Common for medicine

Eugenia equea, *E. malaccensis*, *E. javanica*, *E. michelii* (Myrtac.)	Trees	FI and HG	Wood for houses or others
Garcinia mangostana (Guttif.)	Tree	HG	
Flacourtia rukem (Flacourt.)	Tree	FI and II	
Lansium domesticum (Meliac.)	Tree	HG	Good hardwood for houses
Mangifera indica (Anacard.)	Tree	HG	
M. foetida	Tree	FI, HG	Construction wood and leaves as vegetables
M. odorata	Tree	FI and HG	
Nephelium lappaceum (Sapind.)	Tree	HG and FI	
Musa paradisiaca (Musac.)	Herbac.	HG and FII	Leaves as wrapping material
Psidium guajava (Myrtac.)	Treelet	HG	
Salacca edulis (Arec.)	Palm	HG and FI	
Spondias cytherea (Anac.)	Tree	HG	
Vegetables and spices			
Aleurites moluccana (Euphorb.)	Tree	Introd.	
Claoxylon spp. (Euphorb.)	Bush	FI and FII	
Eugenia polyantha (Myrtac.)	Tree	FI and HG	
Parkia speciosa (Mimos.)	Tree	FI	Construction wood
Pithecellobium jiringa (Mimos.)	Tree	FI	
Pangium edule (Flacourt.)	Tree	FI	
Areca spp. (Arec.)	Palm	FI	
Arenga pinnata (Arec.)	Palm	FI	Sugar palm and fibres for roofing
Ferns			
Dichtyopteris irregularis			
Diplazium esculentum			
Stenochlaena palustris	Herbs	FI	
Others			
Pandanus tinctorius (Pandanac.)	Bush	FI	Leaves for handicraft Food, material for cooking

* FI = primary forest, FII = secondary formations, HG = often cultivated in the homegarden.

to 40 m high, relative cover equals 90% of the plot surface and the tree density is about 110 productive trees/ha). A cinnamon or nutmeg stand forms a lower ensemble between 5 and 15 m high which covers up to 70% of the plot surface. Between these two distinct ensembles, discontinuous tree layers are also present, notably one between 18 and 22 m high with *Toona* and *Alangium*, and another between 5 and 12 m high with fruit species, the latter interfering with the nutmeg/cinnamon ensemble. The ground layer is occupied by spontaneous grasses and by some *Pandanus*. Young replacement trees are also present between these productive tree layers, but obviously they do not have a definite place in the garden architecture. The different ensembles overlap, which induces a high degree of leaf cover (a cumulative canopy cover of about 200% of the plot surface). When both nutmeg and cinnamon are present in the mixture, the lower ensemble becomes quite dense from the ground to 18 m, reducing the relative abundance of spontaneous components (which often occurs in nutmeg- or cinnamon-dominated gardens). Figure 16.4 shows a garden with durian, *Toona* and nutmeg and Fig. 16.5 is a photograph of a cinnamon-dominated garden.

Coffee and wood species established under trees. Most of the coffee gardens are newly established; they take the place of nutmeg gard ns or are established in previously neglected gardens. The tree canopy in coffee gardens is not as dense as in other types and provides only 30–50% of relative cover. The coffee stand will occupy the space from the ground to 5 m, with a stand density of 1,500 bushes/ha. Various trees are introduced at the same time; they are mainly woody species which will form different layers when mature (i.e.,

Fig. 16.4. An agroforestry garden with durian and *Toona sinensis* as the overstorey species and nutmeg as the understorey species (Photo: G. Michon).

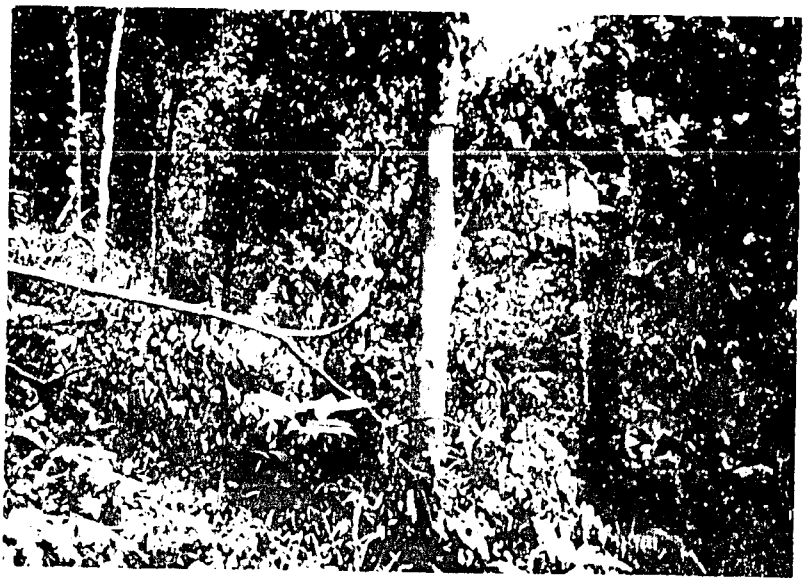


Fig. 16.5. Bark of cinnamon being harvested in a cinnamon-dominated garden (Photo: G. Michon).

within 20–30 years when the coffee declines). *Pterospermum* and *Actinodaphne* will reach the canopy ensemble, whereas *Toona* and *Alangium* will constitute a lower ensemble (20–30 m). During the establishment phase, bananas are also planted and form a productive lower ensemble from 0 to 2 m. Coffee is often associated with cinnamon which will form another ensemble (5–15 m) with a low leaf cover (the density of the cinnamon stand being less than that in the first type).

The association and the interactions among the different types of gardens lead to a complex mosaic on the slopes. Although the specific composition and configuration of individual gardens can change over time, the overall "agro-forest cover" remains stable in time and space. Changes from one type of garden to another, or from an abandoned garden to a renewed one, often occur without any drastic change in the overall structure because clear-cutting and burning are avoided and replacement of crops and trees is progressively staggered so that the balance between the component canopies is usually maintained. Figures 16.6 and 16.7 are schematic representations of the structure of these two major types of agroforestry garden systems.

3.3. *Management*

In managing their gardens, the peasants adopt "agricultural" practices (planting, clearing, manuring, cutting, etc.) and undertake integration of natural

Fig. 16.6. Schematic representation of the structure of a "durian wood species + cinnamon/nutmeg" combination garden.

processes of organic-matter and nutrient cycling and vegetation regeneration. The major determining factor in the maintenance of gardens is the functional interactions among plants – or between plants and soil – and among biological cycles of each individual plant.

Peasants have an intimate knowledge of the ecological requirements of agroforestry species. For example, cinnamon, a medium-altitude species, when grown under 800 m a.s.l. is never put in a position of direct exposure to sunlight but is planted under a dense canopy which will maintain the optimum temperature and humidity. *Toona*, which is a "gap" species in natural forests, cannot germinate under the shade of gardens. In order to obtain seedlings, the peasants manage opened places near *Toona* trees by thinning the canopy and

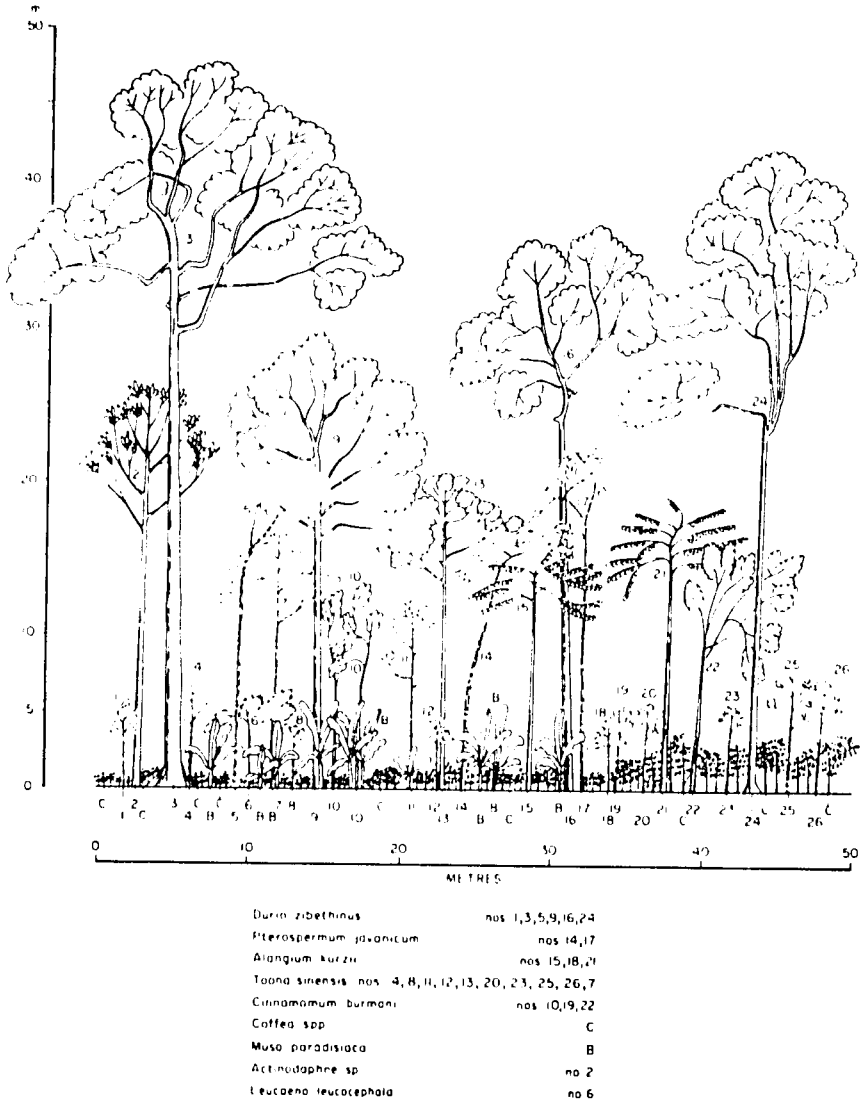


Fig. 16.7. Schematic representation of the structure of a "coffee + timber species under traditional trees" combination garden.

clearing the undergrowth so that the seeds produced by mature trees germinate and seedlings are transplanted after one or two years to chosen places when they can withstand shade.

Regular planting of seedlings is done for a few species only; and even for these "planted" species it is not the exclusive method of reproduction. Planting is always complemented by natural regeneration. The main effect of planting is that the peasant can choose the location of the future tree and promote better growth by associating the seedling with decaying or decomposing trees which will ensure better fertilization. In addition planting is the only

way in which the composition of a garden can be changed or a dominant stand (cinnamon or coffee) renewed.

Except for coffee, cinnamon and wood species, trees are not eliminated before they die or fall down naturally. This natural elimination leads to a free place in the lower layers or a gap in the canopy. Wood, if valuable, is collected or left to decompose on the ground. The evolution of gaps can be summarized as follows:

If the size of the gap is reduced, the increase in light at ground level and the availability of space stimulate the growth of replacement trees waiting in the undergrowth that soon close up the opening;
If no replacement trees are present, or if change is needed, the opened place is used for the introduction of new trees; seedlings are planted near the fallen wood, which will ensure a good fertilization;
If the opening is wide (mainly in renewed gardens where trees are eliminated by the peasant, or after big storms), young seedlings will always be associated with short-cycle, light-demanding crops (bananas, for example), which constitute a "pioneer equivalent" phase and contain the development of natural pioneers. This practice, besides reducing the occurrence of natural seedlings and succession species, provides a good environment for the first stages of growth of the seedlings, which benefit from light shade, humidity and the care given to the banana crop.

In the case of wood species, harvest acts as a natural "thinning" and the evolution of the induced gap is the same as that described above for natural stands. But, for cinnamon, especially when the stand is harvested at one go, harvest induces an abrupt disruption of the garden structure. In order to avoid invasion by undesirable species and to promote a good regeneration of the cinnamon stand, clearings have to be repeated during the first three years, and thinning of the coppiced shoots is necessary.

The colonization of the ground layer of the agroforest by aggressive species (*Eupatorium odoratum*, *Lantana camara* or Urticaceae species) can be an important factor and regular clearing is needed. Gardens are usually cleared before the durian season, but this clearing remains selective: ferns are encouraged (as valuable vegetables), and natural seedlings and saplings of interesting species are retained and looked after.

Retaining natural seedlings applies to fruit species, and above all, wood species. These young trees can grow under conditions of heavy shade and produce straight poles. Trees with poor form (such as *Pterospermum*, which branches near the ground) are pruned in order to promote a better shape and better yields.

Consequently, an intimate association between crops reduces the occurrence and the consequences of pest attacks. However, an important disease is

reported in nutmeg in the southern part of the crater, which is so serious as to threaten the cultivation of nutmeg. No treatment (chemical or biological) is available to the peasants. Some disease occurs on cinnamon also, but the trees are not attacked until they are six years old and the bark can be collected when the trees begin to die. No problems are reported for wood species. For fruits, the main threat is the high degree of depredation by the wild fauna. In the fruiting season the peasants try to scare away monkeys and squirrels by making loud noises in the gardens, but the effect of this method is only transitory.

4. Functional aspects of the system

4.1. *Resource input and utilization*

Land. In each village, agroforest land is divided among clans, each clan owning a piece of land of varying size from the village up to the forest. Within each clan's property, plots are allocated to individuals (the average size of the allocated area varies, according to the villages and families, from 0.01 to 3 ha, with a mean value of 0.63 ha). However, trees, except for cinnamon and sometimes coffee, are not so allocated and are harvested by the whole clan.

The land for rice fields is also allocated to individuals on the same basis. However, the topographic differences among the village result in a great difference in rice fields area per family from village to village – means vary from 0.1 to 1.3 ha per family. Distribution patterns of garden land are more even among villages.

Labour. An average number of 5 persons per household is common with only a few young men aged between 18 and 35 years (because of out-migration). In the agroforest, only family labour is used. The peak season of farm operations is during the durian season and at the time of cinnamon harvest. If needed, mutual help from other farmers is availed of for the cinnamon harvest (men cutting the tree, women peeling the branches and carrying the bark to the village). Most tasks in the agroforest have no fixed period and can be staggered if necessary. Firewood collection and clearing are usually done by women and planting by men; fruit collection is done by all the members of the family. Cutting and sawing up timber trees is done by specialized workers who are paid in kind (a part of the wood) or cash.

Garden work is delayed during the peak periods of labour demand in the rice fields, such as land preparation or harvest. However, durian collection, which employs everyone full time, is given top priority; rice harvest can fail if it coincides with the durian season.

Capital and other inputs. There is no mechanization of the work in the gardens, and the use of animal power is minimal. However, some villages have tractors for land preparation in the rice fields, and buffaloes are also commonly used. The only tools used in the gardens are machettes, axes, hoes and sometimes chainsaws. Seeds are collected from the agroforests. Pericarps and other wastes from durian or nutmeg and dried pericarp of coffee are used as manure, mainly for coffee. Chemical fertilizers are not used.

4.2. *Production*

Production figures have been obtained for commercial products, but estimated for consumed products. Of the total income from agricultural produce (rice fields + gardens), the agroforest products account for 26–80%. One hectare of garden produces Rp 365,000–5,000,000 (1,000 Rp = 1 US dollar in 1985). Individual crop products are given in Table 16.3. The total value of the wood products is an underestimate because only the commercialized part could be taken into account. The total value of products collected from wild plants is also unknown. A summary of the role of the agroforestry gardens in satisfying the basic needs of villages is given in Table 16.4.

Table 16.3. Value of the agroforest products in two villages.

Product	Mean price (Rp)	Home consumption/ sale	Total (million Rp)	
			Village 1	Village 2
Cinnamon				
1st quality	680/kg	0/100	41.1	133.8
2nd quality	250/kg			
Nutmeg				
nuts	1,800–900/kg	10/90	3.6	15
macis	1,950/kg	0/10		
Coffee	1,000/kg	10/90	16	30
Durian	150–250/fruit	10/90	17.5	165.5
Firewood	300/set	70/30	4	13.5
Timber	Variable	60/40	20	25
Others	Variable	90/10	No data	No data
Rice	300/kg	Variable	285	192
Total value			387	514
Total value (agroforest only)			202	514
Total value/family			931,000	1,222,000
Agroforest value/family			49,000	93,000

1 US $ = Rp 1,000 (approx.) (1985).

Table 16.4. The role of agroforestry gardens (AFG) and rice fields in satisfying the basic needs of the villagers.

Types of needs	Source of product or money
Food needs	
rice	Rice field
fruit	Collection in AFG and homegarden
vegetables and spices	Collection in AFG, homegardens and dry fields
meat and fish	Homegardens, lake and streams
coffee	AFG plantation
Non-food needs	
firewood	AFG (cinnamon and dead wood)
construction wood and material	AFG (culture and collection)
daily expenses (school) and others	AFG: sale of cinnamon, nutmeg, coffee
Seasonal expenses	AFG: sale of durian, cinnamon, coffee
Exceptional expenses	AFG: sale of timber trees
Money savings	AFG: surplus from sale of durian, cinnamon

5. System dynamics

5.1. *Growth of the system*

Boundaries between rice fields and agroforests, or between agroforest and forest, are well defined and already fixed. No expansion of agroforests has been reported in recent times. However, some structural changes occur within the agroforestry mix itself. In some villages, the relatively large areas under rice provide surplus rice for sale; then agroforests are not well tended and they are used mainly for collection of products such as wood (fuel and construction), fruits, vegetables, etc. for domestic use.

Gardens located far away from villages, which were previously dominated by coffee, are also often abandoned. However, some of them are renewed by clearing and/or harvest of the coffee stand.

5.2. *Sustainability*

Though agroforests can yield multiple products for home consumption as well as for cash, they are subject to changes as a result of the increase in population. The traditional out-migration is a factor that can neutralize the effect of population growth and maintain the system's continuity. Another

determining factor in the agroforest's stability over time is the strict form of land tenure which conserves trees and land as an inalienable inheritance.

Failures have sometimes occurred for some of the commercial crops, e.g., coffee, due to a drastic drop in international prices (1940), and the present nutmeg failure due to severe pest problems. But they have not resulted in a general decrease in the area of the agroforest garden system. Because of the high diversity of species and their functions, and their low-input nature, agroforests have a high degree of biological as well as economic stability and sustainability. They are also flexible systems: crops or tree species can be changed without affecting the overall structure and productivity. This gives the gardens a fundamental adaptability to changing economic conditions. The system's composition can be altered according to the economic situation: the subsistence and cash components can replace each other if needed. The main negative point is the low direct "rentability" of the individual commercial crop compared to the intensive monocrop plantations of the same species. But as export crops are high-risk enterprises, peasants in Maninjau prefer to put a stake in long-term sustainability than in immediate rentability.

6. Evaluation

6.1. *Merits*

1. The continuous ground cover on the slopes is a *sine qua non* for the maintenance of the whole agricultural system. Agroforest cover, i.e., close-layered canopy, a diversified root system and a permanent soil cover by grasses and bushes, is essential to avoid disastrous landslides and maintain soil fertility on slopes and the stability of the rice fields.

2. Agroforests act as an efficient buffer zone between villages and the forest reserve. The ecological transition between forest and open agricultural lands is progressive; agroforests ensure a continuous extension of forest structures down to the villages and their simplified homegardens. Agroforests also provide many products for peasant life: they produce wood, forest foods, material and cash income, as natural forests traditionally do for the forest people, and thus limit the intrusion of peasants into the forest reserve for gathering purposes. The protection of forest resources in the agroforest is increased since these resources are appropriated by families and managed in order to ensure their reproduction. Agroforests in Maninjau represent an efficient buffer for natural forest protection.

3. The great species diversity of agroforests represents a valuable gene bank for forest species as well as for domesticated species. Many species native to the original forest of the crater have been able to reproduce within the agroforest structure which provides a humid and shady environment. The

great Dipterocarp species have almost disappeared, but other valuable species of trees remain and reproduce in the agroforest. Various fruit and crop species represent years of selection (both natural and human). Durian, for example, has a great level of genetic diversity, and represents a valuable gene pool for breeding or improvement programmes.

4. Export crops produced in Maninjau contribute to West Sumatra's exports. Significant among these are cinnamon (50% of the sub-province exports) and nutmeg (55%), and to a lesser extent coffee (10%). Wood for construction and fuel from agroforests supplies the surrounding deforested areas while fulfilling local needs.

5. Income provided by agroforests is comparable to, or even greater than, that provided by rice fields (annual net income of Rp 500,000–800,000/ha for rice fields, Rp 365,000–1,210,000/ha for agroforests). Diversity of products as well as of production possibilities allows the peasants to distribute their economic risks.

6.2. *Constraints and requirements for improvement*

1. Technical support is not provided for the agroforest as a system. Extension workers deal with cinnamon, nutmeg or coffee as monocultural crops, experiments on improvement or pest eradication are conducted in monocultural stands, and actual plant associations as practised by the peasants are not taken into account. This is also true of the administrative aspects related to garden culture which include mainly taxes on land and produce. Taxes are paid to Forest Services for wood and forest products, export crops are attached to Plantation Services and fruits to the Agricultural Services. This makes for complex management and, above all, a complete misunderstanding of the agroforest system by administrative and technical services. Neither is it of any benefit to the peasants who have to pay different taxes to different services, and sometimes to pay twice for the same product.

2. Pest problems have not yet been solved. In the southern part of the crater where nutmeg and durian are badly attacked by insect pests, and disastrous landslides have also occurred, the peasants believe in global "illness" or "exhaustion" of the land caused by "spirits" and prefer to migrate out of the area.

3. Production levels from the gardens are fairly low. Clonal variations and irregularities in fruiting seasons cause high variability in the production of coffee, nutmeg and durian from year to year. This situation could be rectified by using regular cultivars as well as improved management methods (pruning, cutting, etc.).

4. The peasants have no control over prices for export crops. Trade co-operatives are limited to a few villages and should be promoted to ensure

a better control and provide storage, credit opportunities and power for negotiation with the wholesale dealers in Padang.

5. Animal husbandry is not developed in Maninjau, as in the surrounding areas. Agroforests could provide a good basis for commercial husbandry with cows or buffaloes with regulated grazing or integrated use of ground cover as forage.

6.3. *Extrapolatability*

Agroforests in Maninjau provide a good basis for:

- Modelling efficient buffer zones around protected forests. Interesting practices and strategies of integration of forest resources into the agroforest structure through cultivation of forest species and protection of natural components can be learned from the agroforest in Maninjau.
- Promoting peasant integrated silviculture for timber. The variety of wood species and silvicultural practices could serve as an example for the surrounding area. Forest Services undertake "regreening" programmes near Bukkittinggi, but they often use exotic species, seedlings of which are expensive for the peasant (the . are "government species" for the peasant who is reluctant to plant or protect them). Integrated wood production based on local species would have better changes to succeed and the valuable species can be found in the Maninjau system.
- Growing cash crops under a canopy of useful trees. Peasants in Maninjau have developed successful methods to manage export crops within a complex tree structure. Though they still need to be improved, these methods can serve as a basis for the promotion of commercial agroforests in similar areas. However, the success of the Maninjau agroforestry system is closely linked to a particular social system. Extrapolating this type of agroforest to other areas with different socio-economic backgrounds can be problematic. The influence and impact of the land-tenure system, and traditional laws and customs, have to be thoroughly studied in each case.

6.4. *Research needs*

The present study did not get detailed information on:

- Qualitative and quantitative interactions between plants and soil in the different types of associations;
- Positive and negative effects between associated plants as far as yields or pests are concerned; or

- Precise production data for commercial and subsistence products in different villages, as well as the variability of production during the year and over the years.

In addition to the above, information on the following is also needed:

- Improving the use of the ground layer (by forage plants or valuable crops); Better soil management techniques, especially for soil "rehabilitation" after nutmeg cultivation;
- Use of compost, green manure or nitrogen fixing plants in order to improve yields of export crops; and
- The integrated use of pioneer plants such as *Eupatorium*, *Lantana*, and trees such as *Laportea*, *Pisonia*, that are traditionally known as soil improvers.

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Addendum to Chapter 16

Editor's Note

Although this is the only paper from Indonesia under the "Agroforestry System Description Series" of ICRAF's global inventory of agroforestry systems, there are several other well-known agroforestry systems in Indonesia; for example, the *Talun kebun* or homegardens of Java. Several studies have been reported on the Javanese homegardens and other agroforestry systems of Indonesia. The abstracts of two such descriptions that have appeared in *Agroforestry Systems* are reproduced below with the consent of the authors concerned.

1. Wiersum, K.F. 1982. Tree gardening and taungya in Java: Examples of agroforestry techniques in the humid tropics. *Agroforestry Systems* 1: 53–70.

Tree gardening, or the cultivation of a wide variety of crops in a multiple-storeyed agroforestry system, is an indigenous practice on private lands, while taungya, or the intercropping of young tree plantations with staple crops, is practised on the state forest lands. Both systems are described with regard to their management characteristics and past development as well as possibilities and constraints for further development. These two practices are then compared on the basis of various attributes, like producer group, production purpose, area of cultivation, land-ownership situation, structural organization of crop combinations, possibilities for improved cultivation techniques, and suitability for application in rural development for specific target groups.

2. Torquebiau, E. 1984. Man-made Dipterocarp forest in Sumatra. *Agroforestry Systems* 2: 103–127.

Traditional plantations of *Shorea javanica* in southern Sumatra deserve mention on three main points: (1) it is a rare case in Indonesia of successful cultivation of an indigenous species. This species being a Dipterocarp is an even more attractive reason: Dipterocarps are in the paradoxical situation of being the largest family of timber trees in natural forests of tropical Asia but are almost never used for silvicultural purposes; (2) the tree is grown in association with many other useful trees to constitute an agroforestry system of both cash and subsistence incomes; and (3) such plantations represent a good potential for the production of natural resin in the humid tropics.

17. Food, coffee and casuarina: an agroforestry system from the Papua New Guinea highlands*

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Abstract. The paper describes an agroforestry farming system from the Papua New Guinea highlands (1,400–2,100 m) that has been developed by village farmers since about 1960 and has expanded rapidly since about 1970. Major components of the system are numerous species of annual and perennial food crops (especially bananas), Arabica coffee and *Casuarina oligodon*. This system provides food, a cash crop and timber for construction and fuel. It is likely that returns on labour inputs are very favourable, but no formal assessments have been made. Evaluation of the system as a whole, and research on certain key components (casuarina ecology, banana cultivars, timing of operations), are suggested as high-priority areas for systematic studies.

1. Introduction

Just over a million people live in the central highlands of Papua New Guinea (PNG). Most of these are village dwellers whose major cash crop is Arabica coffee (*Coffea arabica*). These smallholders produce 70–75% of the nation's total production of coffee, which is the major export crop. The majority of new coffee plantings made by smallholders in recent years have been in agroforestry systems that incorporate annual and perennial food crops, coffee and shade species. One such system is described here.

2. General description of the area

PNG, with a land surface area of 464,000 km^2, is located between the equator and 12° S latitude and between 141 and 156° E longitudes. The dominant natural environments are mountains, foothills of less than 1,000 m altitude and peaks to 4,500 m. The central highlands consist of a complex association of mountains and intermontane valleys (Allen 1983).

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The nation lies wholly within the humid tropics and humidity is high everywhere. The main influence on temperatures is altitude and, away from the moderating influence of the ocean, there is a very close and linear relationship between temperatures and altitude. Madang, with mean maximum and minimum temperatures of 30°C and 23°C, is typical of coastal locations. Mount Hagen town (1,700 m) is typical of locations in the intermontane valleys with a mean maximum and minimum temperature of 24°C and 13°C, respectively. Seasonal temperature variations are everywhere small to negligible. Mean annual rainfall varies from 1,000 mm to over 8,000 mm, but most people live in locations which lie within the range of 1,500 to 4,000 mm. Many locations experience a drier period between May and September, but there are variations in this, including a reversal of this pattern in some localities.

Floristically rich and luxuriant rain forests cover over 75% of PNG's land area. The forest types are broadly categorized into five or six sections, based on altitude, floristic composition and physiognomy of the structural forms. They include various vegetation forms of lowland (coastal, mangrove, evergreen, etc.), montane and subalpine types (Kwapena 1983).

The system described here is practised over an estimated 25,000 ha in PNG highlands (Carrad 1982) at an altitude ranging from 1,400 to 2,100 m where the annual rainfall varies from 1,900 to 5,000 mm (mostly between 2,000 and 2,800 mm). The soils on which the system is practised are variable, but typically contain significant amounts of volcanic ash, are high to very high in organic matter (5 to 20%) and are often poorly drained.

Sweet potato (*Ipomoea batatas*) is the staple food of both the people and their most important animal, pigs. Numerous other species are grown as food crops, often in mixed vegetable gardens that do not include sweet potato. It is these mixed vegetable gardens that form the basis of a recently developed food crop/coffee/casuarina system. At these altitudes, firewood for cooking and household heating is an important part of the ecosystem. In many highland areas it is now a scarce resource.

3. Structure of the system

The major species used in the system are numerous annual and perennial food crops, Arabica coffee and *Casuarina oligodon*. *C. oligodon* is a fast-growing woody species that provides shade and timber for fencing, house construction and firewood. Its timber is easy to split and it burns well. The food crops include bananas (*Musa* cvs) (mostly triploid cultivars at these altitudes), taro (*Colocasia esculenta* and *Xanthosoma sagittifolium*), sugarcane (*Saccharum officinarum*), maize (*Zea mays*), highland "pitpit" (*Setaria palmifolia*), *Amaranthus* spp., *Oenanthe javanica*, *Rungia klossii* and others. Other components

which may be present are nut pandanus (*Pandanus julianettii*) at altitudes above 1,800 m and oil pandanus (*Pandanus conoideus*) below 1,700 m. Pigs commonly graze under established coffee/casuarina/banana stands, but they are not a critical component of the system. Cassava (*Manihot esculenta*) is an important component of a similar system used on better drained soils, but not in this system on the wetter soils.

The basic structure of the system is that mixed vegetable gardens are gradually converted into coffee/banana gardens and eventually into coffee/casuarina stands. Figure 17.1 shows the establishment of casuarina and coffee mixed with food crops in an area where some mature casuarina trees already exist. Figure 17.2 shows an established system with 3–4 year-old bearing coffee under the shade of triploid banana and some casuarina. Other agricultural crops are no longer cultivated at this stage.

4. Functional aspects of the system

The first phase is that fallow vegetation is cleared, drains are established and all of the food crops are planted in the mixed vegetable garden. Most plantings are made seasonally towards the end of the drier months (September to December). Coffee seedlings may be transplanted into the gardens when the food crops are planted, but usually they are not planted until the short-term crops, such as the leafy green vegetables, have been harvested. Casuarina seedlings are sometimes transplanted at the same time as coffee, but they may be established up to 12 months after coffee. Seedlings of coffee and casuarina are usually obtained from self-sown plants in older coffee gardens and along alluvial flats, respectively. The food crops are planted in a mixed planting arrangement without regular spacing or species associations. By contrast the coffee and casuarina seedlings are planted in a regular manner that approximates to the recommended spacing (1.5 × 2.5 m for coffee).

The timing of planting of the major components is extremely variable. Shading of young coffee is provided by different species during different periods. Initially it is done by the taller food crops, particularly maize, *Colocasia* taro and sugarcane. Once the bananas are established, they provide an increasing proportion of the coffee's shade needs. About a year after planting, they are the major shade species. After about two years, they are increasingly supplemented by the slower growing casuarina. Bananas and casuarina both provide shade up to 5–7 years, by which time casuarinas are replacing bananas. Depending on altitude, one or two *Pandanus* species may be significant components of the coffee/casuarina stand.

The major input is human labour. The major outputs of the system are the vegetables that supplement the sweet-potato staple, the cash crop (coffee) and eventually timber from casuarina. Productivity and other details of the system are poorly documented.

Fig. 17.1. Young coffee and casuarina seedlings in a mixed planting with food crops (highland "pitpit", *Colocasia* taro, etc.) and some mature casuarina trees (Ambum Valley, 2,000 m).

Fig. 17.2. Young bearing coffee (ca 3–4 years) shaded by triploid bananas and some casuarina. Other food crops have all matured by this stage (Nembi Plateau, 1,700 m).

5. System dynamics

Coffee was promoted as a village cash crop in the highlands from the mid-1940s onwards. The official government recommendation was that short-term shade trees (*Crotalaria micans*, *Tephrosia vogelii*) or permanent shade species (*Casuarina oligodon*, *Leucaena leucocephala* or *Albizia chinensis*) should be established prior to field plantings of coffee seedlings without any interplanting of food crops. The official system was used initially, but from about 1960 onwards the system described here, and other similar ones that incorporated food crops, were developed by the villagers themselves. Their systems expanded so much that by the late 1970s most new coffee plantings by villagers in the highlands were being established in systems similar to this one. The system described here is an extension of the traditional mixed vegetable garden system and it is the most widely practised of the recently developed integrated food/coffee/timber systems.

The overall performance of the system has not been quantified and hence not evaluated. Judging by the system's rapid expansion and widespread adoption, it is much more efficient than the officially promoted method of establishing coffee. Based on theoretical calculations of economic returns from integrated systems in comparison with the coffee/shade system, Carrad (1982) concluded that the integrated one was much superior, especially from planting to year 7.

6. Evaluation

This agroforestry system provides food, cash from coffee and some marketed food, and timber for construction and fuel. It has not been critically evaluated, but based on the author's judgement it is certain that returns on labour inputs would compare very favourably with alternative systems. Because the canopy is maintained continuously by a sequence of faster and slower growing species, the need for weeding is minimized.

The author does not see many major weaknesses in the system for smallholders It is a conservation system in that the soil is protected from the direct action of the elements by continuous vegetative cover. Conversion of land suitable for mixed vegetable gardens into permanent coffee stands may be a problem in those few areas where this land type is limited in extent. Sometimes growers using the system fail to establish a good coffee stand. The reasons for this are not clear. A reasonable level of managerial ability is needed to manage the system, but this is within the capability of most village growers. The level of management may be more difficult to attain when larger plantings are being established in a limited time, for example areas larger than 3 ha.

The system provides significant quantities of perishable food. Because of poorly developed marketing infrastructure in PNG, marketing of this is likely to pose problems for larger growers.

Similar systems have been developed by villagers elsewhere in PNG for other export tree crops, including cacao (Bourke 1976), coconuts (Gallasch 1976), rubber and oil palm. There is wide variation in the details of this and other systems, especially in relation to timing of operations and species used for shade. It is very likely that some growers have refined the system; for example, selection of superior banana cultivars for shade or the timing of transplanting of coffee and casuarina seedlings. Such refinements are likely to have wider applications, at least within the PNG highlands and perhaps elsewhere. *Casuarina oligodon* is restricted to the highlands of the island of New Guinea where it grows between 650 m and 2,700 m (standard deviations for the species' altitudinal limits are 60 m and 55 m, respectively) (Bourke 1984). Casuarina is known to fix atmospheric nitrogen, although the amount is yet to be quantified. The species' useful characteristics and agroforestry potential are widely recognized within PNG (Thiagalingam 1983) and it may have potential as a shade and timber species in other subtropical and tropical highland environments.

7. Research needs

The research needs for this system are numerous and urgent, given that this farming system and similar ones are the most important ones that are used to establish new plantings of PNG's major export crop. There is no published information within PNG on the potential of different food species and patterns of admixture of their species or cultivars to provide shade for coffee as well as to produce food; particularly so for bananas which are a critical component of this system. The timing of the various operations appears to be important, but this has not been formally evaluated. The first priority is to study the system and its variations as presently practised by village growers. Some studies have commenced (Carrad 1981; Hayfield 1982) and these need to be expanded.

Once farmer practices have been documented, innovations and potentially superior techniques need to be evaluated in controlled experiments. The growth pattern, nitrogen-fixing ability and ecological requirements of *Casuarina oligodon* also require immediate study.

Acknowledgements

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18. Dynamics of fallow successions and introduction of robusta coffee in shifting cultivation areas in the lowlands of Papua New Guinea*

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Abstract. The traditional shifting cultivation system in the lowlands of Papua New Guinea consists of mixed food crop gardens in which yams (*Dioscorea* spp.), bananas, taro (*Colocasia esculenta*) and sugarcane predominate. The cropping cycle is usually for 18 months, followed by a fallow cycle of up to 30 years. During the cropping cycle, two species of fruit trees, *Pometia pinnata* and *Artocarpus altilis*, are also planted, with the leaves of the former being used as a mulch and green manure in yam cultivation. Fallow succession follows rather systematic patterns about which farmers have a thorough understanding. Robusta coffee, a cash-crop component, has been added to the system in some areas since the late 1950s. It is usually grown in permanent blocks, but is interplanted with *Leucaena* as shade. Food crops are planted in the establishment stage, bananas and *Xanthosoma* being retained even in mature coffee gardens. The system seems to be a potentially promising one. But very little quantitative information is available on the production and performance of the system and practically no systematic research has been undertaken. Since the Papua New Guinea fallow gardeners are willing to accept innovations, it will be appropriate and timely to undertake serious studies so that the system can be improved. A few items that merit immediate research attention are indicated.

1. Introduction

Systems of shifting cultivation have long been characterized as "primitive" and resource depleting. In situations where national and multinational timber companies come into competition for forest resources with shifting cultivators, it is common to hear arguments that these primitive forms of land use should be replaced by permanent cultivation and the use of fertilizers and high-yielding introduced plant varieties. However, recent interest in agroforestry and sustainable systems of agriculture is giving support to arguments presented in

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the 1970s that many forms of shifting cultivation are viable systems of land use and are critically important in the context of increasing dependence of high inputs in modern agricultural systems (Clarke 1976; CSIRO 1972; Grandstaff 1978). Systems of shifting cultivation too are vulnerable to changes such as a shortening of the fallow period where a grass fallow replaces a tree fallow. It is in this context that the concepts of agroforestry and the development of viable, sustainable tropical agroforestry systems have much to offer towards the improvement of systems of shifting agriculture. The agroforestry system described here is such a traditional system of shifting agriculture, with a recently added tree-crop component. A similar situation involving open-field cultivation of food crops, coffee and *Casuarina oligodon* has been described recently from the highlands of Papua New Guinea (PNG) (Bourke 1985).

2. General description of area

A general description of PNG in relation to agroforestry has recently been given by Bourke (1985). Approximately one-quarter of the forested area of PNG is well developed secondary forest, created and maintained by shifting cultivation (Paijmans 1976). The system being described here is located on the southern fall of the north-western coastal mountains, which run north-west and south-east and separate a narrow coastal plain to the north from the basin of the Sepik River, the second largest in the country, to the south.

The foothills of the coastal ranges are Pliocene mudstones interbedded with siltstones and sandstones, gently dipping to the south, which have been eroded into strongly slumped, polygonally branching hill ridges. The original lowland hill forest has been replaced with secondary vegetation ranging from gardens under cultivation, village coffee plantations, fallow garden regrowth (tall cane grass to tall secondary forest) to relatively undisturbed forest. Soils are brown forest soils, shallow dark clay soils, reddish clay soils (Eutropepts) and strongly weathered red and brown clay soils (Dystropepts), the latter two being widespread over similar hill country in PNG (Bleeker 1983).

Mean annual rainfall increases along the ranges from west to east and is less seasonal in the west. For the station nearest the site under description, mean annual rainfall has been 2,159 mm (12 years of record). May to September is notably drier than November to March. Mean daily temperatures are 26°C (mean max. 29.9 C, mean min. 22.2 C).

All land-use systems in the region are a variation of a forest fallow system of shifting cultivation. To the east, fallow regrowth has been reduced to tall cane grass and scattered low tree species as a result of higher populations, lower total rainfall and greater seasonality, whereas to the west, gardens are cleared from well developed secondary forest. The system falls into two fairly discrete parts: mixed food-crop gardens, which are cleared from forest each

year, cultivated for a maximum of 18 months, and then fallowed for up to 30 years; and permanent blocks of robusta coffee, from which almost all cash income is produced. Some land has been cleared of all forest and sown to pasture grasses for cattle, but in almost all cases attempts at cattle farming have failed. Pigs are the traditional livestock. Most pigs are now Papua New Guinea-European crossbreeds. Sows are allowed to roam in the forest and in fallow garden areas where they mate with feral boars.

3. Structure of the system

Land is cleared of fallow vegetation using axes and machettes and the debris burned at the end of the dry period. Planting then takes place at the beginning of the wet period. The cultivated plots, known as "gardens", consist of mixed crop stands in which yams (*Dioscorea* spp.), banana (*Musa* spp.), taro (*Colocasia esculenta*), and sugarcane (*Saccharum officinarum*) predominate, but in which at least 27 other species are also cultivated (Table 18.1). During the cultivation period seedlings of two tree species, *Pometia pinnata* and bread-fruit (*Artocarpus altilis*), are planted and they form "orchards" along the upper margins of ridges used most often for gardening. Sago palms (*Metroxylon sagu*), coconuts (*Cocos nucifera*) and *Gnetum gnemon* are the other tree species which are grown from seed.

Between 1942 and 1945 Japanese and Allied armies fought across this area with consequent severe disruption to village life. After the war many people experimented with radical changes to traditional life. One experiment involved the cultivation of hill rice for sale as a cash crop. But the venture failed because of poor processing and marketing facilities. In the late 1950s the government introduced robusta coffee as a cash crop, recommending that each family plant 500 trees in bush gardens, shaded with *Leucaena*.

Coffee has been widely adopted, but the average size of coffee gardens is small, consisting of between 150 and 250 trees. It is, however, almost the only source of monetary income in the area, apart from government or mission salaried employment. Coffee gardens and food gardens are located on discrete sites. However, when forest is cleared for coffee, food crops are commonly planted during the *Leucaena* establishment stage, and when the garden is fully established bananas and *Xanthosoma* are often found amongst the coffee trees. At present coffee gardens are stable with little replanting or expansion. It is probable, however, that some people will shortly expand coffee planting onto 20 ha "communal" gardens.

Food gardens fall into three categories. The first garden planted following forest clearing is the most important and contains a restricted number of species. Yams planted in these gardens provide tubers used in ceremonies and exchanges and the gardens have many ritual restrictions. After the first

Table 18.1. Cultivated and non-cultivated food crops in the mixed crop gardens.

Family	Botanical name	
Acanthacae	*Graptophyllum pictum*	
Amaranthaceae	*Amaranthus* sp.*	
	Amaranthus tricolor	
	Deeringia polysperma	
Anacardiaceae	*Mangifera indica***	
Araceae	*Alocasia macrorrhiza***	
	Colocasia esculenta	(11 cultivars)
	Xanthosoma saggittifolium	
Bromeliaceae	*Ananas comosus**	(2 cultivars)
Burseraceae	*Canarium* sp.	
Caricaceae	*Carica papaya**	
Convolvulaceae	*Ipomoea batatas**	
Cruciferae	*Brassica chinensis**	
	Nasturtium homalospermum	(2 cultivars)
Cucurbitaceae	*Citrullus vulgaris**	
	Cucumis sativus	
	Cucurbita moschata	
	Lagenaria siceraria	
	Trichosanthes anguina	
Dioscoreaceae	*Dioscorea alata*	(22 cultivars)
	D. bulbifera	
	D. esculenta	(43 cultivars)
Euphorbiaceae	*Manihot esculenta**	
Gnetaceae	*Gnetum gnemon*	(2 cultivars)
Graminae	*Saccharum edule*	(14 cultivars)
	Saccharum officinarum	(9 cultivars)
	Zea mays	
Leguminosae	*Arachis hypogaea**	
	*Phaseolus vulgaris**	
	Psophocarpus tetragonolobus	(2 cultivars)
Alliaceae	*Allium cepa*	
Malvaceae	*Abelmoschus manihot*	
	A. moschatus	(2 cultivars)
Moraceae	*Artocarpus altilis*	(3 cultivars)
	Ficus copiosa	
Musaceae	*Musa* cvs.	(26 cultivars)
Myrtaceae	*Eugenia malaccensis**	
Oxalidaceae	*Averrhoa carambola**	
Palmae	*Areca catechu**	(2 cultivars)
	Cocos nucifera	(2 cultivars)
	Metroxylon sagu	
Piperaceae	*Piper betle*	
Rutaceae	*Citrus sinensis**	
Sapindaceae	*Pometia pinnata*	(2 cultivars)
Solanaceae	*Capsicum frutescens**	
	*Lycopersicon esculentum**	

* Introduced since c. 1900.

** Cultivated outside of gardens.

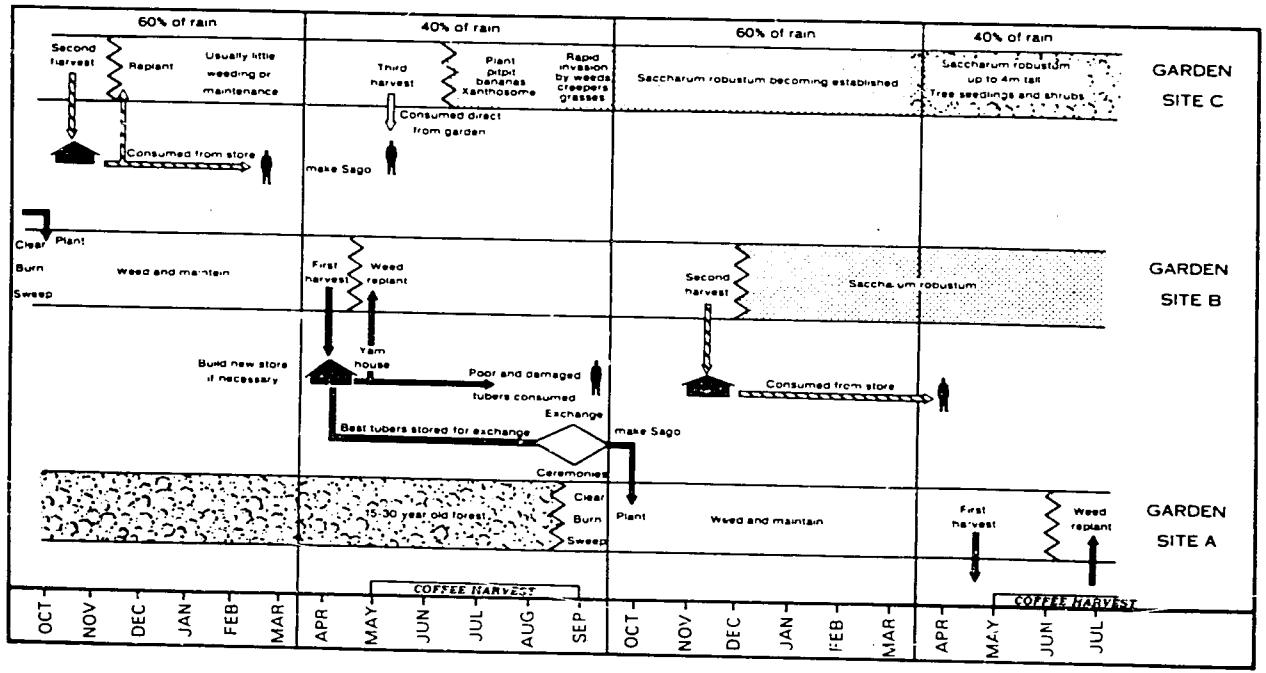

Fig. 18.1. The sequence of garden-site clearing, planting and harvesting and natural regrowth.

harvest, yams are replanted almost immediately in the holes left by the first crop. Thereafter fewer restrictions apply and more introduced species are planted. A third yam crop is sometimes planted following the second harvest, but this is a less common practice because it involves a greater effort in weeding. After the last planting has been harvested the garden is allowed to return to fallow. But even in the fallow period the land continues to produce food crops such as bananas, *Xanthosoma* and sugarcane which can compete with the invading tall cane grasses for some years.

The general arrangement of the system is shown in Fig. 18.1. Garden Site A is the newly cleared garden, B the replanted garden and C the less common third planting. After the garden site is allowed back into fallow it is rapidly invaded by weeds and short grasses, dominated by *Imperata*. Within a year the short grasses will be shaded out by the tall cane grasses, dominated by *Saccharum robustum*. This is an important succession providing cool, damp,

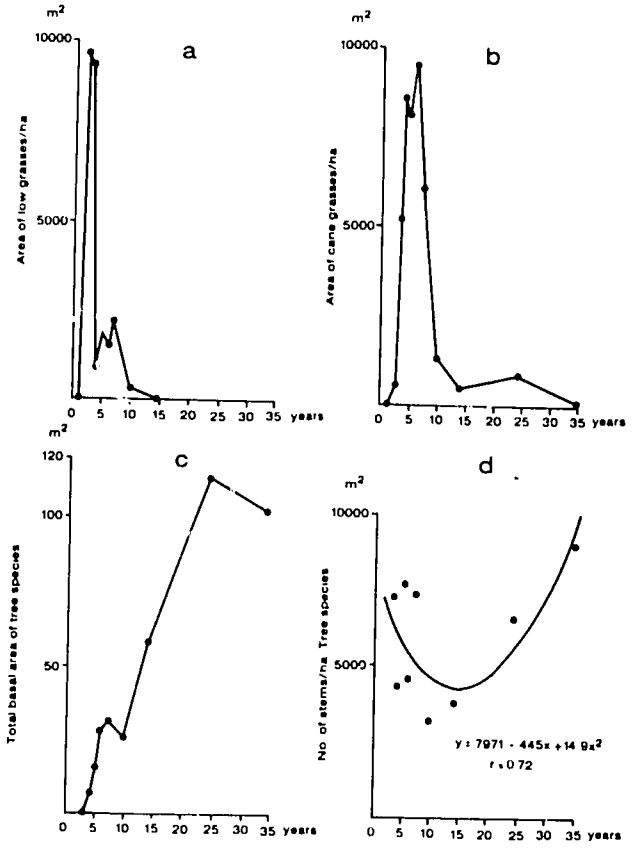

Fig. 18.2. The pattern of regrowth of fallow garden sites: (a) area of low grasses (mainly *Imperata*) per ha; (b) area of cane grasses (mainly *Saccharum*) per ha; (c) total basal area of tree species per ha; (d) number of stems of tree species per ha. The horizontal axis in each figure represents the number of years since clearing.

dark conditions for seedlings, particularly during the drier part of the year. After about 12 years tree successions begin to shade out the cane grasses and 25 years after clearing a 10–15 m tree succession becomes established. The pattern of species succession in fallow regrowth is given in Figs. 18.2 and 18.3. New gardens are cleared in 15–25-year-old fallows, with land nearer the village cultivated more often than land farther away. Fallow successions are categorized by type, not by time: fallows ready for re-cultivation are known as "ripe" fallows. Farmers avoid letting fallows go beyond the "mature" stage because of the dangers involved in felling tall forest. Yam gardens are established along the upper slopes of ridges. Many coffee gardens are also found in these locations as a result of the extension advice to farmers to plant the introduced crop on their "best" land.

A particularly interesting aspect of the system is the use of *Pometia pinnata* leaves during yam planting. The *Pometia* is a large handsome tree, related to the litchi and with similar fruit. The fruits are borne on the ends of the branches between November and February. Harvesting is accomplished by climbing and lopping off fruit-bearing branches. Later, during yam planting, the then dry leaves are collected by women, carried to the gardens in large bundles and applied into the ground with the "seed" yams. Gardeners believe that the leaves "give the tubers room to grow", but the leaves, rich in nitrogen, provide a good mulch in addition to their nutrient value. The regular cutting back of the trees appears to have an effect similar to pruning and stimulates fruiting. Figure 18.4 illustrates the method used to carry *Pometia* leaves, and Fig. 18.5 shows bundles of leaves in a new garden.

4. Functional aspects of the system

Almost all inputs into the system come from within the village community. Land is occupied under laws which guarantee rights to customary owners and access to land is controlled by the leaders of extended families. Inheritance of land rights is normally from father to son, but daughters, particularly widows, have no difficulty in obtaining land for food crops. Many food gardens are cultivated on a usufructory basis and land which is not being cultivated is open to all village residents for collecting fuelwood and building materials or for hunting. Land for coffee is more restricted, and some families have coffee gardens at a distance from the village. However, most people build a substantial "garden" house in which they live while they work in gardens or coffee blocks away from the main village.

Most families clear land for gardens in co-operation with up to 15 other families. Once the heavy tasks of clearing and burning are completed, each family becomes responsible for its own individual block. Coffee blocks are established in a similar way. A very small amount of paid labour is employed

A
B

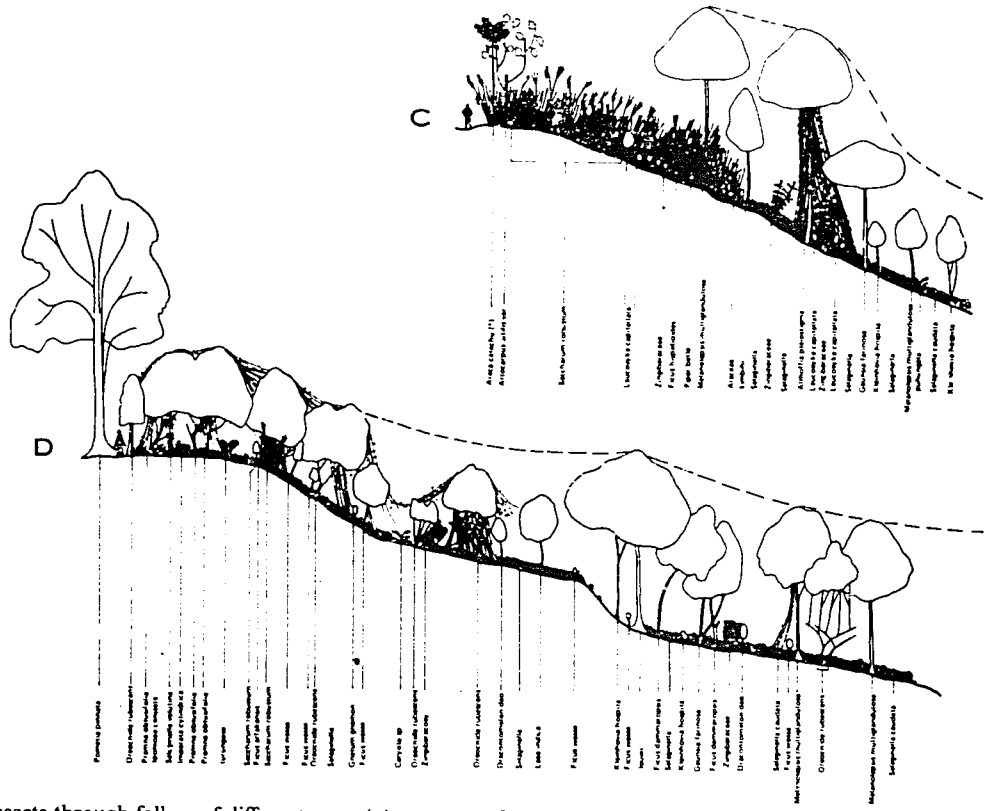

Fig. 18.3. Cross-sectional transects through fallow of different ages: (a) one-year after clearing and planting – the right-hand slope has been weeded and replanted for a third time, the left has been allowed to go back into fallow; (b) a five-year-old fallow – tall cane grass and fast-growing softwood tree species dominate, but some food crops still remain; (c) ten-year-old fallow – on the lower, moister slope tree species have shaded out the cane grass, which remain dominant on the upper slope; (d) 25-year-old fallow – all cane grass has now been shaded out and the first tree species are being succeeded by slower growing trees. The large *Pometia* has been planted during some previous cultivation. The site is ready for re-cultivation.

Fig. 18.4. Large bundles of dry *Pometia* leaves are collected together and carried to the new yam gardens by women, to be used by their husbands in planting the yam crop. Bundles commonly weigh over 40 kg.

in coffee gardens, usually small bands of youths or unmarried girls raising money for such social activities as a sports club or a youth club. During the introduction of coffee, government nurseries were established, but now people raise coffee seedlings themselves from established trees.

Productivity measurement in mixed gardens of this nature is very difficult. Yields of individual species are highly variable within and between sites. Harvesting of some species occurs within a restricted time, while others are harvested continuously over the life of the garden. Yield estimates of the most important crop, *Dioscorea*, range from 10 to 20 t ha^{-1} for *D. esculenta* and 16 t ha^{-1} for *D. alata*. When rice was grown, yields ranged from 0.45 to 2.8 t ha^{-1}, and coffee yields are around 250 g of dried parchment per tree, or about 115–120 t ha^{-1}. The average price for dry parchment at the "farm gate" for 1982 was 0.55 kina per kg (1 kina = US$ 1.2). Thus coffee provided the average family with a cash income of around US $ 60 in 1982.

Fig. 18.5. A newly cleared yam garden during planting. Seed tubers have been laid out near holes prepared for them and bundles of *Pometia* are ready for use. The trees which previously covered the site have been pollarded and killed by burning, but are not felled. The surface of the garden has been swept of ash and debris but otherwise is undisturbed.

Production of the yam staple is markedly seasonal, but other crops such as sugarcane, taro and bananas are less seasonal. Coffee production occurs mainly between May and September (Fig. 18.1). Variability from year to year is low and is dependent on rainfall as well as social demands. Production is increased to meet the requirements of large ceremonies, with planning occurring some years ahead to build up planting materials and to select sites which are known to produce good yam harvests.

All coffee production is for sale for cash and marketing is done through a regional co-operative society which is involved solely in coffee marketing. Small amounts of food are sold in a bi-weekly market on a nearby government station where the main buyers are government employees.

An important feature of the system is that ground cover is maintained almost permanently, except for a short period between clearing and the development of the crops. Even during clearing and planting, the surface is disturbed as little as possible. Large trees are not felled but are pollarded and the bases burned to prevent regrowth. Smaller trees, in particular some of the *Ficus* species, do regrow and help speed the recovery of a tree cover. Branches from the taller trees are cut up and stacked for fuelwood and only the leaves are burned.

The proportion as well as the spatial arrangement of cleared land in relation to land in regrowth/secondary forest is such that erosion does not occur on a

large scale. Poles are laid along the contour, supported by pegs, to reduce surface run-off, and yams are planted in individual holes up-slope from the barrier. Other crops are spaced amongst the yams, also across the slope. However, much backward rotational slumping occurs in the area and many gardens are deliberately sited on slumps to take advantage of the recent soils found there. Thus small slumps within gardens are not uncommon. On the other hand, some gardens are sited on slopes over 30 degrees and little soil movement occurs.

Men and women share the labour of food and cash-crop production relatively equally. Men carry out the heavier tasks of clearing while women sweep and arrange slash material for burning. Customarily, women may not cultivate the soil with digging sticks or spades in the first yam garden, so men plant most of the yam crop, taro, sugarcane and bananas. Women plant restricted varieties of yams in piles of ash above the ground surface, and greens. Women do most of the weeding, while men attend to the other aspects of crop management such as tying up vines and covering exposed tubers with soils. The first yam crop is harvested by men, but after that restrictions on women harvesting the crop are somewhat relaxed. Both sexes pick, process and sell coffee. Children also help with garden work. The major bottleneck in coffee production is the processing of the cherry to parchment.

5. System dynamics

The food production system is a very old one. Recent changes, in particular the introduction of malaria-control programmes and modern medicines, have contributed to a decline in infant mortality, and that, coupled with a relaxation of customary restrictions on sexual activity, has resulted in an increase in population. Emigration has helped reduce the rate of increase in resident populations, but in areas with greater seasonality and population pressure, the system is degrading from forest fallows to cane-grass fallows. The introduction of steel tools and implements has reduced the amount of labour required and allowed larger trees to be cleared.

The coffee production system is only 30 years old. It involves a tree cover and maintains sustained production without outside inputs such as fertilizers. However, most blocks are underexploited, probably because of lack of incentives for higher production and the high labour costs of processing. Investigations are under way into the possibilities of producing either wet cherry or dried cherry to encourage greater production. Meanwhile, most people produce at a level which just satisfies their day-to-day cash requirements for improved foodstuffs, local taxes and school fees.

6. Evaluation

The system provides almost all the food and immediate cash requirements of the household and involves practically no external inputs. However, it is vulnerable to any changes which bring about a shortening of the fallow period to the point where a grass fallow replaces a tree fallow. Robusta coffee, a new tree crop in the locality, has been very quickly and successfully adapted to the system. But there is, at present, a serious gap in knowledge of the requirements of the individual crops, the relationships between the fallow vegetation communities and soil conditions, so that sound advice cannot be given on methods of avoiding degradation of the tree cover in areas where the fallow period is being shortened, and on other aspects of management of the system. The PNG shifting cultivators have a deep knowledge of the fallow succession characteristics, and they are willing to accept innovations if sufficient incentives are provided. This strength of the farmer is a major aspect which should be built upon in any attempt to improve the system.

Similar systems exist in many parts of lowland and mid-altitude PNG, and results and experience of one system could, within limits, be extrapolated to others. Critical site factors influencing the stability of the system are rainfall and, to some extent, altitude, which determine the rate of growth of successional tree species and thus the vulnerability of the system to degradation.

It is essential that research be undertaken urgently with a view to providing appropriate guidance to improve the system and enable the farmers to attain optimal productivity on a sustained basis. Some studies that have been carried out in the mid-altitude localities of the country (Manner 1977; Clarke 1971) are of significance in this context. Similarly, in the immediate area of the system described here, land-evaluation studies have been undertaken by CSIRO of Australia (CSIRO 1972; Heyligers 1968). Some other studies on a country-wide basis are also under way (McAlpine and Keig 1982). Areas on which research needs to be intensified on a priority basis include:

- The pattern and dynamics of grass and tree succession following cultivation;
- The conditions which each succession provides for the development of the following succession;
- The relationship between the succession communities and soil fertility;
- The effect of intervention in natural succession (through shortening of fallow cycles, introduction of new species, and so on) on the sustainability of the system;
- The agronomic requirements of individual crops for optimal production in the system.

Acknowledgements

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19. Agroforestry in the South Pacific region: an overview*

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Abstract. The developing countries of the Pacific Region consist of 27 countries and territories with a total land area of 542,000 km^2 and over 5 million inhabitants. Though highly variable in physical characteristics and land-use pattern, in general these countries give higher priority to production of export crops than other agricultural crops, so that they are net importers of food. Natural forests of the region are luxuriant and floristically rich, but the level of commercial exploitation is low. Swidden cultivation is the mainstay of the subsistence livelihood, but with an increase in population the system is now causing severe environmental and land-use problems.

The major agroforestry systems and practices in the region include various combinations of tree crops such as coffee, coconut and cacao with nitrogen-fixing trees such as casuarina, gliricidia and leucaena, and food crops (mostly tubers) such as cassava, taro, sweet potato and yams. Additionally, some improvements to swidden (shifting) cultivation are also being tried in several places, the most common being the use of *Casuarina oligodon* before abandoning the swidden, as in the PNG highlands, and intercropping food crops in tree-crop stands.

The land-tenure system in most of the countries is the traditional one of extended family control over land. This can have either a positive or negative influence on the adoption of agroforestry practices depending on the extent and duration of the tenure enjoyed by the assignees.

Several governments of the region are now promoting the agroforestry approach. In hilly areas with poor access, farmers are forced to produce most of their basic necessities locally. On the other hand, the lack of roads and communication facilities can pose a problem in marketing surplus products.

The immediate opportunity in agroforestry in the region lies in making better use of the unexplored potential of a large number of locally available trees and agricultural crops. Intercropping in tree crop stands and the taungya system seem to be promising methods for the Pacific region.

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1. Introduction

The Pacific Countries and Territories (PCT) consist of a group of 31 countries and territories lying between 130° east and 110° west longitude and 50° south and 50° north latitudes, having a total land area of 8,445,000 sq km (Fig. 19.1). With the exception of Australia, Japan, New Zealand and Hawaii State of the USA, all countries of PCT are classified as developing countries.

These developing countries have a total land area of 542,000 sq km and over 5 million inhabitants. The focus of this paper is on these developing countries of PCT, which will collectively be referred to also as the Pacific Region.

1.1. *Environment*

These countries and territories are a group of islands varying in area from 464,000 sq km (Papua New Guinea) to 10 sq km (Tokelau). In general, they have tropical climates that are highly influenced by the ocean. Some of the islands, especially Cook Islands, Fiji and Tonga, lie within the hurricane zone and are affected by two to three severe storms a year. Although direct hits by tropical cyclones are less probable, they are affected by high winds and wave damage (Hamnett and Franco 1982). Mean annual rainfall varies from 1,000 mm (for example, in Noumea, New Caledonia) to about 3,500 mm for example in Truk, Micronesia). There are also places receiving as much as 8,000 mm per annum, as in Lae, Papua New Guinea (PNG). Most places are characterized by hot (23–35°C) and humid (relative humidity above 80%) climatic conditions with little seasonal variation. But there are also hilly and mountainous highlands with a complex structure of mountains and inter-montane valleys, as for example, in the central higlands of PNG.

1.2. *Population*

On the whole, the annual growth rate of population in the Pacific Region (excluding the developed countries) for the period 1974–1979 was 2.5%. However, the population densities are generally low. Even in countries with over 2% population growth per annum (e.g., French Polynesia, New Caledonia, Norfolk Island, Solomon Islands, Vanuatu) the population density is low (less than 50 persons/sq km). Tuvalu is an exception where both population growth rate (2.5% per annum) and population density (233 persons/sq km) are high. At the other extreme, there are some units where there has been net negative population growth (e.g., Cook Islands, Niue, Tekelau), which is attributable to out-migration.

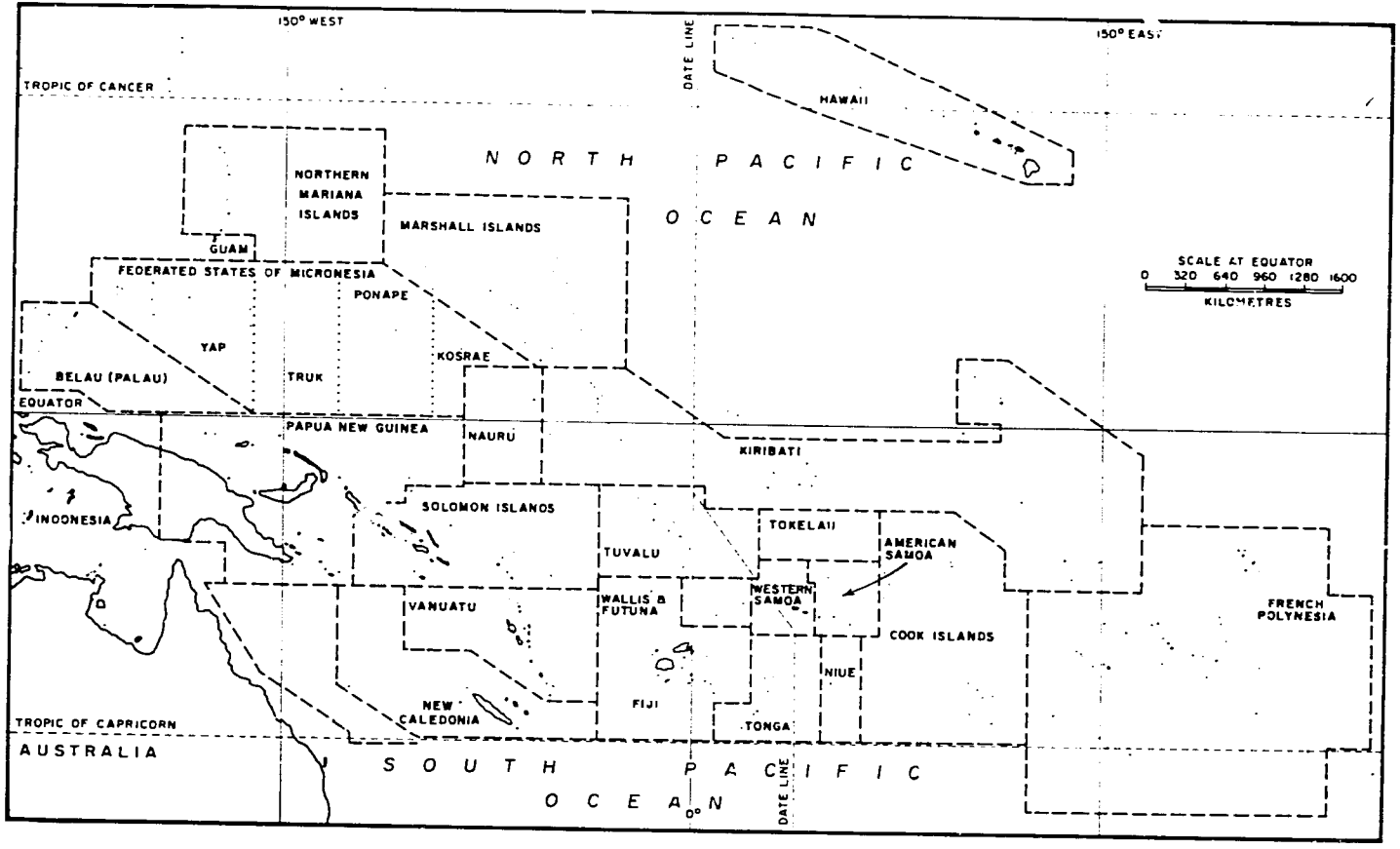

Fig. 19.1. A map of the South Pacific region.

1.3. *Land resources*

Land-resource statistics are reported in various ways by individual countries and territories according to their historical background and socio-economic conditions. The figures compiled and reported by FAO (1981) indicate that there are great variations in the pattern of land use in different units of PCT. Units with a high proportion of land under cultivation include Niue (61.5% cultivated land) and Tonga (23.9%), whereas some have relatively high percentages of land under permanent crops, e.g., American Samoa (20%), Cook Islands (21.7%), French Polynesia (19.1%), Tonga (55.2%) and Western Samoa (23.2%), Several of the PCT also have high percentages of land under natural forests.

2. Land-use systems

In addition to agriculture and forestry, under which all biological land-use systems are commonly described, separate treatment will be given in this paper to shifting cultivation. Prominent and promising agroforestry systems will be identified and briefly described in a later section.

2.1. *Agriculture*

As a consequence of the history of colonization in the PCT, there has been an emphasis on the production of export crops such as sugarcane, oil palm, coconut, coffee and cacao. There has also been some interest in some countries on minor export crops like bananas, ginger, citrus, various other fruits and vanilla. Therefore, the best agricultural lands, as well as the main agricultural activities, are devoted to these crops. These export crops, especially coconut (most of the copra is produced from natural stands of coconuts), form an important component of the economy of all the countries (Yang 1979). The PCT accounted for over 7% of the total world production of about 4.5 million tons of copra in 1977 (FAO 1979).

Root crops are the main subsistence crops for home consumption throughout the region. The main root crops, in order of general preference by the local population, are taro (*Colocasia esculenta* and *Xanthosoma sagittifolium*), yams (*Dioscorea* spp.), sweet potato (*Ipomoea batatas*), and cassava (*Manihot esculenta*). Other food crops include sugarcane, maize (*Zea mays*), highland "pitpit" (*Setaria palmifolia*), *Amaranthus* sp., bananas and fruits (see Richardson 1983 and Dahl 1980 for details).

There are three types of primary agricultural production system in the PCT, namely, subsistence food crop systems, mixed subsistence and cash-crop

systems, and plantation-crop production systems. Subsistence-crop production is the major activity of a large number of people in most of the PCT, for example 85% of the estimated labour force of 1.25 million in PNG and over 50% in W. Samoa. These activities are, however, undertaken with other income-generating activities except in very remote areas such as the atolls of Polynesia or the very inaccessible highlands of PNG.

Among the PCT, American Samoa, Cook Islands, Tonga and W. Samoa are net importers of food. Between 1972 and 1974, Fiji, PNG, and W. Samoa used imported food to meet 76, 96 and 99.7%, respectively, of the food energy needs of their people; the corresponding figures of dependence on imported food for protein needs were 82.3, 96.9, and 100% in these three countries (Yang 1979). The situation has not changed for the better since then, and according to FAO's agricultural commodity projections for 1975–1985 (FAO 1979), these countries' dependence on food imports is unlikely to be corrected in the near future.

2.2. *Forestry*

As indicated earlier, floristically rich and luxuriant tropical forests exist in several PCT countries. These include American Samoa (50%), Fiji Islands (64.8%), French Polynesia (31.4%), New Caledonia (51.2%), PNG (71.3%), Solomon Islands (93%), and W. Samoa (47.4%). Depending on the environmental conditions, the forest types vary considerably: the variation is so great that the International Union for Conservation of Nature and Natural Resources (IUCN) has recognized as many as 19 biogeographical provinces (IUCN 1982). The main forest types include tropical rain forests (lowland, montane/submontane), bamboo, riverine and swamp/bog (mangrove) and woodlands and scrubs. Available information on forestry from the region is mostly qualitative (Dahl 1980).

Commercial exploitation of forests in the region has been relatively low because of the following factors: (a) extractable saw-log volume is low (around 50 m^3 per hectare) compared to South-East Asia and is less attractive to investors, (b) harvestable volume is spread over a great number of species, many of which are not known in the world markets.

2.3. *Shifting cultivation*

Shifting cultivation or slash-and-burn agriculture is practised widely in the South Pacific and is the mainstay of subsistence farming in the island nations. Like similar systems in Asia, this traditional form of agroforestry, usually known as swidden cultivation, involves cutting down the forest vegetation,

burning the sun-dried biomass to clear the area of debris and return the nutrients to the soil, planting food crops until the productivity is depleted in one to three years, and moving to a new site to repeat the cycle. Meanwhile, the "abandoned" site goes through the natural vegetative succession and returns to a forest fallow which rejuvenates and prepares it for the next round of swiddening (cropping).

Pacific swiddeners often reside in more-or-less stable communities but rotate the fields within their customarily owned lands during the cut-burn-crop-fallow process. Depending on the population density, fallow periods may last up to 25 years. In heavily populated areas like Fiji or the PNG highlands, cases of fallows of less than 10 years have been observed.

As indicated earlier, the most important food plants cultivated in Pacific swiddens are root crops such as taro, yams sweet potato and cassava. In some instances maize and rice are also grown. Farmers also often grow bananas, papaya and other non-woody perennials for food.

On steep hillsides, swiddens are abandoned when erosion has degraded the soil and has reduced its productivity to non-profitable and non-sustainable levels, or when weeds have become unmanageable under manual tillage techniques. The weeds, including grasses, will eventually be suppressed and eradicated by the ensuing forest fallow. In many cases, however, frequent burning of the grass has prevented the re-emergence of trees in the natural vegetative succession. Thus, the extent of anthropogenic grasslands has increased considerably. for example, in the PNG highlands, low hills of the Solomons, and in the interior hills of Fiji, Tonga and Western Samoa. Where cattle production is undertaken, such as in Fiji and the Solomons, these grasslands may be of some use as pastures. In the PNG highlands, however, where pigs rather than cattle are the preferred livestock, these expanding grasslands represent wasted areas withdrawn from productive uses. The only possible way to restore them to productive status seems to be through costly establishment of man-made forests by governmental efforts.

In at least one case, i.e., in the highlands of PNG, hill farmers intervene in the re-establishment of fallows by planting *Casuarina oligodon* in swiddens prior to abandoning them (Bourke 1985; Thiagalingam 1983). This is a significant departure from the traditional practice of depending entirely on natural vegetative succession for the creation of forest fallows that rejuvenate depleted farms. This practice not only assures the early emergence of forest in the fallow phase of the cycle, but also enables desirable species, such as the N-fixing *Casuarina*, to be introduced to the degraded site to hasten rehabilitation.

In some areas, increasing pressures have caused progressive reduction of the length of fallows to periods that are insufficient to restore the productivity of degraded swidden so that the once-admired sustainability of long-fallow

swiddens is gradually being lost. Thus, shifting cultivation is perceived today by many land-use planners and administrators as being destructive both in terms of the forest resources destroyed in the slash-and-burn process, and of the soil degradation that occurs subsequently. As a consequence, in many of the Pacific countries, as in other tropical nations, "anti-shifting-cultivation policies" are being formulated.

3. Agroforestry systems

The status of agroforestry systems as practised in the Pacific region has recently been reviewed and summarized in a workshop on the "Role of Agroforestry in the Pacific" in Suva, Fiji, in December 1983 (Schirmer 1984). The situation reports presented by the workshop participants indicate that some forms of agroforestry exist in almost all countries of the Pacific region. Although there are some broad similarities among the countries with respect to their agroforestry situations, there are also many differences among them consequent to the variations in the physical, socio-economic, land-use and other factors. Table 19.1, based on available information and the authors' field visits, gives a summary of the major agroforestry systems/practices that exist in the Pacific region. Some of these promising systems and practices are described briefly here.

3.1. *Casuarina, coffee and food-production systems*

This agroforestry farming system developed by village growers in the highlands of PNG since about 1960 is one of the most promising AF systems in the Pacific region. Currently the system is practised over an estimated 25,000 ha in the PNG highlands at an altitudinal range of 1,400–2,100 m where the annual rainfall varies from 1,900 to 5,000 mm (mostly between 2,000 and 2,500 mm).

The major species used are the numerous annual and perennial food crops, Arabica coffee, and *Casuarina oligodon*. Sweet potato is the staple food of both the people and their most important animal, the pig. *Casuarina oligodon* is a fast-growing nitrogen-fixing woody species that provides shade and timber for fencing, house construction and fuelwood. Figure 19.2 shows a stand of the system. See Bourke's description (1985) (Chapter 17) for a detailed account of the structural and functional aspects of this system.

The overall performance of the system has not been quantified and hence not evaluated in quantitative terms. Based on theoretical calculations of economic returns, Carrad (1982) concluded that this system was far superior to the coffee/shade system, especially from planting to year seven. Bourke

Table 19.1. An overview of the major agroforestry systems and practices in the Pacific islands.

System/practice	Country/territory	Major components		
		Woody	Herbaceous	Livestock
Agrisilvicultural				
1. Improvements to shifting cultivation	Several countries, notably Papua New Guinea, Solomons	Various fruit trees, e.g. *Incarpus edulis*, *Morus nigra*, *Spondias dulce*	Common subsistence crops (tubers, cereals, banana, vegetables etc.), sweet potato and other tuber food crops, yams	
(a) Introduction of tree species in the fallow phase				
(b) Intercropping in tree stands	e.g., Papua New Guinea, Solomons, W. Samoa	*Leucaena* *Gliricidia* + cacao *Erythrina*		
2. Crop combinations with plantation crops	PNG highlands, Solomons and other places	Cacao and coconut and/ coffee in association with *Casuarina oligodon*, *Gliricidia*, *Leucaena*, etc.	Subsistence food crops	
(a) Integrated production of plantation crops in mixed, dense associations				
(b) Shade trees for commercial plantation crops	Many countries of the region	*Casuarina*, *Leucaena*, *Gliricidia*		
(c) Intercropping in stands of plantation crops	Fiji, PNG, Tonga, Vanuatu, W. Samoa	Coconut, coffee	Various food crops, banana, papayas, sugarcane, etc.	
Silvopastoral				
Cattle under trees (CUT)	Fiji, Kiribati, Solomons, Tonga, W. Samoa, Vanuatu	Coconuts	Various pasture grasses	Cattle, goats
	Solomons Vanuatu W. Samoa	*Cordia alliodora* *Eucalyptus deglupta* *Swetania macrophylla*	Various pasture grasses	Cattle
Agrosilvopastoral				
Homegardens (tree-crop-livestock mix around homestead)	PNG highlands, Fiji	Various trees such as *Casuarina oligodon*, coconut, other plantation crops, several local species	A large number of subsistence crops	Pigs, cattle, poultry

Fig. 19.2. Casuarina oligodon + coffee in the highlands of Papua New Guinea (Photo: P.K.R. Nair).

(1985) highlighted the various merits of the system such as production of food, cash from coffee and some marketable food, and timber for construction and fuel. Because the canopy is maintained continuously by a sequence of faster and slower growing species, the requirement for weeding is also minimized. Above all, *Casuarina* is known to fix atmospheric nitrogen which then contributes to the nitrogen economy of the system.

3.2. *Coconut, cacao and food-production system*

In the coastal plains the ubiquitous perennial crop is coconut, the basis of the copra trade during the colonial, pre-World War II era. With spacing varying from 8 to 10 m between palms, other useful species are grown between and under the palms. For example, intercropping cacao among coconuts has become a promising practice in New Britain and New Ireland of Papua New Guinea after the War. Certain sections, but not all of the farms, often contain a third element: root crops such as sweet potato, cassava or taro for supply of staple food.

In farms where the introduction of cacao in existing coconut plantations arose from a late recognition of the potential of the wide and unutilized interspaces between the palms, the coconuts were of fully fruit-bearing age (around 30 years) at the time of intercropping. However, new plantations involve the simultaneous planting of coconut and cacao (and, sometimes, root crops). Market-oriented farms owned by expatriate entrepreneurs generally raise only coconut and cacao as cash crops, while small farms owned by indigenous farmers are more oriented towards domestic use and include an appreciable food-cropping element.

Fig. 19.3. Leucaena leucocephala + coffee, sometimes under coconuts, in Western Province, Solomon Islands (Photo: P.K.R. Nair).

3.3. *Coconut, legume-tree, cacao production systems*

A variant of the above mentioned coconut-cacao-food-crop system is a three-tiered all-perennial combination that excludes the annual food component, the third perennial component being a legume tree species: *Leucaena leucocephala* in Papua New Guinea and *Gliricidia sepium* in the Solomons. The major functions of the legume trees are to provide partial shade to cacao plants, to serve as a source of fuelwood, and to enrich the soil through symbiotic nitrogen and addition of leaf litter.

As in the other cases, this form of agroforestry is a post-War development pioneered by expatriate farmers. It has been adopted by the local farmers in post-independent farm operations and is now fairly widespread in PNG, the Solomons and Western Samoa. Figure 19.3 shows such a combination of *Leucaena* and cacao in the Solomons (but coconuts are not seen in the picture).

3.4. Leucaena, *coffee and food-crop systems*

In inland areas with a favourable topography, and with elevations of up to about 1,200 m, coffee rather than cacao is the usual cash crop, and *Leucaena* instead of coconut is the overstorey species. In upland Wau, Morobe Province of PNG, this crop combination predominates. Staple crops integrated with this system during the first 2–3 years include root crops (sweet potato, taro

and cassava), non-woody perennials (papaya, sugarcane and bananas) and some grain crops (maize). Because of the shading caused by the *Leucaena* and coffee, there will be little or no growth of grasses and other sun-demanding weeds and therefore the cost of tending and maintenance is minimal. Periodic lopping of *Leucaena* branches avoids excessive shading of coffee plants and generates fuelwood for the farmers. Small branches and leaves are left on site to serve as a mulch and green manure.

3.5. *Silvopastoral: grazing under perennial crops*

As stated earlier, coconuts are the most prevalent perennial crop in the South Pacific Island countries. As market-oriented crops, the area devoted to them is usually more extensive than that to subsistence crops and there are great problems of weed control between widely spaced trees. Mechanized weeding used to be undertaken, mostly by expatriate farmers before the oil crunch. Today, in the wake of high prices of fossil fuel, the plantations, especially the smaller-sized ones, have to seek alternative tending operations at affordable costs. Pasturing cattle under coconuts to keep down the competing and fire-hazardous grassy weeds has been found to be a feasible alternative, as demonstrated in the Solomons, the coastal areas and outer islands of PNG, Tonga and Fiji. In this system, cattle contribute to the production of animal protein for local diets, recycle the biomass and provide nutrient inputs in the form of cattle manure to improve soil fertility and help increase farm income and employment of the farmers.

In government-established pine plantations in Fiji, cattle are used to clear the grass and thus save the cost of land preparation prior to planting. When the pine seedlings are big enough to avoid being trampled, cattle are brought in again to keep down competing grasses and to minimize the accumulation of biomass fuel that could be a fire hazard to the plantation. The Solomons has a cattle under trees (CUT) programme that combines coconut or plantation forest production with cattle in a complementary and mutually supportive way (Smith 1983, Smith and Whiteman 1983a, b).

In most of these projects, quantitative analysis of the silvopastoral system in relation to the "without-cattle" system has either not yet been carried out or is still in the process of being done. Therefore, although the advantages of silvopastoral systems are recognized by the people, they are not yet available in quantitative terms.

3.6. *"Improved" shifting cultivation*

In the Pacific two approaches are adopted by the farmers to improve shifting cultivation (a) by shortening the "unproductive" fallow period without sacrificing the ability to restore productivity, and (b) by converting the rotational

(sequential) arrangement of annuals and perennials to intercropping (simultaneous) in order to eliminate the "shifting" nature of the system. As cited earlier, the deliberate planting of *Casuarina* before the swiddens are abandoned in the PNG highlands modifies the conventional stages of vegetation succession (which is agricultural crop – grasses – shrubs and trees), and the nitrogen-restoring capacity of the forest fallow is also increased with the use of a nitrogen-fixing tree species. Thus, even with the reduction of the fallow period to under 10 years, the *Casuarina*-based agroforestry in PNG appears a sustainable system.

Intercropping of *Erythrina* with taro and yam in Samoa, *Leucaena* with sweet potato in PNG, and *Leucaena/Gliricidia* with cacao in the Solomons are examples of simultaneous combinations of annuals and perennials that transform shifting cultivation into permanent and continuous agroforestry practices. Where land resources are becoming a limiting factor, this improvement presents a great advantage because production can be maintained from the same site through elimination of the "wasteful" fallow, and the land area required to support a given population is significantly reduced.

4. Socio-cultural factors related to agroforestry

Studies of human ecology in the PCT region have shown that the adoption of agroforestry practices is influenced by not only biophysical considerations, but also socio-economic and cultural factors.

4.1. *Land tenure*

Land-tenure patterns vary from country to country in the Pacific region. However, an underlying pattern that appears common to most of them is the traditional clan exercising extended-family control or ownership of land as opposed to the private or individual and government ownership in most South-East Asian nations. Clan-owned lands may either be cultivated communally, with each clan member receiving a proportionate share of the output, or apportioned among the individual households of the clan and used in a semi-private manner. Under the latter arrangement, absolute ownership of the land continues to be with the clan. The houseowner merely acquires temporary rights to and control over that piece of land but holds absolute ownership over the plants that he/she cultivates. If the crops are the perennial type, the farmer may retain control over the land for extended periods and the arrangement may appear like a private form of ownership. These, however, are different from the real private ownership covered by titles which were introduced by past colonial governments.

The influence of the clan-type of customary or traditional tenure system upon agroforestry could be either negative or positive. Where clans are not affected by heavy population pressure on land, and do not specify whether the crops cultivated by temporary assignees of clan land should be annual or perennial, the households could readily plant perennial crops in combination with their annual food crops according to the agroforestry approach, as practised by the eastern highlands farmers of PNG. In addition to the perceived ecological and economic benefits of including trees on their farmlands, the farmers enjoy the added advantage of being able to indefinitely prolong their "tenancy" tenure over that piece of clan land for the duration of the perennial crops. In this case, therefore, the clan-type land tenure favours and encourages agroforestry practice.

The opposite situation could arise when clans prohibit the raising of "permanent" perennials, such as fruit trees, for fear that clan lands will be fractured into small plots and taken from clan control for permanent use by individual households. This negative clan attitude has precluded the reforestation of logged-over areas by non-clan members and has discouraged the adoption of agroforestry in the western highlands of PNG. It appears, however, that where this kind of difficulty arises, a solution could be found in the form of a clan-controlled rather than an individual household-owned agroforestry farm, as in the communal *Leucaena*/coffee farms in Wau (PNG). In that event, the clan's fear of having the lands gradually transferred to private control would be eliminated.

4.2. *Population pressure on land*

Ratio of people to land resources is a convenient gauge of pressure on land. Data on total as well as arable land available per capita of population for a selected group of island countries, given in Table 19.2, indicate that the extremely limited land areas of the small islands are now under tremendous human pressure.

4.3. *Marketability of produce*

Achieving the twin goals of productivity and sustainability through agroforestry could result in the production of goods in excess of local demands, which may have to be marketed domestically or abroad for cash incomes. Local sales of sweet potato, papaya, taro and cassava, and export sales of coconut, cacao and coffee among many Pacific countries are examples of enhanced economic activities. But accompanying problems may also arise which could dampen the enthusiasm of agroforestry practitioners. For

Table 19.2. Total and arable land available per capita in selected island countries on PCT.

Country/territory	Total land (ha) per capita	Arable land (ha) per capita
Cook Islands	0.88	0.23
Fiji	3.00	0.38
Kiribati (Gilbert)	1.10	0.55
New Caledonia	12.20	0.06
Papua New Guinea	14.70	0.12
Solomons	12.50	0.24
Tonga	0.70	0.55
Vanuatu	13.50	0.87
Western Samoa	1.80	0.75

Source of basic data: 1980 Population Census, U.S. Department of Commerce.

instance, most agroforestry farms are on remote hilly terrain with poor access. Although this will motivate farmers to produce most of their basic needs within their own farms, there can also be a serious problem of bringing surplus products to local population centres for marketing. The export-oriented outputs of agroforestry may not be significant volume in many of these small countries to attract international carriers, thereby cutting off their access to international markets. Thus, inability to dispose of the surplus outputs profitably may become a disincentive to agroforestry in this region.

Improving physical access to markets requires time and capital resources which many island countries do not possess. Fortunately, the types of products from these countries provide a great degree of marketing flexibility which could outweigh the problems of poor access. For example, the traditional root crops, unlike most vegetables and fruits, do not all mature at the same time, and do not need to be harvested until ready for consumption or for marketing. Thus, harvests can be staggered to take advantage of high demand which raises prices to compensate for difficult access. Similarly, with minimal processing, the storability of exportable products like coffee and coconut can be extended so that when sufficiently large volumes accumulate international shippers could make port calls and collect the goods. This is now happening to coffee, cocoa and copra in Papua New Guinea.

5. Analysis of problems and assessment of potentials

5.1. *Underexploited species of agroforestry potential*

In general, trees may be considered suitable for agroforestry if they complement and support rather than compete with the interplanted food crops. Many of the nitrogen-fixing, fast-growing, multiple-use tree species fall in this

category. Unfortunately, out of the over 2,000 species that satisfy these characteristics, only a handful have been tested and used in agroforestry, such as *Leucaena*, *Albizia*, *Gliricidia* and *Calliandra*. The rest remain untried and therefore their potential is unrealized.

Besides compatibility with intercropped food plants, and suitability to end uses, tree crops in agroforestry must also fit the ecological conditions of the site. That means they must have the ability to thrive and be productive under conditions that are at times extreme, such as excessively arid or waterlogged areas, too alkaline or excessively acidic soils, severely eroded and nutrient-depleted slopes, and too high or too low temperatures. There are species whose natural habitats indicate their capacity to survive under some of these extreme conditions. For example, some species (e.g., *Prosopis chilensis*) can thrive in arid and low-nutrient areas, while others (e.g., *Acacia senegal*) can withstand waterlogged soils. Some (e.g., *Leucaena leucocephala*) like basic soils, while others (e.g., *Acacia mangium*, *Acacia mearnsii*) can thrive in acidic soils. Some species (e.g., *Cassia siamea*) cannot withstand cold, while others (e.g., *Mimosa scabrella*) require cool subtropical temperatures. What all these variations in ecological requirements indicate is that, depending on the location and ecological conditions of an agroforestry project, there is a group of species which is not so well known but which has great potential. There is a great need for research to explore potentials of these species so as to enable land users to make fuller use of such underexploited species. The same applies to agricultural species.

5.2. *Agroforestry as a means to reforestation*

Partly from excessive wood-extraction activities, and partly from unwise conversion of forest areas to unsustainable food cropping, considerable areas of hilly land in the Pacific have degenerated into unproductive grasslands, as in PNG, Fiji, and the Solomons. These lands could be returned to productive and protective status through reforestation if governments could afford to cover the high costs. A relatively cheap alternative to reforestation is agroforestry, where farmers can establish tree crops and food crops simultaneously, and may be compensated in terms of the food outputs. They move to other open areas to repeat the tree-establishment process as soon as the tree crops reach canopy-closure age and preclude further food cropping. This is the taungya system which originated in the mid-1800s and which may be practicable in the Pacific.

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Part 4

Agroforestry systems in Africa

20. The Chagga homegardens: a multistoreyed agroforestry cropping system on Mount Kilimanjaro (northern Tanzania)*

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Abstract. The homegardens are characterized by an intensive integration of numerous multipurpose trees and shrubs with food crops and animals, simultaneously on the same unit of land.

The Chagga are skilled farmers with an intimate knowledge of the crops and their ecological requirements. They have a good idea of functions/uses of the plant species on their farms. The great diversity provides both subsistence and cash crops. It enables the farmer to keep his management options open and provides insurance against drought, pests and economic risks.

1. Introduction

The Chagga are Bantu speakers descended from immigrants of various tribes who migrated into the once-forested foothills of Mt. Kilimanjaro. Then began the process of transforming the native forest. Trees that provided fodder, fuel and fruits were retained while the less useful species were eliminated and replaced with new tree and crop species. This process is still continuing on Mt. Meru – a neighbouring mountain.

Mt. Kilimanjaro is one of the most densely populated areas in Tanzania. This is due largely to the ecological and economic success of the Chagga cropping system. The homegardens enable the farmer to have sustained production with a minimum of external inputs and thus they represent a good land-use model for extrapolation to other areas with similar ecological and socio-economic characteristics.

Although the Chagga homegardens are often cited as an example of model land use (von Clemm 1963; Openshaw and Morris 1979), the system has not been described in any detail. This paper identifies the major components, describes their interactions and management aspects and presents an evaluation of the system's ecological stability, productivity and sustainability.

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2. General description of the area

2.1. *Geographic location*

The Chagga homegardens are found on Mt. Kilimanjaro in northern Tanzania (2.9-3.3° S, 37.0-37.5° E) (Fig. 20.1). The bulk of the mountain covers about 3,100 km^2 and the highest peak is 5,895 m above sea level. The area above the 1,900 m contour is a designated forest reserve and national park.

2.2. *Biophysical environment*

Climate

Mt. Kilimanjaro region has a bimodal rainfall pattern with "short rains" from October to December and "long rains" from March to May. The average annual rainfall ranges from 1,000 to 1,700 mm, with marked variation depending on elevation, exposure and aspect. Thus, Kilimanjaro gets more rainfall on its south-eastern and eastern flanks (where the Chagga homegardens are) than on its northern and western sides which are sheltered from the wet south-east winds.

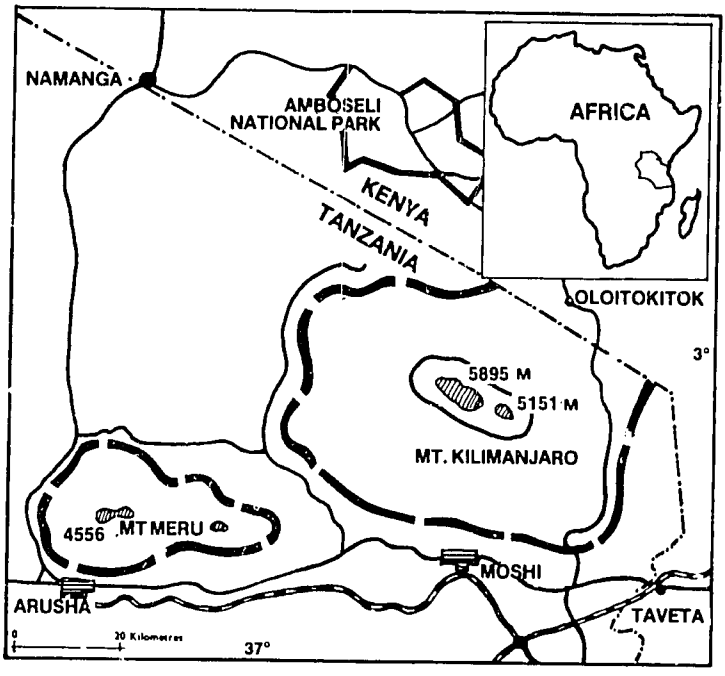

Fig. 20.1. Location of Mt. Kilimanjaro in northern Tanzania.

Soils

There are four major groups (FAO/UNESCO Soil Map of the World – Sheet VI-3):

1. Humic Nitosols and associated humic Andosols
2. Chromic Cambisols and associated eutric Cambisols
3. Orchric Andosols and associated chromic Cambisols and vitric Andosols
4. Mollic Andosols and associated eutric Nitosols.

In general, these volcanic soils are fertile with a high base saturation and cation-exchange capacity. A major limitation is the steep slopes which prevent mechanization and require substantial erosion-control work. Other limitations include stoniness or a shallow petrocalcic horizon.

Vegetation

Climax vegetation is montane rainforest. The forest varies in composition and structure along altitudinal and rainfall gradients. On the wetter south-eastern slopes, there is a zone of *Ocotea usambarensis* and *Podocarpus usambarensis*. This occurs at an altitude of 1,900–2,400 m a.s.l. and rainfall of 1,500–1,800 mm. The drier end of the *Ocotea* forest sometimes grades into a forest with much *Cassipourea malosana* associated with *Myrica salicifolia*. At lower altitudes, what little remains of the forest is characterized by the following species: *Newtonia buchananii*, *Macaranga kilimandscharica* and *Parinari excelsa*. At around 1,200 m a.s.l. and 1,300 mm rainfall, species include *Albizia* spp., *Bombax schumanianum*, *Chlorophora excelsa*, *Diospyros mespiliformis*, *Khaya nyasica*, *Newtonia paucijuga* and *Terminalia kilimandscharica*. In contrast, the drier north-western slopes (1,000–2,800 m) have *Juniperus procera* and the dominant species in association with *Olea africana* and *Olea welwitschii*, and sometimes in pure stands.

2.3. *Landuse systems*

Agriculture

The south-eastern and eastern slopes are characterized by intensive smallholder production of both subsistence and cash crops. Individual homesteads are closely spaced and food crops are grown under the canopies of banana and coffee. In addition, there are state-owned coffee estates and farms. The drier northern and western slopes are used mainly for extensive grazing by the Maasai people.

Forestry

Major plantation species are *Cupressus lusitanica* and *Pinus patula*, of which there are about 3,000 ha in the west and 3,500 ha in north-eastern Kilimanjaro. The Forestry Department carries out various silvicultural operations in natural forests to encourage natural regeneration of root suckers of *Ocotea usambarensis*, *Podocarpus gracilior*, *Podocarpus milanjianus* and *Juniperus procera*.

Agroforestry

The intensive cropping system of the Chagga involves integration of several multipurpose trees and shrubs with food and cash crops and livestock simultaneously on the same unit of land. Within this cropping system several agroforestry practices can be identified. These include the use of multipurpose trees/shrubs:

- to provide shade for coffee
- as live fences
- for fodder and mulch production
- for bee forage
- with anti-pest properties.

A typical homegarden is shown in Fig. 20.2.

Fig. 20.2. Chagga homegarden showing large trees, e.g., *Cordia abyssinica*, *Albizia* spp. and *Grevillea robusta*, in the uppermost storey. Next are the banana and coffee canopies and here the lowest layer is comprised of fodder, herbs and grasses (Photo: E.C.M. Fernandes).

3. Structure of the system

The Chagga homegardens ("vihamba") cover about 1,200 km^2 (120,000 ha) on the south and east slopes of Mt. Kilimanjaro. Recent estimates indicate that the south slopes have a population density of 500 per sq km and an annual population growth rate of at least 3%. Marketing facilities are fair with Moshi town (Fig. 20.1) being the nearest major market and a good road linking Moshi with Arusha, Tanga and Dar es Salaam.

The homegardens are located mainly between 900–1,900 m above sea level. In addition, each family has another plot (*kishamba*) 10 to 16 km away in the drier plains below the southern and eastern slopes. The *kishamba* has only very few trees and is used mainly for growing annual crops.

3.1. *Components of the homegarden*

Crops

Food crops. Banana (*Musa* spp.), beans (*Phaseolus vulgaris*), cabbage (*Brassica oleracea*), cow pea (*Vigna unguiculata*), maize (*Zea mays*), onion (*Allium cepa*), potato (*Solanum tuberosum*), sweet potato (*Ipomoea batatas*), taro (*Colocasia* spp. and *Xanthosoma* spp.), tomato (*Lycopersicon esculentum*), yam (*Dioscorea* spp.).

Cash crops. Coffee (*Coffea arabica*), cardamom (*Elettaria cardamomum*). Surplus bananas and other food crops are also sold. Women are responsible for marketing the surplus bananas, vegetables and milk and they keep the proceeds. Men get the money from coffee, poultry and egg sales.

There are at least 15 different types of banana grown on the homegardens. These include cultivars for food, brewing and fodder. In addition to the fruit, the leaves and pseudostems are also used for fodder while the stem sheaths and dried leaves are used as mulch for coffee bushes. Although a little maize is grown in some homegardens, the bulk of the crop is grown intercropped with beans on the lowland *kishamba*. Finger millet (*Eleusine coracana*), an important crop used for brewing and making porridge, is also grown in the lowlands.

Trees and shrubs

Chagga farmers deliberately retain and manage numerous species of trees and shrubs on homegardens. Table 20.1 provides an indication of the species diversity and their uses (see Appendix 20.1 for an inventory of the plant species). The men are responsible for lopping the fuel and fodder trees while the women harvest the fodder grasses and herbs.

Table 20.1. Woody species commonly found in the Chagga homegardens and their functions and uses.

Species	Functions/uses
Albizia schimperiana	Fuelwood, building material
Bridelia micrantha	Building poles, fodder, roots used medicinally
Caesalpinia decapetala	Live fence
Calpurnia aurea	Coffee shade, poles, tool handles, leaf decoction as antihelminthic for cattle
Carica papaya	Fruit, mosquito repellent
Cassia didymobotrya	Medicinal uses, poisonous to cattle
Cedrela mexicana	Fuelwood, timber
Chlorophora excelsa	Valuable timber
Citrus spp.	Fruit
Commiphora spp.	Fodder, anti-insect properties, live support for yams, fencing material
Cordia abyssinica	Coffee shade, fuelwood, building material, beehive construction
Croton macrostachys	Coffee shade, fuelwood, fodder, anti-insect properties
Datura arborea	Bee forage, anti-*Armilaria mellea*, anti-nematodes
Diospyros mespiliformis	Valuable timber
Dracena usambarensis	Live fence, boundary marker
Dracena afromontana	Live fence, boundary marker
Ethretia spp.	Poles, tool handles, antibiotic properties
Eriobotrya japonica	Fruit, building material, hedge tree
Ficus spp.	Fodder, charcoal
Gardenia spp.	Utensils, anti-insect properties
Grevillea robusta	Coffee shade, fuelwood, building material
Iboza multiflora	Live fence, leaves fed to cattle as antihelminthic, roots have anti-bilharzia properties
Markhamia platycalyx	Termite-proof building poles, fuelwood
Morus alba	Fodder, fuelwood, reinforce live fence of *Caesalpinia decapetala*
Newtonia buchananii	Fuelwood
Olea welwitschii	Valuable timber, fodder
Persea spp.	Fruit
Psidium guajava	Fruit, fuelwood
Rauwolfia caffra	Fuelwood, bark for brewing, anti-pest properties, used as store for maize cobs which are hung in its branches
Rauwolfia inebrians	Coffee shade, fuelwood
Ricinus communis	Seed oil used medicinally, seeds in bait as rodent poison
Syzigium africanum	Fuelwood, fruit
Tectona grandis	Valuable timber
Trema guineensis	Fodder, anti-insect properties, used medicinally
Trichilia emetica	Fuelwood, root decoction as antihelminthic
Uvaria spp.	Fuelwood
Vangueria tomentosa	Fruit, roots as snake-bite remedy and antihelminthic
Other useful plant species maintained in homegardens	
Aloe volkensis	Antibiotic properties, grave marking
Cynodon dactylon	Fodder grass
Pennisetum purpureum	Fodder grass
Senecio kilimandscharica	Medicinal use, especially against kidney ailments
Setaria sphacelata	Fodder grass
Vetiveria zizanoides	Erosion control, roof thatch

Animals

Cattle are kept for milk, while goats and pigs are kept for meat for sale and/or for home consumption. Recently, some farmers have started keeping improved cattle. The more popular breeds are Fresian, Jersey, Ayrshire and crosses involving these and local breeds. Each farmer has an average of 3 cows, 2 goats and 6 chickens (O'Kting'ati and Mongi 1983). In some cases a pig is also kept. Livestock are stall-fed with fodder from trees/shrubs, banana plants and grasses grown on the homestead. Supplementary fodder is harvested from the *kishamba* in the plains or bought at TSh 20* a headload (30–50 kg).

3.2. *Arrangement/interaction of components*

The spatial arrangement of components is irregular and appears very haphazard with the trees/shrubs and food crops intimately mixed. Vertically, however, several relatively distinct zones can be distinguished. A schematic presentation of the canopy structure is presented in Fig. 20.3. In terms of canopy depth, the lowest zone (0–1 m) consists of food crops like taro, beans and fodder herbs and grasses. Included in this zone is the regeneration of the overstorey trees/shrubs. The next zone (1–2.5 m) comprises mainly coffee with a few young trees/shrubs and medicinal plants. Next is the banana canopy (2.5–5 m) with some fruit and fodder trees. Above the "banana" layer, vertical zonation is less distinct with a diffuse zone (5–20 m) of the preferred fuel and fodder species and another zone (15–30 m+) of the valuable timber trees and other fodder and fuelwood species. There is considerable overlap of the storeys among the various zones.

Over 100 crop and other plant species that appear in the Chagga homegardens have been listed in Appendix 20.1 to this chapter.

The intimate arrangement of components results in the interactions between components occurring both in time and space. The nature of interactions varies and can be:

- Direct, e.g., fodder trees/shrubs and livestock; trees/shrubs and bees; cattle manure and crops, trees/shrubs.
- Cyclic, e.g., crop residues and cattle.
- Competitive, e.g., bananas and coffee; tree/shrubs and crops.

No data are available to indicate the magnitude of the direct or cyclic interactions. Trials conducted at the Coffee Research Station, Lyamungu and

* 1 US $ = 12.45 Tanzanian shillings (January 1984).

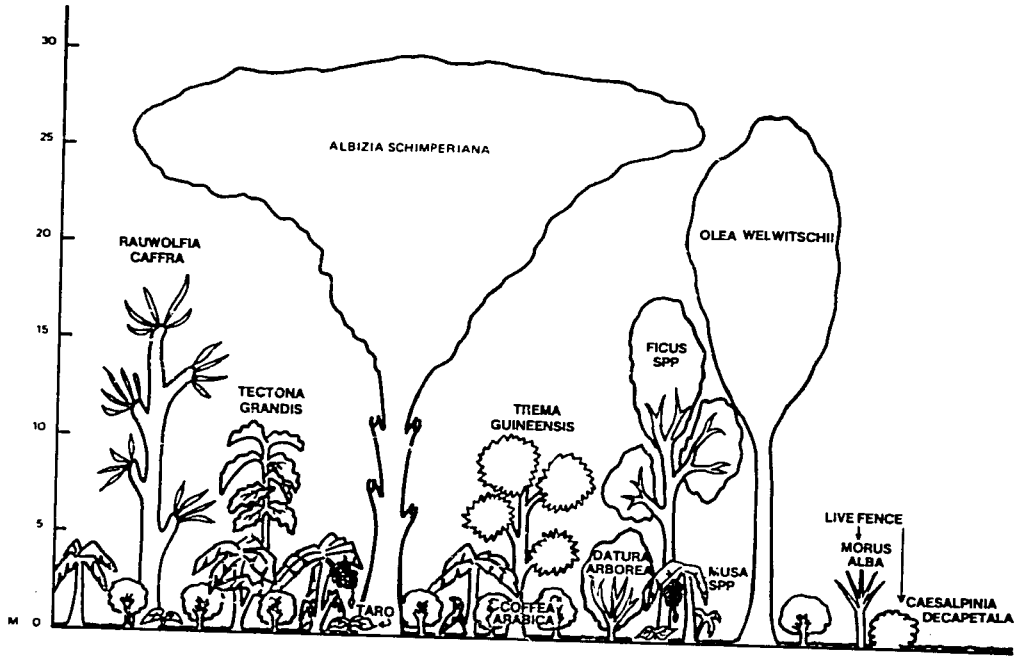

Fig. 20.3. Typical vertical zonation in a Chagga homegarden.

over a part of the main coffee area on Mt. Kilimanjaro showed that bananas interplanted in either young or mature, lightly shaded or unshaded *Coffea arabica* significantly reduced coffee yields (Robinson 1961). Other trials elsewhere showed that provided farmyard manure was applied to the banana clumps, the yield of bananas planted at 960 stools per ha was not greatly affected by the presence or absence of interplanted coffee. Reduction of the density of bananas interplanted in coffee from 960 to 480 stools per ha resulted in lower total banana production, which was partially offset by the higher rate of fruiting and larger bunches from the wider spaced plants (Mitchell 1963). This is significant since it is bananas and not coffee that are the primary crop in the Chagga cropping system.

3.3. *Management aspects*

The Chagga have an intimate knowledge of the various crops and plants and their ecological requirements. Management techniques applied today have been continuously refined and tested over the ages and handed down from one generation to the next. Thus, when the farmers think the time is right, they carry out various operations such as opening up the canopy to ensure better fruiting of the coffee, spacing out the banana stools and manuring the different crops. They maintain plant species (e.g. *Datura arborea*, *Rauwolfia caffra*) that repel or eradicate various pests and know the best fodder trees/shrubs and when and how to lop them.

Each homegarden has a network of irrigation/drainage furrows distributed over its area linked to other homegardens in the vicinity. The farmer is thus able to tap and utilize runoff from the forest reserve and other homegardens on the slopes above.

The number of banana clumps and coffee bushes on a homegarden varies not only with altitude and aspect but also with the management capabilities and preference of the owner. In general, the range of banana clumps per homegarden varies from 200 to 800 (330 to 1,200 ha^{-1}) and coffee 300 to 1,000 (500 to 1,400 ha^{-1}). There are in addition, an average of 39 other trees/shrubs retained and managed on the homegarden. Shade tolerant crops, e.g., taro, yams and beans, are intercropped between the coffee and bananas (Fig. 20.4 bottom) while the more light-demanding species are grown in a section of the homegarden over which the canopy has been thinned to minimize shade.

Coffee extension services provide advice on pruning and spraying against coffee berry disease and leaf rust. Most of the coffee trees have a single stem, while each banana clump is maintained with 3–5 pseudostems of different ages so as to facilitate a continuous banana harvest.

Most Chagga farmers either plant or encourage any natural regeneration of valuable timber species (see Table 20.1; Appendix 20.1). These young trees in

Fig. 20.4 (top) Valuable timber trees are found on most Chagga homegardens. Teak trees (to the left and centre of picture) are seen growing up through the banana canopy. *(bottom)* Taro together with young coffee and banana plants in the lowest storey. Note the hoe used for tillage (Photo: F. C. M. Fernandes)

the understorey experience heavy shade and this encourages straight stems with few branches. When appropriate, the overhead canopy is thinned to allow the tree to grow into the upper storeys. Figure 20.4 shows teak trees growing up through the banana canopy. The trees are allowed to grow to a size approaching 0.6 to 1 m^3, i.e., a rotation of 60–80 years. A large tree (about 1 m^3) of *Olea welwitschii* can fetch a price of TSh 10,000. If such a tree is to be felled

during the lifetime of the present owner, then he in turn plants one so that the next owner will also inherit a valuable tree.

It is important to note that although the great majority of homegardens are intensively cultivated and well managed, one also encounters some that are neglected, overgrown and sometimes abandoned.

4. Functional aspects of the system

4.1. *Resource utilization*

Land

The average size of a homegarden is 0.68 ha with a range of 0.2 to 1.2 ha. Traditionally, the land was divided only between the sons, but nowadays daughters can also inherit the homegarden or part of it. Land tenure is based on a strongly held traditional belief that there is a close "spiritual" link between one's ancestors and the soil (von Clemm 1963). Thus, once a member of the immediate family is buried in the homegarden, tenure is assured for the current owner and his descendants and such a homegarden may even be abandoned for several years without the danger of someone else assuming ownership. This is in contrast to the lowland *kishamba* (allocated by the state and whose size is proportional to the family size) where tenure is on an annual and usufructuary basis. If this land is not used for one or two years it may be claimed by another person.

Labour

An average household size of 9.9 people provides a workforce of four family members. In the homegardens, planting, tending and harvesting of bananas, taro and yams occurs throughout the year. Coffee harvesting usually starts in August and continues till January. The peak labour period is between January and March (M'lambiti 1982). This is because coffee harvesting coincides with land preparation and planting of crops both in the homegardens and on the lowland *kishamba*. In contrast, April to June is a low-labour period and precedes the harvesting of maize, beans and finger millet from the lowlands. In the homegardens all operations are performed by human labour, whereas in the lowlands ploughing may be done by tractor.

Capital

Each farmer has an average of TSh 560 worth of farm implements (axes, hoes and pangas). Only a few farmers own tractors. These are leased to others for ploughing the lowland *kishamba*.

4.2. *Inputs*

Seeds are mostly obtained from previous crops although it is possible to buy seeds from the Tanzania Farmers' Association. Dung from the stall-fed livestock and other household wastes are spread around the banana clumps and coffee bushes. Chemical fertilizers are generally not used. The Kilimanjaro Uremi Cooperative (KUC), a co-operative concerned with the production and marketing of coffee, supplies pesticides free of charge for use against coffee berry disease and leaf rust. In addition, the Chagga use a variety of plant species with anti-pest properties (see Table 20.1; Appendix 20.1). Credit facilities are offered by the KUC and the Tanzania Rural Development Bank (TRDB). The TRDB also offers soft loans for dairy cattle and pig production.

4.3. *Production*

An average homegarden of 0.68 ha produces about 125 kg of beans (184 kg ha^{-1}), 280 kg of parchment coffee (412 kg ha^{-1}) and 275 bunches of bananas (404 ha^{-1}) annually. In August 1983, coffee fetched TSh 16.85 kg^{-1} while the average price of a bunch of bananas was TSh 30. The maize harvest from the lowland plot averages 360 kg per year. Almost all the coffee produced is sold, although the poorer quality beans obtained towards the end of the harvest are retained for home consumption. No production data are available for taro, yams, cardamom and onions. Local sources indicate that crop failure involving coffee and/or maize and beans occurs once every 3 or 4 years. However, total failure also involving bananas, other fruits, root crops and livestock has never occurred. Each farmer keeps between 3 and 5 traditional beehives. It is conservatively estimated that each hive produces at least 5 kg of honey per year. Milk production by traditional breeds under stall feeding is low (1–4 litres per day), whereas improved cattle produce between 8 and 16 litres per day. Pigs are fattened up and sold within a period of 6–12 months.

It is difficult to estimate the quantity of fodder produced in the homegarden, but most of the Chagga farmers are almost self-sufficient in fodder for their livestock. Supplementary fodder is bought if needed.

Fuelwood production in homegardens is estimated to be between 1 and 2 m^3 yr^{-1} (1.5–3 m^3 ha^{-1} yr^{-1}). If we assume a minimum consumption of 1 m^3 per adult per year, then each family requires between 4 and 6 m^3 yr^{-1}. Thus a homegarden supplies 1/4 to 1/3 of the fuelwood requirements. The rest is obtained from the forest reserve or from the *kishamba* where *Acacia* spp. and *Combretum* spp. are retained.

5. System dynamics

5.1. *Growth of the system*

There is no more land (outside the forest reserve) on Mt. Kilimanjaro that is suitable for the Chagga homegardens. Thus expansion in terms of increased area occupied by the cropping system is no longer possible on Mt. Kilimanjaro. Instead, existing homegardens are reaching the limit of intensive use at the present level of management. They are also becoming increasingly fragmented due to sub-division. This land scarcity has led to the migration of some Chagga to Mt. Meru (70 km south-west of Mt. Kilimanjaro), an area that has ecological conditions similar to those on Mt. Kilimanjaro. Local sources indicate that there has been some inter-marriage between the Chagga and Meru (the indigenous tribe on Mt. Meru) and this has probably been an important factor in enabling the Meru (who were formerly pastoralists) to successfully adopt the complex Chagga homegarden system within a period of about 50 years

5.2. *Sustainability*

Although the Chagga cropping system has been stable over at least a century, it is only recently that the system as a whole has come under pressure due to rapid population growth, diminishing land resources and change in dietary habits (maize replacing bananas as the staple food). Migration of youngsters to urban areas leads not only to labour shortages, but also disrupts the traditional transmission, from one generation to the next, of the knowledge and experience required for the successful management and perpetuation of the complex multicropping system. In recent years, coffee prices declined markedly on international markets and this, combined with the labour-intensive nature of the crop, resulted in some Chagga farmers threatening to remove the coffee bushes from their homegardens. Despite these pressures, however, the system still appears to be working well with the majority of farmers. Nevertheless, if the system is to remain sustainable, then its productivity will have to be increased to cater for the rapidly increasing population.

6. Evaluation

6.1. *Merits*

1. The continuous ground cover and high degree of nutrient cycling are the major factors that permit the Chagga homegardens to remain sustainable on the erosion-prone slopes of Mt. Kilimanjaro.

2. Coffee produced by the Chagga contributes significantly towards Tanzania's foreign exchange earnings. Over 52% of Tanzania's export coffee comes from Kilimanjaro and in 1982 this represented an earning of US$ 65 million.
3. The various crop species and varieties in the homegarden represent years of natural selection for survival and farmer selection for better production and quality. These species have a good resistance to prevalent pests, they compete well with weeds and have a generally high level of genetic variability. The Chagga homegardens thus represent a valuable gene pool for use in any breeding programmes to improve crop varieties for multistorey cropping systems.

In addition, the advantages attributed to intimate multispecies, multistorey associations are many. They include soil conservation, nutrient cycling and nutrient efficiency, microclimate enhancement (Nair 1984) and other benefits such as labour efficiency, risk minimization and continuous production.

6.2. *Weaknesses/constraints*

1. Although the Chagga homegardens are a stable land-use system, their productivity is relatively low. In order to meet the demand for food of a rapidly growing population, the productivity of the homegardens must be increased. The problem lies in the need to increase productivity while retaining the stability of the present system.
2. With the present trend of young people migrating to urban areas, it is mostly the older people who are left to manage the homegardens. Extension workers may thus find it more difficult to introduce innovations.
3. Present extension workers focus on individual crops/components. The absence of an integrated approach and subsequent lack of awareness of the possible interactions of the various components and their repercussions can result in problems for the farmer and loss of faith in the extension service.

6.3. *Potential*

On Mt. Kilimanjaro, the homegarden's potential as a productive and sustainable system can be enhanced by:

1. Replacing the less productive trees/shrubs with fast-growing nitrogen-fixing species, e.g., *Leucaena leucocephala*, *Calliandra calothyrsus*, *Gliricidia sepium* and *Lespedeza bicolor*. These would provide increased fuel, fodder and

green manure on the homegarden and would reduce the time spent in travelling long distances to gather supplementary fuel and fodder.

2. Improving animal husbandry so as to achieve, for example, a lactation period of around 300 days per year.
3. Improved apiculture, e.g., the use of top bar hives, better bee strains, improved harvesting and honey-extraction methods.
4. Introducing new crop varieties using the gene pool developed by natural and farmer selection, not only in Tanzania but also from homegardens in other parts of the world.
5. Using fertilizers. Credit facilities could be provided by the Tanzania Rural Development Bank. Purchasing, storage and distribution of the fertilizer could be carried out by the Tanzania Farmers' Association or the Kilimanjaro Uremi Cooperative.

6.4. *Extrapolatability*

Despite the need for intimate knowledge of the components and a high level of management capacity, the Chagga homegardens can be extrapolated to upland areas (e.g., the Kenyan highlands, S.W. Ethiopia, S.W. Rwanda) where ecological conditions are similar and farmers practise less intensive multistorey cropping. Preferences for local species/varieties can be catered for by appropriate substitution or introduction. A demand for maize cultivation in such homegardens could be accommodated by growing the maize between rows of trees. Shade effects could be minimized by an east-west orientation of the rows. Ground cover can be maintained by intercropping the maize with beans or cow peas.

6.5. *Research needs*

Information is required on the following properties that could be used to improve the overall productivity of the homegardens.

1. Optimal spatial and temporal arrangements of the various components.
2. Optimal crop associations. This includes component crops/varieties differing in morphology, maturing period, shade tolerance, rooting depth and photoperiod sensitivity.
3. Since chemical pest control is no real alternative in smallholder cropping systems, information is required on crop/species combinations with a greater potential to reduce pests, diseases and weeds. The effectiveness of the plant species with anti-pest properties that are already used by the Chagga could be investigated as a first step.

4. Better soil management techniques, e.g., green manure, mulches and the most appropriate time of application.
5. Appropriate fertilizer prescriptions for the intimate multispecies associations present in the Chagga homegardens.

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Appendix 20.1

PLANT SPECIES IN THE KILIMANJARO AGROFORESTRY SYSTEMS*

As a part of the study of the Chagga homegardens an inventory of plant species was undertaken in 30 farms and their surroundings in the Chagga area on the slopes of Mount Kilimanjaro.

The study was conducted on the southern slope of Mt. Kilimanjaro in Hai Mashariki Division, situated at elevations of 800-2,500 m a.s.l. It consisted of an inventory of plant species conducted on farms, farm boundaries and around homesteads in 30 subjectively selected farms. Five farms were selected from each of the following villages: Mwasi Kusini, Mwasi Kaskazini, Kushimundu, Mruwia, Kyaseni and Materuni in the study area.

Plant species were identified by us. Herbarium samples are kept at the National Forestry Herbarium, Tanzania Forestry Research Institute, Lushoto. Data on the local names and uses of the plant species were obtained through interviews with farmers.

The plant species identified and their economic importance are presented in the following table. A total of 111 plant species spread over 42 families were identified. They include 53 tree species, 29 food-crop species, 21 economically useful non-woody plant species and 8 weed species. Except for the weeds, the other plant species are carefully interplanted on the same unit of land to form a very dense multistorey ecosystem, as described in the system description. Most of the plant species are maintained on the farm for two or more uses. For trees, the main uses were fuelwood (90% of the tree species), medicines for humans and livestock (30%), poles (25%), shade (24%), timber production (23%), fodder production (10%), and other uses (19%). Nearly all the non-woody plant species and climbers are grown for fodder or medicinal purposes. The use of nearly all the trees to provide fuelwood is a reflection of the importance of this resource for the day-to-day life of rural communities.

Nearly 30 food-crop species are used in the multicropping system on the same unit of land. In one of the surveyed farms (2 ha in size), more than 15 food-crop species were planted. This phenomenon is very different from the conventional two-crop intercropping that is often reported in the literature and provides the farmer with the insurance for basic necessities that is so crucial under poor economics and the vagaries of climate.

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* This study was originally published in *Agroforestry Systems* 2: 177-186 (1984). The study team consisted of the three authors of the main paper and G.H. Weaver.

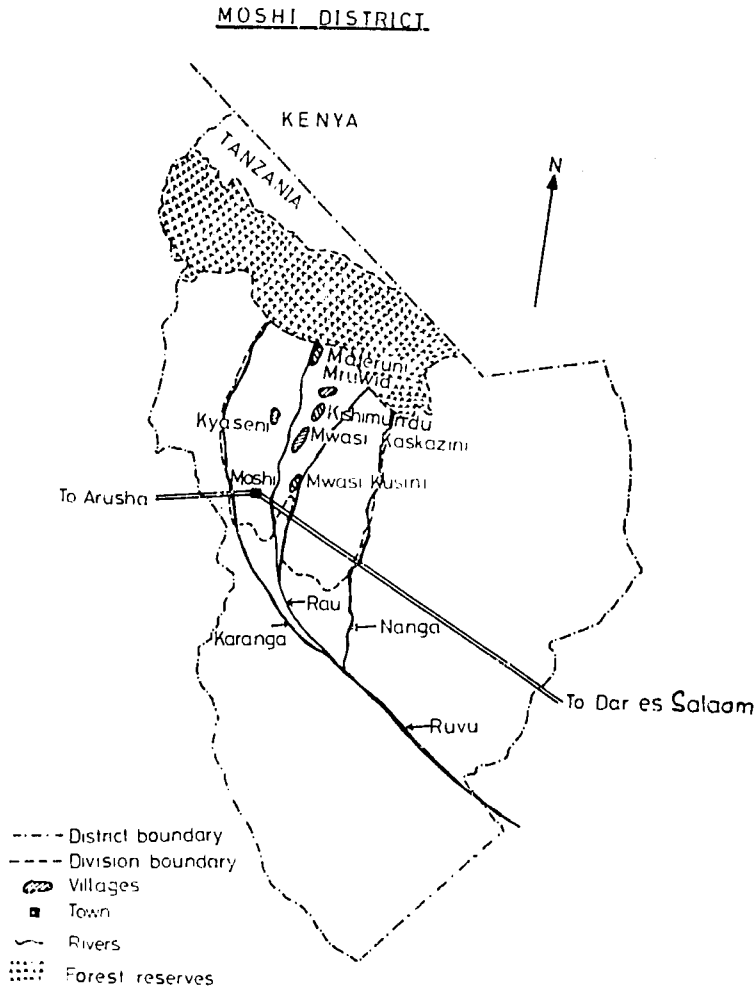

Fig. 20.5. Location of villages sampled for this study.

This inventory brought out for the first time the totality of plant species used in multicropping as practised at the farm level in the region. Most of these species are under-exploited and their role and importance in the rural communities little understood by outsiders.

Appendix 20.1: Table. Plant species in the Kilimanjaro agroforestry system, northern Tanzania.

Family name	Botanical name	Common name	Vernacular name	Uses	Remarks
Alangiaceae	*Alangium chinense*		Mringonu	Fuelwood, fodder and shade	Fast-growing tree to 25 m
Amaranthaceae	*Achyranthes aspera*		Kisoka	Fodder, medicinal	Shade-tolerant shrub
	Amaranthus dubius		Shaana	Vegetable	
Anacardiaceae	*Anacardium occidentale*	Cashew	Mkorosho	Edible fruit and seed, fuelwood	Tree to 12 m
	Mangifera indica	Mango	Mwembe	Edible fruit, fuelwood	Tree to 20 m
	Sorindeia madagascariensis		Mngwera	Shade, fuelwood and edible fruits	Tree 10–15 m
Annonaceae	*Annona muricata*		Mstafeli	Edible fruits, fuelwood	Tree 5–8 m
	Uvaria sp.		Mrisirisi	Timber and fuelwood	Woody climber, shrub or small tree
Apocynaceae	*Rauwolfia caffra*		Msesewe	Timber, fuelwood, catalyst for brewing, medicinal	Tree 12–20 m
	Tabernaemontana usambarensis		Mracha	Fuelwood, medicinal	
Areceae	*Colocasia esculenta*	Taro	Maduma	Edible roots	
Araliaceae	*Cussonia holstii*		Mnengere	Fodder	Tree to 8 m high
Balsaminaceae	*Impatiens kilimanjari*		Sunguala	Weed, ornamental	
Bignoniaceae	*Jacaranda acutifolia*		Not available	Shade, fuelwood, ornamental	Tree to 12 m
	Kigelia africana	Sausage tree	Imomo	Fuelwood, yeast and sponges from fruits	Tree 5–15m
	Markhamia platycalyx		Mtarawanda	Timber, fuelwood, poles	Tree to 22 m
Boraginaceae	*Cordia abyssinica*		Mringaringa	Timber, shade, fuelwood, fodder	Tree to 20 m
	Ehretia cymosa		Mnemvu	Poles, medicinal	
Bromeliaceae	*Ananas comosus*	Pineapple	Mnanasi	Edible fruits	
Burseraceae	*Commiphora zimmermannii*		Mfifina	Fodder	Tree 10–20 m
Caricaceae	*Carica papaya*	Pawpaw	Mpaipai	Edible fruits	
Commelinaceae	*Commelina latifolia*		Torontoro	Fodder	Rambling herb
Compositae	*Ageratum conyzoides*		Mafuna	Fodder	Shrubs
	Conyza sumatrensis		Inanzie	Weed	
	Galinsoga parviflora		Shimakamaka	Vegetable	
	Helichrysum spp.		—	Weed	Herb/shrub

	Senecio spp.		Ifuifui	Medicinal	
	Vernonia subuligera		Iduhuduhu	Medicinal, weed	Shrub or small tree to 6 m
Convolvulaceae	*Ipomoea batatas*	Sweet potato	Shisowia	Edible roots, vegetable	
Cruciferae	*Brassica oleracea*	Cabbage	Kabichi	Vegetable	
Cucurbitaceae	*Telfairia pedata*		Makungu	Fat from seed	Climber with stems to 30 m long
Dioscoreaceae	*Dioscorea alata*	Yam	Ngao, Shia	Edible tubers	
	D. bulbifera	Yam	Nduu	Edible tubers	
Ebenaceae	*Diospyros mespiliformis*		Msindesinde	Timber, fuelwood	Tree to 20 m
	Euclea divinorum		Mkinyanyi	Fuelwood, red dye from bark	Shrub or small tree
Erinaceae	*Agauria salicifolia*		Not available	Fuelwood	Tree 12–15 m
Euphorbiaceae	*Bridelia micrantha*		Mmarie	Fuelwood, poles, withies, fodder	Tree to 15 m
	Croton macrostachyus		Mfurufuru	Shade, fuelwood and goat fodder	Tree to 15 m
	Jatropha curcas		Mchimbakaburi	Boundary and grave marking	Tree to 6 m
	Manihot esculenta	Cassava	Muhogo	Edible root, vegetable	Shrub to 4.5 m
	Maragaritaria discoidea		Mshamana	Fuelwood, poles, fodder	
	Ricinus communis	Castor-oil tree	Mbarika	Purgative oil, medicinal	Short-lived shrub to 6 m
	Synadenium volkensii		Mracha	For making graves and boundaries poisonous sap	Tree with fresh branches
	Tragia brevipes	Stinging nettle	Kimangima Shiwawo Kilachia		
Gramineae	*Eleusine coracana*	Finger millet	Mbege	Grains are used in the preparation of local brew (mbege) and making porridge	
	E. indica				
	E. africana	Fowl-foot grass	Kikwale	Pasture grass	
	Panicum monticola		Mlaa	Pasture grass	
	Saccharum officinarum	Sugarcane	Miwa, Mauwa	Edible stem	
	Tripsacum laxum	Guatemala grass		Fodder	
	Vetiveria zizanioides	Vetiver	Khuskhus grass (manzao)	Thatching, anti-erosion	
	Zea mays	Maize	Mahindi, Meemba	Staple food	

Appendix 20.1: Table. (continued).

Family name	Botanical name	Common name	Vernacular name	Uses	Remarks
Labiatae	*Geniosporum rotundifolium*		Isuwambewa	Weed	
	Hoslundia opposita		Tarambe	Hedges, fodder	
	Iboza riparia		Mombo, Ombo	Medicines for stomach ache and fever	
	Ocimum suave		Ikachi	Medicine for stomach ache	
Lauraceae	*Persea americana*	Avocado	Mparachichi	Edible fruits, shade, fuelwood	
Leguminosae (Caesalpinioideae)	*Caesalpinia decapetala*	Mauritius thorn	King'utuo	Boundary marking, hedges	Thorny shrub
	Cassia didymobotrya		Iwinu	Purgative, antihelminthic leaves	Shrub to 6 m
	C. fioribunda		Otcio	Weed	
Leguminosae (Mimosoideae)	*Albizia schimperiana*		Mruka	Fuelwood, shade	Tree 20–30 m
	A. petersiana		Muula	Poles, fuelwood, shade	Tree to 12 m
	Newtonia buchananii		Mkufi	Timber, shade, fuelwood	
Leguminosae (Papilionoideae)	*Calpurnia aurea*		Mletangawo	Poles, fuelwood, antihelminthic, insecticide	
	Erythrina abyssinica		Mriri	Shade, fuelwood	
	Phaseolus vulgaris	Beans	Maharagwe	Food	
	Pisum sativum	Peas	Njegere	Vegetable	
	Tephrosia aequilata		Urutupa	Fuelwood, poisonous seed	
	Vigna unguiculata	Cowpea	Kunde, Soko	Food	
Liliaceae (Alloideae)	*Allium cepa*	Onion	Vitunguu	Spice	
Liliaceae (Asphodeloideae)	*Aloe volkensii*		Sale la njofu, Iratune	Grave marking, sap medicine for wounds	
Liliaceae (Dracaenoideae)	*Dracaena afromontana*		Masale	Fence, boundary marking and grave marks	

Malvaceae	*Sida acuta*		Mlenda	Fodder	
Meliaceae	*Trichilia emetica*		Mbomu	Timber, fuelwood, poles, shade	
	Turraea robusta		Mokyanyama	Fuelwood	
Melianthaceae	*Bersama abyssinica*		Mchakuru	Timber, shade and fuelwood	
Menispermaceae	*Stephania abyssinica*		Not available	Weed, climber	
Moraceae	*Artocarpus heterophyllus*	Jack fruit	Mfenesi	Edible fruits, fuelwood	Tree 10–20 m
	Chlorophora excelsa			Timber	Tree to 35 m +
	Ficus exasperata	Fig	Msasa	Shade, fuelwood	Tree to 20 m
	F. natalensis		Mfumu	Shade, ritual tree	Tree 1–20 m
	F. vallis-choudae		Mkuu	Shade, fuelwood	Tree 1–20 m
	Morus alba	Mulberry	Ipala, Wero Iwero	Boundary marking, hedges, edible fruits	Tree to 15 m
Musaceae	*Musa nana*	Banana	Kiguruwe	Edible fruits, fodder	
	M. paradisiaca	Plantain	Mshare	Edible fruits, fodder	
Myrtaceae	*Eucalyptus camaldulensis*		Mkaratusi	Fuelwood, poles, crushed leaves relieve colds	
	E. citriodora		Mkaratusi	Fuelwood, poles, crushed leaves relieve colds	
	E. grandis		Mkaratusi	Fuelwood, poles, crushed leaves relieve colds	
	E. robusta		Mkaratusi	Fuelwood, poles, crushed leaves relieve colds	
	E. saligna		Mkaratusi	Fuelwood, poles, crushed leaves relieve colds	
	Myrica salicifolia		Mkaratusi	Fuelwood, medicinal	
	Psidium guajava	Guava	Mpera	Edible fruits, fuelwood	Tree to m
Oleaceae	*Olea capensis*		Mwisi, Mmasi	Fuelwood, edible fruits	Tree to 25 m
Passifloraceae	*Passiflora edulis*	Passion fruit	Loliondo, Mchio	Timber, fuelwood, poles, withies	Tree 20–30 m
Proteaceae	*Grevillea robusta*	Australian silky oak	Isapiku	Edible fruits	Climber
Rosaceae	*Eriobotrya japonica*	Loquat	Mkawilia	Timber, shade, fuelwood	Tree to 30 m
			Sambia	Edible fruits	
	Rubus steudneri		Mstafeli	Edible fruits, fuelwood	Tree to 7.5 m
			Mawero	Hedge, edible fruits	Shrubs

Appendix 20.1: Table. (continued).

Family name	Botanical name	Common name	Vernacular name	Uses	Remarks
Rubiaceae	*Coffea arabica*	Coffee	Mkahawa	Coffee, fuelwood	
	Pentas lanceolata		Not available	Weed, ornamental	
	Vangueria madagascariensis		Ndawiro, Ndoro	Fuelwood, edible fruits	Tree to 10 m
Rutaceae	*Citrus limon*	Lemon	Mlimau, Ndimu	Edible fruits, fuelwood	
	C. sinensis	Sweet orange	Mchungwa, Ichungwa	Edible fruits, fuelwood	
Solanaceae	*Capsicum annum*	Red pepper	Mpilipili	Spices	
	C. frutescens	Bird chillies	Ngogwe	Edible fruits	
	Datura arborea		Not available	Boundary marking	Tree to 7 m
	Lycopersicon esculentum	Tomato	Mnyanya	Edible fruits	
	Nicotiana tabacum	Tobacco	Mbatu	Snuff and tobacco	
	Solanum incanum		Ndu	Medicine for stomach ache and anti-snake bites	Shrub 1–2 m
	S. nigrum		Nafu	Vegetable	
Ulmaceae	*Trema orientalis*		Mrisio	Fodder, fuelwood	Fast-growing trees to 15 m
Verbenaceae	*Lantana camara*		Singarere	Hedge, grave marking, weed	Shrub 1–2.5 m

21. The role of agroforestry in the farming systems in Rwanda with special reference to the Bugesera-Gisaka-Migongo (BGM) region*

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Abstract. Rwandan farmers, who are faced with a perpetual land shortage, have evolved certain intensive systems of organic agriculture such as homestead (compound) farming which involve the combination of food, fodder and tree crops. To a certain extent these systems can satisfy the multiple needs of the subsistence farmers who live with several risks and constraints. However, they cannot cope with the expanding food demand of the rapidly increasing population.

Some multipurpose, low-input technologies and agroforestry approaches have been designed to improve the productivity of these traditional systems. These include inter/mixed cropping systems and rotations, alley cropping with leguminous trees and shrubs, use of planted "fallow", planting tree legumes on anti-erosive lines, mixed farming, community forestry and woodlots, and tree planting on farm/field boundaries. The essential aspects of these technologies are briefly discussed.

1. Introduction

Rwanda is a small land-locked country of 26,000 sq km situated just south of the equator in the east-central part of Africa. It has a high population density (480/km^2 of cultivable land) and an acute shortage of arable land. The average farm size was 1.19 ha in 1982 and it is expected to shrink to 0.71 ha in the year 2000 with the high population growth rate (3.6% per annum). This demographic pressure has not spared the grazing lands and marginal areas reserved for planting woodlands/forests. Only a small percentage of the country's need for firewood and timber is satisfied by forestry plantations; the rest comes from deforestation and land clearance. The land available for small-farm agriculture is virtually fixed at 1,200,000 ha, while the land under planted

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woodlands is planned to increase from 57,200 ha to 200,000 ha in the year 2000 (Delepierre 1985). This may ease the firewood-supply situation to a certain extent. The severe scarcity of arable land, rapid growth of population, insufficient production of food and fuelwood and the financial incapacity to modernize agriculture (unavailability of inputs and inadequate infrastructures) have been listed as the main impediments to agricultural development in Rwanda (Ntezilyayo 1983).

Continuous cropping without addition of adequate nutrients, cultivation of marginal and fragile lands not suited for crop production, and increasing deforestation have caused serious soil degradation throughout the country. Given the country's financial constraints, increased production of food and firewood must come from the rational intensification of low-input crop production systems utilizing the locally available resources to a maximum extent. Although Rwandan farmers have a few trees on their farms, well-managed agroforestry systems are not widely practised. However, in the prevailing conditions of subsistence agriculture and other forms of land use in the country, sustainable agroforestry systems are of great relevance (Nair 1983). A few initiatives in this direction have already shown promising results (Newmann 1983; Zeuner 1981). This paper evaluates the existing land-use systems of Rwanda, with special emphasis on the Bugesera-Gisaka-Migongo (BGM) Region, with a view to identifying the possibilities of agroforestry interventions and other improvements.

2. General description of the area

The BGM Agropastoral Project area, where the ISAR/IITA FSR Program is being implemented, is situated in the southern part of the eastern savanna zone, as shown in Fig. 21.1 (02°00′ and 02°26′ S and 29°58′ and 30°53′ E). The altitude ranges from 1,200 to 1,800 m with a gently undulating topography. A large number of lakes found in this zone constitute the major water resources for humans and animals.

2.1. *Biophysical environment*

Climate

The savanna zone is semi-humid with a mean annual rainfall between 700 and 1,000 mm, and a pronounced dry season of four months or more (June-September). There are two rainy seasons: "short rains" from October to November and "long rains" from mid-February to May; the annual rainfall is equally distributed between two seasons. The mean annual temperature is around

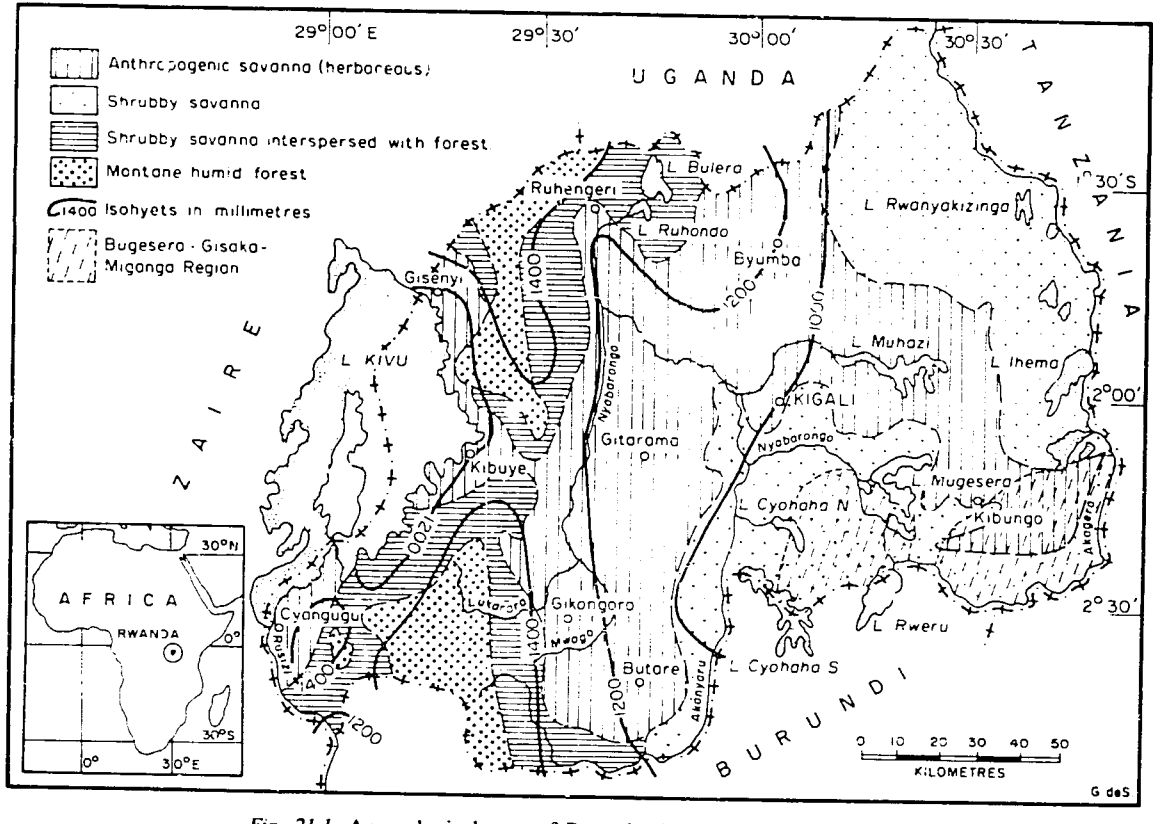

Fig. 21.1. An ecological map of Rwanda showing the study region.

21 °C and relative humidity 55–75%. Drought risk is very high in this zone due to the irregular distribution of rainfall.

Soils

The soils of the BGM region have developed from quartzite, schist, schist-quartzite, mica-schist, granite, gneiss, intrusions of basic rocks (dolomites) and colluvium/alluvium derived from the above (Frankart 1963; Neel 1975).

The main soil types are:

Raw mineral soils (Entisols) These are too shallow and gravelly to be cultivated; are found in hill tops, eroded steep slopes, and exposed hard-pans; cover about 30% of the area and should normally be left under planted forest.

Tropical black clays (Vertisols) Occupying about 5% of the area, mainly in valley bottoms and low-lying areas bordering the lakes and rivers, these soils are chemically rich but have poor physical properties; their productivity can be improved by providing drainage and incorporating organic matter.

Tropical brown soils (Inceptisols) These have developed from colluvium and are found in the foothills and lower slopes just above the valleys/lakes; they have excellent potential for agriculture, but they cover only about 5% of the total area.

Ferruginous and ferrallitic soils (Oxisols, Ultisols, Alfisols) These are highly variable in depth, gravel and organic-matter content, fertility, and susceptibility to erosion and drought; they cover a major part of the region (60%) and are found on the plateaux as well as the mid- and lower slopes of the gently sloping hills; their agricultural potential is fair to medium; addition of organic matter and nutrients and control of erosion will be necessary to improve and maintain their productivity.

Indigenous vegetation

The Bugesera-Gisaka-Migongo Region is characterized by natural tree savanna with its various formations and densities of tree stands being mainly a function of different soil types. The following genera are represented:

Trees and shrubs

Acacia, Acanthus, Albizia, Brachistigia, Canthium, Combretum, Commiphora, Crotalaria, Dombeye, Erythrina, Euphorbia, Kigelia, Markhamia, Rhus, Ricinus, Sesbania, Solanum, Vernonia.

Herbs

Bidens, Brachiaria, Cymbopogon, Cynodon, Cyperus, Eragrostis, Hyparrhenia, Panicum, Setaria, Sporobolus.

The rarely or never-cultivated swamps are dominated by *Cyperus papyrus* and *Phoenix reticulata* (palms).

2.2. *Land-use systems*

Agriculture

As mentioned earlier, the population of Rwanda increases at a very high rate of 3.6% per annum and consequently the average size of farm holding decreases steadily over the years. Table 21.1 shows the estimated trends in these changes. As in the other parts of Rwanda, 95% of the regions' population is rural and the people live in individual houses scattered over the plateaux and hills. The mean family size in this region is 6.2 members, as compared to the national average of 4.5 (Table 21.2). As this area has been newly inhabited, mean arable land per family (2.3 ha) is also larger than the corresponding figure of 1.2 ha for the nation. Each production unit consists of 2–3 parcels – homestead (compound) farm and distant parcels – the latter located at some distance from the compound either on the plateaux, in the valley bottom or near the lakes. Important crops in the homestead are coffee, banana, beans, groundnut, maize and sorghum. In the distant plots, cassava,

Table 21.1. Estimated trends in population growth and size of holding in Rwanda.

Particulars	Years			
	1982	1987	1992	2000
Total population (millions)	5.46	6.57	7.84	10.24
Farming population (millions)	5.02	5.86	6.67	7.77
No. of farm holdings (millions)	1.12	1.36	1.59	1.94
Family size (no. of individuals)	4.50	4.30	4.20	4.00
Available land/family, ha	1.19	1.00	0.87	0.71

Source: Delepierre (1985).

Table 21.2. Mean family size, farm area and labour in Rwanda and in the BGM region.

Particulars	Rwanda 1982	BGM 1983
No. of persons per family	4.5	6.2
No. of active workers per family	—	3.1
Arable land per family, ha	1.2	2.3
Arable land per worker, ha	—	0.7
% of families with non-farm income	—	36.1

Source: Data for the whole of Rwanda from Delepierre (1985), those for the BGM Region from Balasubramanian and Price (1983), and Price *et al.* (1983).

Table 21.3. Trees, shrubs and perennial climbers in rural Bugeresa region (Rwanda).

Family	Botanical name	Form	Origin	Multiplication	Part of the plant used	Uses, particulars
Acanthaceae	*Acanthus pubescens*	s	n	Seed	le	Fodder, trad. remedy (acne)
Anacardiaceae	*Mangifera indica*	t	n	Seed	fr, st, br	Edible fruit, fuel
Asteraceae	*Vernonia amygdalina*	s	n	Seed	le, rt, st, ba	Trad. remedy (abscess, hepatitis, expelling of afterbirth)
Bignoniaceae	*Jacaranda acutifolia*	t	e	Seed	st, br, fl	Carvings, bee forage, timber, fuel, ornamental
	Kigelia africana	t	n	Seed	st, br	Fuel
	Markhamia lutea	t	n	Seed	st, br	Timber, fuel, poles, utensils
	Spathodea campanulata	t	e	Seed	st, br	Ornamental, fuel
Bombacaceae	*Ceiba pentandra*	t	n	Seed	se, st, br	Silkcotton (kapok), fuel
Caesalpiniaceae	*Cassia spectabilis*	t	e	Seed	st, br	Fuel, timber, hedge, windbreak
Caricaceae	*Carica papaya*	t	e	Seed	fr, le	Edible fruit, meat tenderizer
Combretaceae	*Combretum* sp.	t	n	?	st, br	Fuel
Euphorbiaceae	*Euphorbia candelabrum*	t	n	Cutting	—	Property delimitation
	E. tirucalli	s/t	n	Cutting	st, le	Property delimitation, fuel, trad. remedy (animal eye diseases)
	Ricinus communis	s	e	Seed	se, le, st	Stakes, trad. remedy (poisoning, constipation)
	Synadenium grantii	s	n	Cutting	le, latex	Trad. remedy (headache), glue
Fabaceae	*Cajanus cajan*	s	e	Seed	fr, br, le	Legume, fuel, trad. remedy, fodder
	Erythrina abyssinica	t	n	Seed	fr, br	Fuel, utensils, furni ture, beehive
				Cutting	fr, ba	fixing, trad. remedy (hepatitis, constipation)
	Sesbania macrantha	s	n	Seed	le	Fodder, fallow
	S. sesban	s	n	Seed	br, le, fl	Fodder, fuel, stakes, trad. remedy (eyes)

Lauraceae	*Persea americana*	t	e	Seed	fr, st, br	Edible fruit, fuel
Mimosaceae	*Acacia hockii*	t	e	Seed	st, br, fl	Fuel, utensils, bee forage
	A. polyacantha	t	n	Seed	st, br, ba,	Fuel, charcoal, bee forage, trad. remedy
	A. sieberana	t	n	Seed	st, br, ba, fl	Fuel, charcoal, bee forage, trad remedy (cyst.)
	Albizia chinensis	t	e	Seed	st, br, fl	Timber, fuel, bee forage, shade for coffee
	A. gummifera	t	n	Seed	st, br, fl	Bee forage, utensils, timber, fuel
Moraceae	*Ficus gnaphalocarpa*	t	n	Cutting	st, br, le	Utensils, fuel, fodder, fences
	F. thonningii	t	n	Cutting	st, ba, le	String, utensils, fuel, fodder, furniture, poles, fences
Myrtaceae	*Eucalyptus* spp.	t	e	Seed	st, br, le, fl	Fuel, timber, trad. remedy (asthma), bee forage
	Psidium guajava	t	e	Seed	fr, st, br	Edible fruit, fuelwood
Passifloraceae	*Passiflora edulis*	c	e	Seed	fr	Edible fruit (industrial juice production)
Proteaceae	*Grevillea robusta*	t	e	Seed	st, br	Timber, fuel, furniture
Rhamnaceae	*Maesopsis eminii*	t	n	Seed	st, br	Timber, indoor construction, fuel
Rubiaceae	*Coffea arabica*	s	e	Seed	fr	Fruit for coffee export, trad. remedy (expelling of afterbirth)
Rutaceae	*Citrus* spp.	t	e	Seed	fr	Edible fruit, fuel
Solanaceae	*Solanum aculeatissimum*	s	n	Seed	br	Fences, fuel
Ulmaceae	*Trema orientalis*	t	n	Seed	st, br	Fuel, timber

Legend: t = tree; s = shrub; c = climber; n = native; e = exotic; le = leaf; ba = bark; br = branch; st = stem; rt = root; fl = flower; fr = fruit
Source: ISAR (1985).

sweet potato, sorghum and fodder grass which require less intensive care are grown. Other minor crops observed in this region are colocasia, yam, Irish potato, soybeans, cowpeas, peas, vegetables and fruits.

Forestry

The indigenous forest (savanna woodland) of the region has almost disappeared due to conversion to agricultural land by the increasing population and charcoal production for the country's capital. Therefore, the Rwandan Government encourages planting of community forests for fuelwood and timber production throughout the country. Trees for fruit, fodder and other uses are planted as well. While trees for fuelwood and timber (mainly *Eucalyptus* spp., *Pinus* spp., *Grevillea robusta*) are usually planted in small community and private woodlots or along roadsides, fruit and fodder trees are more often integrated into homesteads and cultivated areas. Seedling production is assured by 10–15 nurseries per 60,000 inhabitants funded by the government and development projects. Table 21.3 lists the most important tree species which are integrated into farms.

Agroforestry

As pointed out earlier, many of the farmers are accustomed to retaining and integrating trees into their farmland. Data in Table 21.4 show the importance of trees in small farms of the BGM region.

About 86% of the households have at least a few trees on their farms. They are arranged mainly around the houses (*Ficus* spp., *Sesbania* spp.) and along road sides (*Cedrela serrulata*, *Cassia spectabilis*, *Grevillea robusta*), integrated into banana fields (*Acacia* spp., *Maesopsis eminii*, *Ricinus communis*), or other crop fields (*Albizia* spp., *Erythrina abyssinica*, *Markhamia lutea*, *Solanum* spp., *Vernonia* sp.) and/or planted on property boundaries (*Euphorbia tirucalli*). Live and fodder hedges, however, have rarely been recognized in this area. Two field examples of these indigenous agroforestry practices are shown in Figs. 21.2 and 21.3. The essential aspects of these traditional agroforestry practices are described below.

Table 21.4. Importance of trees in small farms in the BGM region of Rwanda.

Particulars	Bugesera	Gisaka-Migongo	Mean for BGM region
Farms with fruit trees %	83.0	88.5	85.7
No. of fruit trees/farm	11.0	7.3	9.1
Farms having woodlots, %	—	16.0	—
Area in woodlots, 100 m^2	0.4	2.0	1.2

Source: Data for Bugesera from Price *et al.* (1983), those for Gisaka-Migongo from Balasubramanian *et al.* (1984).

Fig. 21.2. Cedrela trees intercropped with sweet potato, taro, banana, avocado, etc. at Kamembe, Cyangugu District, 1,550 m a.s.l. (photo: A. Egli).

Fig. 21.3. A multispecies plant association on a small farm at Mugusa, Butare District: trees include mango, cedrela and ficus, with coffee and banana in the foreground (photo: A. Egli).

3. Structure of the system

3.1. *Homestead farming*

Crops

Banana (*Musa* spp.) is the principal crop; it is normally intercropped with beans (*Phaseolus vulgaris*) and groundnut (*Arachis hypogaea*), both mixed with maize (*Zea mays*) during both seasons and with sorghum (*Sorghum bicolor*) during the January–May season (Table 21.5). Other food crops planted under banana are sweet potato (*Ipomoea batatas*), cassava (*Manihot esculenta*), colocasia (*Colocasia* spp.), pineapple (*Ananas comosus*), cabbage (*Brassica* sp.), chilli pepper (*Capsicum* sp.), etc. Several types of bananas (beer, cooking and dessert types) are planted in mixed stands. Production and sale of banana beer is crucial to the farmers' monetary income. The surplus of cooking- and dessert-bananas and other food crops is sold in the nearby markets.

Table 21.5. Banana-based cropping systems practised in the Bugesera region of Rwanda during 1983/84.

Cropping systems	% of mean area*
October–December, 1983	
1. Banana sole	52.4
2. Banana + beans + maize	17.2
3. Banana + sweet potato	7.6
4. Banana + beans + maize + cassava	4.8
5. Banana + cassava	2.6
6. Banana + beans + cassava	2.6
7. Banana + cowpea	2.6
8. Banana + cocoyam	2.5
9. Others (11 systems)	7.8
February–May 1984	
1. Banana sole	32.7
2. Banana + sorghum	22.6
3. Banana + beans	10.1
4. Banana + beans + maize	6.5
5. Banana + sorghum + cassava	5.1
6. Banana + beans + sweet potato + cassava	3.5
7. Banana + sweet potato	3.4
8. Banana + beans + maize + sweet potato	3.1
9. Banana + cocoyam	2.4
10. Others (24 systems)	10.6

* Mean banana area = 0.45 ha/farm over 100 farms sampled.

Coffee (*Coffea arabica*) is an important cash crop and the entire production is sold for cash. According to Balasubramanian and Price (1983) the main sources of cash income for the families during 1983 in the Gisaka-Migongo region were as follows: banana 38.3% of total cash income, other food crops and their products 13.9%, salary and wages 28.4%, coffee 11.7%, livestock 5.2% and other off-farm income 2.5%.

Trees and shrubs

Farmers plant a variety of fruit trees and other perennials in the homestead; important among them are papaya (*Carica papaya*) and avocado (*Persea americana*), followed by guava (*Psidium guajava*), jack fruit (*Artocarpus heterophyllus*), citrus (*Citrus* spp.), mango (*Mangifera indica*) and passion fruit (*Passiflora* spp.). On the average, each farm has nine kinds of trees (Table 21.4). Other woody perennials found in the homestead are castor bean (*Ricinus* sp.) and a few stands of *Grevillea robusta*, *Cassia spectabilis* and/or *Markhamia* sp. around the house for shade in the compound. Castor bean, which grows tall and produces forked branches at a height of about 3 m, is grown in banana fields and the well-grown stems support heavy bunches; their large leaves are used as cover for sorghum fermentation. Other trees are grown for construction poles/wood and firewood. Dried leaves and small twigs are composted along with other household wastes.

Animals

Both cattle and small ruminants are kept by farmers and the mean number per household is 12 (Table 21.6). Most of these animals are local breeds, although a few progressive farmers have started raising improved ones, particularly cattle and chickens. The local cattle breed, "Ankole", is being improved by selection and cross-breeding with Jersey, Sahiwal and Friesian to achieve better milk and meat production. Owing to the lack of sanitation and proper

Table 21.6. Mean number of farm animals per household in the BGM Region during 1983.

Type of animal	Bugesera	Gisaka-Migongo	Mean for BGM
Cattle	2.0	0.8 (1.8*)	1.4 (1.9*)
Goats	3.0	4.0	3.5
Sheep	0.4	0.5	0.4
Rabbits	—	0.4	—
Pigs	0.1	0.2	0.1
Birds	6.0	5.5	5.7

Source: Data for Bugesera from Price *et al.* (1983), those for Gisaka-Migongo from Balasubramanian *et al* (1984).

* Includes the animals kept on ranches by individual farmers in Rusumo.

feed, these improved breeds have not dispersed into the rural environment to the extent needed to make an impact (Iyamuremye 1983).

The area under pasture is gradually diminishing, and this will force farmers to reduce the number of cattle and increase the number of small animals such as goats, sheep, rabbits and pigs kept on individual farms. On average, each farm presently has 1.9 cattle, 3.5 goats, 0.4 sheep, 0.1 pig and 5.7 chickens (Table 21.6). Thus, small livestock will play an increasingly important role in animal production by small farmers.

In the Gisaka-Migongo region, 40% of cattle, 82% of goats, 67% of sheep, 97% of rabbits, 95% of pigs and 80% of birds (mainly chickens) are kept in full or partial confinement and stall-fed. The rest are kept on free-range. Fallow plots and communal grazing lands are used for grazing animals on free-range. Cut fodder and crop residues are used to feed animals kept in stalls (Balasubramanian 1984).

3.2. *Planted woodlots*

Many farmers plant *Eucalyptus* spp. and *Grevillea robusta* on relatively infertile and degraded parts of their land which are not suitable for cropping. These private woodlots are intercropped with food crops (beans, groundnut, sorghum, maize, etc.) during the first 2–4 years when the planted trees are young. During intercropping, the branches of trees are lopped off to reduce inter-species competition for light and water, and the loppings used as mulch and/or fuel. On average, each farm had 120 m^2 of such planted woodlot in 1983 (Table 21.4).

3.3. *Arrangement/interaction of components*

The arrangement of the components in the above systems is haphazard. However, a distinct vertical zonation of tall trees (6 m and above), banana (3–4 m), cassava and sorghum (2–3 m), and low-growing food crops (0–1 m) is evident in banana fields. There is considerable overlap of storeys in the compound farms.

Coffee, however, is grown as a monocrop. The Rwandan Government has prohibited intercropping of coffee fearing that there might be a reduction in coffee yield from the possible inter-species competition for nutrients and water. Presently some farmers grow grasses (*Tripsacum* sp., *Setaria* spp. and *Vetiver* sp.) on field boundaries and anti-erosive lines; these grasses are periodically cut and used for feeding animals and/or for mulching. The system is somewhat comparable to that of the Chagga homegardens of northern Tanzania (Fernandes *et al.* 1984; Chapter 20).

The following interactions between components can be observed:

- Direct: trees/shrubs and food crops, grass strips and coffee, and cattle manure and crops, trees/shrubs;
- Cyclic: crop residues and livestock;
- Competitive: trees/shrubs and food crops, bananas and other food crops and coffee.

Farmers also use crop residues from sorghum, banana and beans as mulch for coffee which results in a transfer of fertility from food-crop fields to coffee plots. Consequently, the yields of food crops decline rapidly unless the nutrient loss is compensated by the addition of manure. Another effect is the reduction in total banana production due to wider spacing of bananas to allow intercropping; here the reduction in banana yields is probably more than compensated by the yield of associated food crops. These interactions have not been researched in detail to obtain quantitative data.

In planted woodlots, there is competitive and complementary interaction between the young tree seedlings and the interplanted food crops. Cultivation of food crops improves infiltration of water into the soil, reduces weed problems and favours the growth of tree seedlings. However, competition for moisture and nutrients between food crops and tree seedlings is inevitable, particularly during drought periods and on poor and marginal soils. Farmers manage the above cropping systems according to their present demands. Shade-tolerant crops such as colocasia, beans and cassava are selected for intercropping with bananas. During the intercropping period, the bananas are pruned by removing the old and photosynthetically inactive leaves in order to open up the canopy for the understorey crops. The weeds and banana wastes are used as mulch on the banana stands. Cattle manure and compost are preferentially applied to bananas and the intercropped beans, sorghum and vegetables in fields close to the compound. Farmers also plant some sweet potatoes on flat land under the banana canopy to conserve the planting material through the long dry season (June–September); these conserved sweet potato vines will be used for planting in the October–December season. Voluntary crops of chilli pepper and tomatoes are allowed to grow in the banana field. Spreading melons/pumpkins (*Cucurbita* spp.) are also interplanted with bananas and they cover the soil quickly.

4. Management of the system

In Rwanda, farmers traditionally have permanent land-use rights. Sons of each family share the family properties equally and this leads to continuous subdivision of holdings. As mentioned earlier, the national mean for farm size

in 1982 was 1.2 ha, whereas in the recently inhabited BGM region it is about 2.3 ha (Table 21.2).

A holding has to support an average of 4.5 members of a family for the country as a whole and 6.2 members in BGM region. Wherever possible, each family tries to possess plots on the plateau as well as in the valley bottoms. About a third of the land is in the homestead and its close vicinity.

An average family with 6.2 members provides a work force of 3.1 active workers in the age group of 15–59 years (Table 21.2). Thus, about 50% of the population is outside this age group and has to be supported by the active members. Generally banana and coffee are taken care of by men and food crops by women.

Cash for the purchase of a few inputs and for hiring labour is obtained from the sale of surplus food crops and their products, salary and wages, coffee, livestock, and off-farm income, as indicated earlier.

Mostly locally available biological inputs (manure, compost, crop residues, seed from previous crops) are used by farmers in the BGM region. Only about 8.4% of the cropped area is planted with improved seeds by 42% of the farmers (Price *et al.* 1983). About 40% of the cropped area owned by 71% of the farmers receives organic manure. Farmers neither apply chemical fertilizers nor use tractors for food-crop farming. The BGM project distributes improved cattle on loan to selected farmers to encourage mixed farming. Other credit facilities are very limited.

Each holding is operated on a subsistence basis, producing the family's food requirements. In 1983, each family in the Gisaka-Migongo region produced an average of 458 bunches of bananas, 393 kg of beans, 94 kg of groundnut, 461 kg of sorghum, 911 of cassava, 1,142 kg of sweet potato and 112 kg of coffee (Balasubramanian and Price 1983). About 45% of the food products and 100% of the coffee are sold. Poor crop yields due to drought may be encountered once in 3–5 years; complete crop failure has never occurred.

Average livestock production per farm was 302 litres of milk and 343 eggs per year during 1983. Fodder production during rainy seasons is adequate, but during the dry season (June–September) animals suffer from an acute shortage of forage.

Land under perennial crops (coffee and banana) is fairly well protected against erosion. In addition, these fields are also mulched and manured to a certain extent to maintain soil fertility. Food-crop plots are neither manured nor mulched. However, inclusion of legumes in rotations and mixtures adds some biologically fixed nitrogen to the system. The fallow cycle is very short, i.e., one year or less which is not enough to restore soil fertility. As such, there is a continuous decline in soil fertility and crop yields with time.

5. System dynamics

5.1. *Rate of growth*

Owing to scarcity of arable land, farmers have started tilling marginal land normally reserved for grazing and planting trees. This practice, coupled with inadequate nutrient addition and soil-conservation measures, has caused serious soil degradation. Therefore, the already-low crop yields are declining further. The introduction of more efficient production systems adapted to the poor soils and semi-arid climate of the region is necessary to produce sufficient food from the existing land.

5.2. *Sustainability*

The system described above cannot be sustained in its present form and meet the food requirements of the increasing population. Soil degradation and decreasing yields have to be arrested as soon as possible. Restoration and maintenance of soil fertility are possible only with some modifications, keeping in mind their long-term sustainability, as discussed below.

5.3. *Special features*

The positive features of Rwandan smallholder farming are the following:

- Absence of burning as a land-clearing method;
- Mixed cropping of non-legumes and legumes, and rotation of grain legumes with cereals;
- Mulching of coffee and bananas;
- Effective use of household wastes, crop residues and weeds through composting;
- Use of well adapted mixtures of local varieties, careful working of the soil with hoes, and good care of major crops (Neumann 1983).
- Use of overlapping mounds which aid in trapping rainfall and moisture conservation;
- Use of grass strips on anti-erosive lines to reduce erosion and obtain mulch and fodder; and
- Establishment of woodlots for firewood.

The negative features are:

- Overcropping without the addition of adequate nutrients and cropping of marginal lands;

- Poor integration of cropping and livestock activities;
- Poor handling and conservation of cattle manure, resulting in loss of nutrients;
- Absence of the rational and systematic use of leguminous trees and shrubs in farms;
- Absence of the use of planted fallows to improve soil fertility; and
- Overgrazing of pasture land due to excess stocking.

6. Evaluation

6.1. *Merits*

To the positive features of the systems mentioned above, the following merits can be added:

- The high-quality coffee produced by the small farmers (mostly by manual handling) contributes significantly towards the country's foreign-exchange earnings;
- Well adapted local crop varieties, particularly of beans and sorghum, give fairly high yields and have a good level of resistance against insects and diseases (ISNAR 1983); and
- All the benefits of mixed/intercropping of annual crops with or without perennial crops and trees/shrubs; (a) better use of space, nutrients and moisture; (b) reduced risks due to unpredictable drought and pests; (c) continuity and variety in food supply; (d) extended soil cover and effective erosion control; (e) flexibility in labour utilization and demand; (f) fair satisfaction of farmers' present multiple needs.

6.2. *Weaknesses/Constraints*

Apart from the negative features pointed out above, these systems suffer from the following drawbacks:

- The growing food demand cannot be met by the present productivity level of these systems; and
- Scattered distribution of farmers and farm families all over the region makes it difficult for the extension service to effectively reach all of them.

6.3. *Extrapolatability*

The small-farmer systems of the BGM region have evolved over a period of continuous land scarcity which has forced the farmers to try innovations and

produce more food with the skilful use of locally available resources. These systems should be studied, understood and improved, wherever necessary, for introduction to other tropical areas with a similar environment. With suitable alterations these systems can also be effectively introduced into the lowland tropics. As pointed out by King (1979), about 65% of the area of the tropics is considered ecologically fragile and these areas need similar systems of intensive organic farming to improve and sustain the agricultural productivity of the land.

6.4. *Research needs*

Study and understanding of the existing systems evolved through ages by the industrious and inventive small farmers must be the starting point for research to develop improved systems. It is true that experience with organic agriculture and traditional cultivation methods offers many clues for the successful development of efficient low-input technologies (Ntezilyayo 1983). The research strategy must be oriented to select new crops and varieties and develop improved, sustainable production systems which are adapted to the region. Some of the research approaches that deserve special attention are listed below.

Inter/mixed cropping systems and rotations

Rational use of grain and green-manure legumes in the inter-mixed cropping systems based on cassava, sweet potato, sorghum, beans and bananas is under experimentation. The grain legumes selected for this study are beans, cowpeas, soybeans and groundnuts, while the green manure/mulch legumes are *Crotalaria* sp. and *Mucuna pruriens*. Different spatial and temporal arrangements of these crops are being investigated. Evaluation of the new systems takes into account not only their food-production potential but also their contribution to the supply of fodder for animals and green manure/mulch for soil improvement and the duration of canopy cover for soil protection. The timing and nature of these sole and inter-cropping systems in suitable rotations is very important to take full advantage of the rainfall distribution and to ensure a continuous supply of a variety of foods throughout the year (Ezumah and Balasubramanian 1983).

Alley cropping with leguminous shrubs and trees

Alley cropping is an agroforestry system in which food crops are grown in alleys formed by hedgerows of trees/shrubs that are periodically pruned during cropping to prevent shading, minimize intercrop competition for

moisture and nutrients, and provide green manure/mulch for the associated food crops (Wilson and Kang 1981). Additionally, the alley (hedgerow) species provides stakes for climbing crops, firewood for cooking, protein-rich fodder for livestock, protection against soil erosion (especially when the hedgerows are planted along the contour) and substantial amounts of biologically fixed nitrogen to improve soil fertility. The deep roots of trees/shrubs will help recycle nutrients from the subsoil to the surface. The species selected for alley cropping must be fast growing, deep rooted and able to withstand frequent pruning (Kang *et al.* 1984).

The suitability of this system for the BGM environment is being investigated using four leguminous shrubs, namely *Leucaena leucocephala*, *Calliandra callothyrsus*, *Cassia spectabilis* and *Sesbania sesban*. The first and the third species are also being evaluated for alley cropping with fodder grasses such as *Tripsacum* sp. to improve the quality of cut fodder (Balasubramanian *et al.* 1984).

Use of planted fallows

Owing to the severe land shortage in the BGM region, the duration of fallow has been reduced to one year or less. Such short-season fallows covered by weeds and grasses and used as temporary pasture for grazing domestic animals are not effective in fertility restoration. If these fallows are planted to green manure/mulch legumes such as *Crotalaria* sp., *Mucuna pruriens*, *Cajanus cajan* and *Sesbania sesban*, which are found to grow well under minimum care in this semi-arid zone, a significant improvement in soil fertility is possible within short periods. These species also form good fodder for animals, add substantial amounts of fixed N to the soil and offer an excellent protection to the soil (cover crops).

Planting tree legumes on anti-erosive lines

At present, the BGM farmers use mostly grass strips planted with *Tripsacum* sp., *Setaria* sp. and *Vetiver* sp. on anti-erosive lines to reduce runoff and control soil erosion. Periodic cutting of these grasses for use as fodder and mulch has led to the depletion of soils and consequently poor growth of grasses on anti-erosive strips. In 3–5 years, the growth rate of grasses is so low that the primary function of erosion control is defeated. The grass strips can be stabilized by planting tree/shrub legumes in association with grasses; in this arrangement the legume species will provide the biologically fixed N to sustain the growth of grasses. If properly managed, the tree components will provide fodder for animals, fuelwood for cooking, stakes for climbing crops, and green manure/mulch for soil amelioration. At present, *Leucaena leucocephala*, *Cassia spectabilis* and *Cajanus cajan* are being evaluated for their effectiveness

in stabilizing anti-erosive grass strips. Other suitable trees may be *Grevillea robusta* and *Cedrela serrulata* (Balasubramanian *et al.* 1984).

Mixed farming

The BGM Project encourages mixed farming by providing cattle on loan. The positive influences of combining cropping and livestock activities are effective utilization of crop residues as fodder, efficient production of milk, meat and manure, and, wherever feasible, use of cattle for draught power. Fodder cropping with legume shrubs and trees as well as grasses will meet the feed requirements of the livestock.

Community forestry and woodlots

At present, *Eucalyptus camaldulensis*, *E. tereticornis* and *Grevillea robusta* are the most commonly used trees for afforestation of community land and private lots. Several species are under investigation at the Karama Research Station to select the most suitable species for this region where drought and termite attack are serious problems causing more than a 30% loss of planted trees. Two recently-introduced fast-growing trees, namely, *Acrocarpus fraxinifolius* and *Melia azedarach* appear to be promising from early results of the above trials.

Planting trees on the farm/field boundaries

Most farmers in the BGM region use *Euphorbia tirucalli* to demarcate farm boundaries and fields because this species is easy to establish from cuttings, is fast growing and is highly resistant to drought and termites. Planting of this and other multipurpose species is being supported by the BGM project.

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22. *Acacia albida* and other multipurpose trees on the Fur farmlands in the Jebel Marra highlands, Western Darfur, Sudan*

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Abstract. This paper describes the traditional agroforestry systems based on *Acacia albida* and other multipurpose trees as practised by the sedentary Fur people on the lower slopes and highlands of the Jebel Marra massif, Sudan. The basic agrosilvopastoral system consists of terraced village fields, where semi-permanent rain-fed cropping of staple millet and other subsistence crops takes place under stands of multipurpose trees dominated by *Acacia albida*, *Cordia abyssinica* and *Ziziphus spina-christi*. Trees have been retained primarily for food, wood and fodder. Thorn from cut and browsed branches makes good fencing material.

This system has sustained a densely settled population over centuries. However, recent out-migration of people from the montane dry-farming areas has caused a gradual return to shifting cultivation. As a consequence, the present-day subsistence farming in the region is characterized by a general level of carelessness and exploitative management and this is reflected in a successive decrease of the tree cover.

The evaluation of the AF practices described includes a discussion on their regional importance and extrapolatability within the framework of similar situations, especially in Africa, emphasis being given to montane and highland conditions. The outstanding potential of *Acacia albida*-based AF systems to be sustained and spread almost all over semi-arid to semihumid Africa is highlighted by illustrating its ecologic and economic variability. Extrapolation of such examples, however, is not feasible without thorough investigations concerning the ecological, ethnological and socio-economic conditions in the respective project areas. Basic research needs for improving and extending the system are also indicated.

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1. Introduction

The Jebel Marra massif is an isolated volcanic complex which rises up to 2,000 m from the surrounding peneplain. The area has elevations of up to 3,000 m a.s.l. and therefore moderate climatic conditions, contrasting with the Sahelian surroundings. At present the massif is inhabited by the Fur tribe who are negroid, sedentary, hoe agriculturalists of still-unknown origin. They succeeded earlier cultivators who could be traced back to Neolithic times (Belfour-Paul 1955), and who presumably started to convert the originally wooded slopes of the mountains into the terraced anthropic landscape which is to be found nowadays almost over the entire area. Obviously there have been several drastic fluctuations in population density and type/intensity of land use, being caused mainly by climatic changes, historical events and epidemics. The population density (1976) in the Jebel Marra massif is about 20–37 persons/km^2 (Watson *et al.* 1977), so that more or less extensive types of land use, such as shifting of fields and (periodically) whole villages are predominant.

Semi-permanent cultivation types with significant integration of trees and animals (agrosilvopastoral systems) are maintained only in small areas, where historic agglomerations of population are still found. Here, *Acacia albida* may be the dominant tree component in the altitudinal range between 1,400 and 1,900 m a.s.l. This "ideal farm tree" (Kerr 1942) has been the subject of several studies and scientific publications (Felker 1978), and basic data are now available about its ecology and geographic distribution (Wickens 1969; Fig. 22.1).

Most descriptions of *Acacia albida* agroforestry systems, however, refer to lowland localities in West Africa – especially Senegal and Burkina Fasso. Previous investigations on *Acacia albida* in the Jebel Marra area – which were undertaken mainly in the course of the UNSF-Jebel Marra Project (FAO 1968; Hunting Technical Services 1977a; Wilson 1979) – concentrate on the most conspicuous *Acacia albida* farmlands of the Wadi Azoum alluvial system in the pediplains west of the massif (Wilson *et al.* 1980; Radwanski and Wickens 1967). In contrast to those riverine habitats, the special feature of the montane *Acacia albida* populations in the Jebel Marra massif is their zonal distribution in all topographic situations that have sufficient fine-textured rooting substrate, thus seemingly independently of a perennial ground water-table.

Although the mountain regions are of limited extent within the Sudano-Sahelian zone, these agroforestry systems represent a most spectacular indigenous land-use system. Therefore, the Fur agroforestry systems are described here and the description is based on the field visits to selected villages in 1982 and 1983. The major scope of this paper is the evaluation of the Jebel Marra example within the framework of similar practices reported from other comparable (African) regions, in order to highlight the potential of *Acacia albida*-based AF systems on a wider ecological scale.

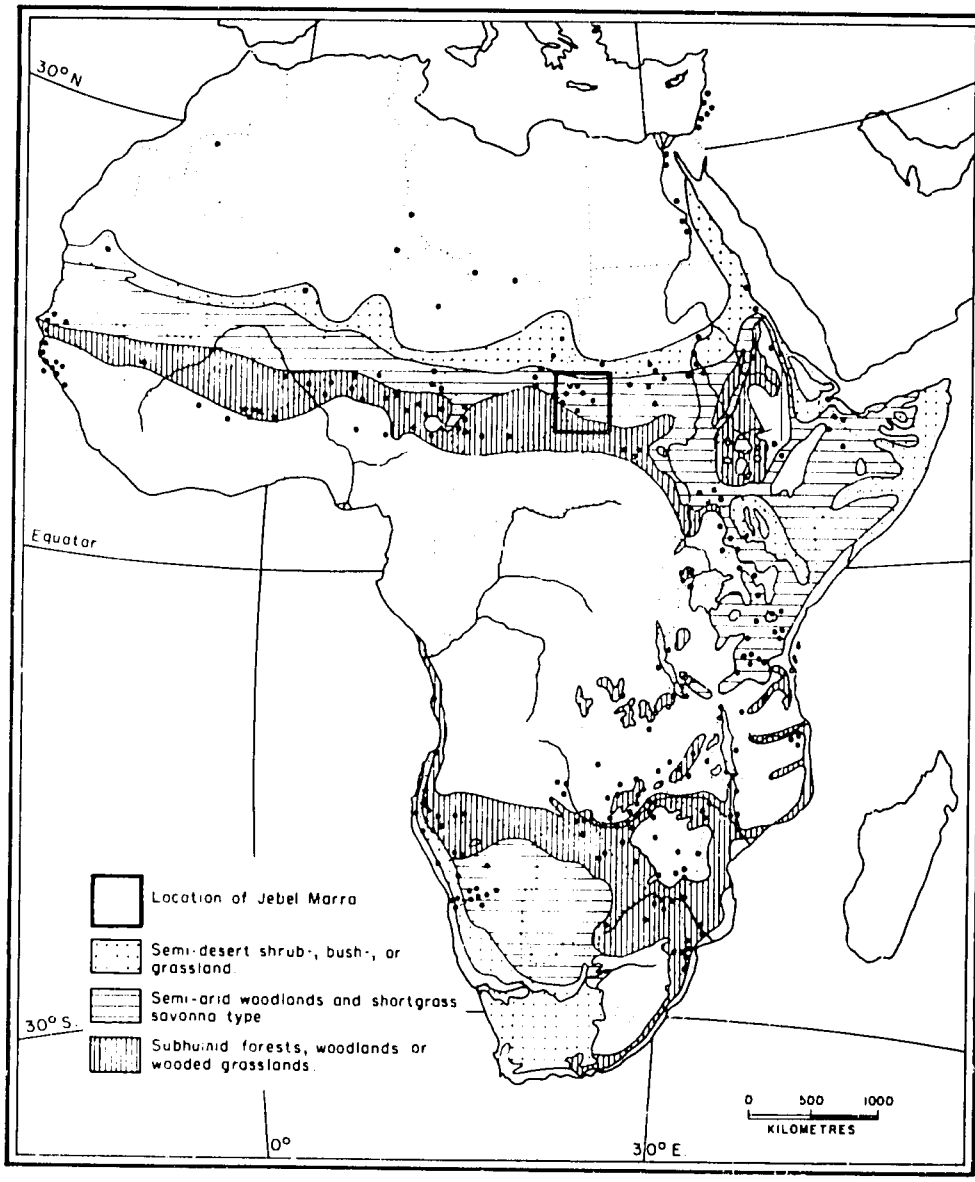

Fig. 22.1. Distribution of *Acacia albida* in Africa and the Near East. Each dot indicates either a literature reference or a herbarium record at Kew. Information is inadequate, especially from francophone West Africa. The box indicates the location of the Jebel Marra highlands.
Source: Redrawn from Wickens (1969), with kind permission.

2. General description of the area

2.1. *Geographic location*

The volcanic massif of Jebel Marra is located in the Western Darfur Province of the Sudan Republic almost in the centre of the African continent (12.5–14° N, 24.0–24.7° E), forming the watershed between the basins of Lake Chad and the Nile (Fig. 22.1). Uplands and highlands with summits around 3,000 m a.s.l. cover an area of at least 3,500 km^2.

2.2. *Biophysical environment*

Climate

Arising within the Sahel/Sudan zones of the tropical margin, the Jebel Marra massif is characterized by a semi-arid climate with unimodal rainfall and a pronounced six-month dry season. The regional climate, however, is strongly modified within the massif; the average annual rainfall rises from about 600 to 1,000 mm, with maxima on the western flanks and on the highlands above 2,000 m a.s.l. The temporal variability of rainfall is reduced, and the effectiveness of rains is increased, due to moderation of temperatures (lapse rate about 0.6° C/100 m). The mean annual temperature in Koronga is about 20°C. Night frosts occur during the generally cloudless winter months. Frequent hailstorms are an important agro-ecological factor. The mean growing period in Koronga, when precipitation exceeds potential evapotranspiration, extends between 5 July and 20 September, approximately 78 days (Hunting Technical Services 1977c).

Soils

The soils of the massif are poorly developed from basalt flows covered or interbedded with ashes, pumice and agglomerate. Regional characteristics are a tendency to acidity, negligible concentrations of soluble salts and very low $CaCO_3$ and organic matter content, wide C/N ratio, and a predominance of kaolinitic clay mineral. The agricultural value of the steep rocky slopes is limited by stoniness, but terracing brings about an efficient conservation of soils. The ash soils on which *Acacia albida* dominates are mostly deep and porous, have relatively high nutrient reserves (35 meq P and 160 meq K per 100 g) but low organic matter content (1%, C/N 13.6); are slightly acidic (pH 5.9) with relatively high values of cation exchange capacity (12 me/100 g) and base saturation (>50% of CEC) (White 1967). Even though these soils may be classified as Andosols in a wider sense, they differ considerably from the dark, humic montane soils occurring under more humid highland conditions.

2.3. *Vegetation*

As a consequence of several thousand years of human occupation, the natural vegetation of montane woodlands and forests has been converted to savanna. At least 60% of the massif surface has been terraced, causing an initial or subsequent removal of the woody vegetation. The secondary vegetation established under the influence of frequent fires, wood cutting and grazing on abandoned ancient terraces resembles the "savanna" types of unterraced land; the sub-montane zone (1,200–1,800 m a.s.l.) below the thermic upper limit of most tropical lowland plants, including sorghum and millet, constitutes the main area of rain-fed cultivation. Secondary vegetation is characterized by short and tall grasslands, woodlands dominated by *Anogeissus leiocarpa*, *Combretum* spp. and *Terminalia* spp., with *Azanza garckeana* occurring as a characteristic fallow pioneer. On remote sheltered basalt slopes, some *Khaya senegalensis*, *Dombeya quinqueseta* and *Cordia abyssinica*, *Erythrina abyssinica*, *Cussonia arborea*, *Maesa lanceolata* and *Syzygium guineense* may also be found. The herbaceous layer consists largely of perennial Gramineae (*Andropogon*, *Cymbopogon* and *Hyparrhenia* spp., *Heteropogon contortus*, etc.). Between 1,800 and 2,300 m a.s.l., *Acacia albida* dominates and forms the transition to the montane zone proper; in the herb layer of this pseudo-climax, bracken (*Pteridium aquilinum*), *Hyparrhenia hirta*, *Themeda triandra* and tall *Andropogon* spp. prevail, and these are replaced by *Hyparrhenia multiplex* and other weedy annuals in heavily grazed areas.

Acacia albida extends into the montane zone, where a partially evergreen dwarf-shrub and "tussock" grassland formation is combined with sparsely scattered evergreen trees and shrubs. *Olea laperrinei* and *Ficus palmata* (Saharo-montane and Afro-Oriental flora elements) are the only woody species occurring above the proper limit of *Acacia albida* (2,500 m a.s.l.). *Themeda triandra*, *Hyparrhenia hirta* and *Andropogon distachyos* are the dominant perennial grasses in this region, whereas the dwarf-shrubs include members of the Labiatae (*Lavandula pubescens*, *Satureja punctata*) and Compositae (*Conyza*, *Helichrysum*, *Gnaphalium* spp.). The percentage of ground-cover by trees in the highlands above 2,000 m is very low, usually below 5%. Figure 22.2 shows a general overview of the prevailing vegetation and land use in the Jebel Marra Highlands.

2.3. *Land-use systems*

Agriculture

At present, only about 10% of the total area of the Jebel Marra massif is cultivated annually, the remainder comprises either steep inaccessible slopes

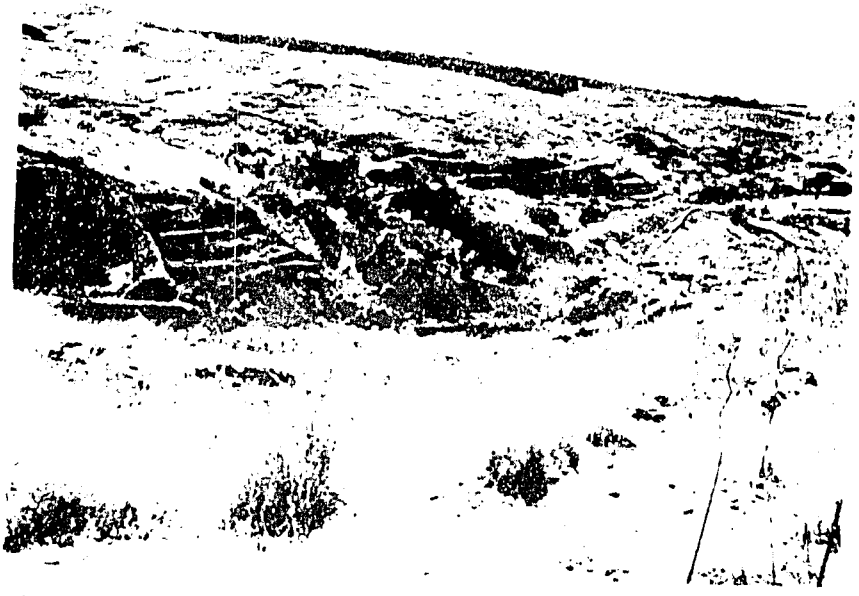

Fig. 22.2. A general view of the prevailing land-use systems in Jebel Marra: an example of Wadi Saria plateau (2,300 m a.s.l.; ash-basalt mixed soils; February 1983). Centre: modern, irrigated cash-cropping on re-cultivated, ancient terraces; taungya-like agrisilviculture (onions under young mango and citrus trees). Top left: rough grazing lands dominate the highlands; *Acacia albida* trees can be found scattered there. Centre background: one of the *Cupressus lusitanica* plantations; these are low-yielding and contribute little to the villagers' firewood needs. The summit region of the Jebel Marra (3,042 m a.s.l.) can be seen in the background; extensive grazing is practised there.

and "badlands", or fallow land which is utilized as rough grazing land. With this low degree of human occupation, the fire hazard is considerable all over the massif.

Rain-fed, smallholder cultivation of the staple cereals is the predominant agricultural system in the region; millet and sorghum, grown up to 2,000–2,200 m a.s.l., form the daily diet *asida* (a kind of porridge eaten with a vegetable sauce, usually enriched with some dried meat or curdled milk). Whereas livestock raising is less important in the Fur economy, irrigated (off-season) cultivation constitutes a traditional part of the smallholder production wherever perennial watercourses occur. In the olden days onion, tomato and chilli pepper used to be grown under irrigation for home consumption, and wheat as a cash crop. Only very recently (since about 50 years ago), has the irrigation sector been drastically extended as a part of rural development projects. The introduction of cash crops such as mango, citrus and guava, as well as potatoes and other vegetables, and the improvement of infrastructure and marketing facilities transformed the Fur economy into an at least partially commercialized production system. The highland plateau above 2,300 m a.s.l. is almost exclusively cropped with cash crops such as

potato, wheat, onion and garlic. Minor traditional occupations such as hunting, gathering of honey (wild bees and/or beekeeping), insects and wild plants, cotton-growing and weaving, etc. are vanishing rapidly. Local salt production from saline soil around Koronga is still economically important within the massif.

The influence of agricultural extension activities on the traditional rain-fed cultivation sector in the Jebel Marra massif has been negligible so far.

Forestry

Government timber plantations have been established on the massif since 1937, mainly on abandoned terraces, between 1,200 and 2,500 m a.s.l. (present extent: 1,151 ha) (Hunting Technical Services 1977c). Main plantation species are *Cupressus lusitanica*, *Pinus radiata*, *P. patula*, *Grevillea robusta* and *Eucalyptus* spp. The plantations are managed in a rather haphazard manner: *Cupressus lusitanica* has been regarded as a failure under the semi-arid climate of Jebel Marra, and the risk of fire could not be reduced. Apart from some part-time employment for plantation work, the forestry plantations are of little value for the local population.

In addition, 2,283 ha of fallow land have been declared a forest reserve for conservation purposes, where cultivation, grazing and wood cutting have been restricted. Although grazing continues and fires still occur periodically, a noticeable regeneration of woodland has been achieved in the submontane part of the forest reserve.

Agroforestry

Silvopastoral systems. These are widespread all over the Jebel Marra where livestock graze in wooded grasslands. Occasionally transhumant Arab herders enter the submontane zone at the end of the dry season in case the lowland pastures do not provide enough fodder, but they are regarded with mistrust and not welcomed by the mountain Fur (in contrast to the Wadi Azoum area, no manuring contracts exist). The stocking rate of livestock in the highlands above the millet-sorghum zone is rather low (1–13 LSU/km^2), and the fodder provided by the grassland is usually sufficient. Thus the *Acacia albida* trees, though locally abundant, are only occasionally lopped by the herders. Goats, however, climb up and browse all accessible trees and shrubs, even of *Olea laperrinei*.

Agrisilvicultural systems. With the introduction of fruit trees to irrigated cropland, a "taungya" type of agrisilviculture was developed by the Fur. During the establishment phase of fruit-tree plantations, herbaceous subsistence and cash crops are interplanted on the same irrigated terrace fields:

maize, sugarcane, onion, garlic, tomato, chilli pepper, okra, sweet potato and herb species are the usual crops.

Agrosilvopastoral systems. These are only maintained in the most densely populated areas of traditional rain-fed cultivation.

3. Structure of the system

The AF system described in detail here consists of semi-permanently-cropped village fields where the staple cereals are grown under preserved multipurpose trees, especially *Acacia albida*. The distant montane grasslands with scattered *Acacia albida* trees can be regarded as a supplementary sub-system of the main system described.

A good example of the *Acacia albida* system developed by the Fur cultivators in the Jebel Marra massif was studied in a 20 km^2 area in Koronga region (13 N, 24.2 E), extending between 1,600 and 1,800 m a.s.l. in the submontane NW aspects of the massif. Average annual rainfall is estimated to be less than 800 mm. Close to the ground, night frosts occur in winter. In comparison with the overall population density of 37 persons/km^2 in the Jebel Marra massif, the population concentration in this area is estimated to be between 120 and 250/km^2. Koronga holds a rather important position within the well-developed network of weekly markets in the area, especially for marketing of locally produced meat and salt. All goods must be transported by burden animals (camels, donkeys), but marketing facilities are fair. The nearest major supra-regional market is Nyertete (1,160 m a.s.l.), 10 km (trade) westwards, recently connected with the Province capital by an asphalt road.

Koronga has one each of the few governmental schools and dispensaries within the massif. The village community belongs to the traditional District Lewinge, at whose disposal a certain area of rough grazing land in the Jebel Marra highlands is placed. These pastures are located above 2,000 m a.s.l. up to one day's walk away.

The village area itself forms a topography-dependent mosaic of more or less agglomerated compounds, village fields and uncultivated marginal areas, intersected by numerous valleys and ancient gullies with seasonal or perennial watercourses where small irrigated orchards may be found. As sloping ground prevails, most of the village fields have been established on terraces stabilized by dry-stone (basalt) walls, whereas the compounds prevail on ash (plateau) sites (see Fig. 22.3).

Fig. 22.3. Ziziphus spina-christi tree (on the right) that has been lopped to obtain fodder and poles. Note the straight growth of branches. On the left are some leafless *Acacia albida* (photo taken in August 1982).

3.1. *Components of the village fields*

The commonly cultivated crops are bulrush millet (*Pennisetum glaucum*), sorghum (*Sorghum bicolor*), hot (chilli) pepper (*Capsicum frutescens*), cherry tomato (*Lycopersicon esculentum* var. *cerasiforme*), roselle (*Hibiscus sabdariffa*), groundnut (*Arachis hypogaea*), many types of beans, maize (*Zea mays*), fenugreek (*Trigonella foenum-graecum*), melons and squashes (Cucurbitaceae). Millet as the preferred food grain dominates on the light soils. Several local varieties are known which may be divided into two groups: a dwarf (90 130 cm) variety with many lateral shoots, and a tall variety (210 295 cm) with few lateral shoots, 120-day growing period and even ripening (Hunting Technical Services 1977c). The former dominates in the mountains. Sorghum is only cropped in small quantities near the compounds to provide flour for brewing the local beer, which is regarded as a staple food in addition to the millet porridge. Also maize (eaten unripe and slightly toasted as a relish vegetable in the "hungry season"), groundnuts and cucurbits are cultivated on a small scale around the huts, whereas peppers, cherry tomatoes, roselle, beans and fenugreek are the commonly associated minor crops on millet fields. They are grown mainly for home consumption (as ingredients of the *asida* sauce); some surplus may be sold on the local market.

Fig. 22.4. Acacia albida trees on terraced fields. Note the regeneration of the trees on the lower terraces (vine in foreground is *Cissus*). View see Fig. 22.6.

Three main species of trees have been preserved on the cultivated village fields around Koronga (Figs. 22.3, 22.4 and 22.5).

Acacia albida, followed by *Zizyphus spina-christi*, dominates over wide areas where the (terrace) soils contain large proportions of volcanic ashes. On terraced basalt flows and ash-basalt mixed soils, *Cordia abyssinica* may gain importance and dominance. Table 22.1 lists the principal uses of these trees. There are also some less dominant trees, restricted to fallow land and or the compound areas, which are also of some importance in the Fur subsistence economy. These are also listed in Table 22.1.

The dominance of *Acacia albida* on village fields is explained by the cultivators in Koronga by its outstanding usefulness compared with the other trees around. It is primarily valued as a dry-season fodder resource. This is particularly important because the lack of adequate grazing-ground in the village area is a limiting factor for raising domestic livestock. All farm trees are heavily lopped, the crown frequently being reduced to a few weakly regenerating shoots off the main trunk. The regeneration potential is enormous, but death of trees caused by the rather careless management is common. Usually children herding the village animals climb the trees and cut the branches within their reach. Leaves and pods are browsed by all stock. The lopped thorny twigs and branches dry out and are later used for fencing the fields during the cropping period, and after harvest are collected for fuel. Even though of low quality, the wood of large lopped branches and the trunk of dead trees is used for fuel and even for construction. Fences around the

Fig. 22.5. Millet fields protected with thorn against animals that graze on uncultivated slopes and ridges. *Cordia abyssinica* dominates in the field, but it did not seem to have affected the vegetative growth of millet (photo taken in the rainy season in August 1982).

Table 22.1. Woody components of Fur village fields in Koronga and their uses.

Species	Characteristics and uses
Dominant species	
Acacia albida	Leafless during the cropping period: leaves/pods as animal fodder and green manure; branches for thorn fences; bark for medicinal purposes; ashes for tanning; branches and wood for fuel; fair regeneration
Cordia abyssinica	Evergreen seasonal*; browse/dry-season fodder reserve; fruits eaten and boiled for syrup, sweets and drinks; wood for construction (furniture), most appreciated firewood; overexploited, poor regeneration
Ziziphus spina-christi	Evergreen; browse (goats, camels); excellent fire- and construction wood (poles for hut roofing), thorn enclosures; fruits eaten; abundant regeneration; fallow invader; potential live fence (not planted as such in Koronga)
Less dominant species	
Acacia seyal	Deciduous; browse, thorn enclosures; fallow pioneer
Acacia sieberiana	Deciduous; pods and leaves excellent fodder for all stock; browse (important when *Acacia albida* is leafless and the grass layer not yet developed), thorn enclosures; esp. valley slopes
Anogeissus leiocarpus	Deciduous; firewood (most appreciated besides *Cordia* and *Ziziphus*), construction wood (poles), leaves and bark for tanning, twigs for tea; over-exploited in Koronga but most common tree of submontane zone
Azanza garckeana	Evergreen seasonal* fruits edible (boiled to syrup); browse esp. for goats; second most common tree species in the sub-montane zone; dominant fallow pioneer on basalt
Balanites aegyptiaca	Evergreen; wood for fuel, writing slates and construction; thorn for fencing; leaves less appreciated as browse in Koronga; weedy invader of degraded sites.
Dichrostachys cinerea	Deciduous; browse (camels, goats); bark for ropes; reputed to improve the soil; common fallow pioneer (basalt)
Euphorbia tirucalli	Aphyllous succulent; occasionally live-fence around the compounds; introduced
Ficus palmata	Evergreen; fruit edible; bark for cordage; wood for fencing, hut-roofing and fuel in case of non-availability of other wood; restricted to the highlands (above 1,800 m a.s.l.)
Ficus sycomorus	Deciduous; browse for all stock; shade tree; common in the village area/on valley slopes
Ficus thonningii	Evergreen; shade tree of compound area; browse; dry-season fodder for all stock; epiphytic germination on *Acacia albida* and *Cordia abyssinica*; kills the host
Khaya senegalensis	Evergreen seasonal;* young leaves for fodder/ browsed; fire- and construction wood; over-exploited: almost disappeared from Koronga area
Olea laperrinei	Evergreen; excellent fire- and construction wood; browsed by camels, sheep and goats; highland pastures above 1,900 m a.s.l.; over-exploited
Phoenix reclinata	Possibly once retained or cultivated palm (fruit, sweet sap, seedlings as vegetable): frequent in the valleys and occasional remnants in abandoned compound areas; present use not known apart from goats browsing young leaves
Vitex doniana	Evergreen seasonal;* fruit edible, browse for all stock; fuelwood; rare relics on basalt in reach of groundwater (ancient AF component? potential: fruit processing, flowers most attractive for bees)

* Partial shedding of leaves or facultatively evergreen, or immediate succession of young leaves after shedding.

compounds traditionally consist largely of wood (mostly trunks), heaped on the remnants of former stone walls. These woody fences also serve as fuel reserves. Large, less badly lopped *Acacia albida* trees are also kept in the compound area, being appreciated for their shade during the dry season. Even though the practice of collecting *Acacia albida* leaves for manuring the fields has been mentioned (Wickens 1969), this was not observed in Koronga, nor mentioned by its inhabitants. Very few of the present-day Fur cultivators seem to realize the fertilizing effect of *Acacia albida* on croplands; they ascribe the fertilization of the fields rather to the animals leaving their droppings in the shady places under the trees than to the trees themselves. Felling of *Acacia albida* trees is forbidden by law, but people seldom care about these restrictions on communal lands. In Koronga, only dead trees may be cut to use the wood. Theoretically, in the rough-grazing areas of the highlands lopping is free to all people with land-use rights in the respective district, except in the section which has been declared a forest reserve. Nowadays, no religious taboos influence the attitude of the Fur people towards *Acacia albida*, even though this was probably the case before Islamization (15th–19th century), when spirits played an important role in their religious life. Some minor uses of *Acacia albida* have been reported (Wickens 1986), such as the use of bark for medicinal purposes, and occasionally to construct beehives, and ash for tanning. *Acacia albida* regenerates abundantly as a fallow pioneer on ash soils in Koronga – as well as from seeds, from stumps or root suckers.

Ziziphus spina-christi, a weedy fallow invader in its spiny shrubby form is widely distributed over arid Sudan, often forming impenetrable thickets. In Koronga it grows into a medium-sized tree (10 m) with a well-developed trunk which is valued as fuel and construction wood. *Ziziphus* is primarily retained for its wood: the straight branches are cut periodically when they are long enough to form the basic construction for the thatched roofs of the local round huts (see Figs. 22.3 and 22.6). Smaller branches are lopped as dry-season fodder for camels and goats and later used for fencing. Though the species regenerates vigorously, it is susceptible to strong browsing pressure during the late dry season. Also heavy destructive cutting of fencing material and fuel affects its regrowth and encourages the shrubby form of growth.

The fruits are sweet and are eaten. They are collected by children and women, after having been blown to the ground by storms, and sold on the local market. Once they were important substitutes for sugar and were made into various sweets and syrups before being replaced by sugar.

Fruits of *Cordia abyssinica* are also valued for this purpose. Sweets prepared from the pulp and nuts are still regarded as a delicacy during Ramadhan and a mixture of fruits from *Ziziphus*, *Cordia* and *Azanza garckeana* makes an appreciated drink during the holy month. *Cordia* leaves have been reported to be used for cooking and to ferment *Cleome viscosa* and other wild herbs are used as ingredients for the *asida* sauce. At present, the leaves of *Cordia abyssinica*

Fig. 22.6. A dense stand of mature (or over-mature), moderately lopped *Acacia albida* trees with millet underneath. No young trees have been retained in this field. In the foreground is a damaged granary for the roof of which *Ziziphus* poles have been used.

are primarily appreciated as dry-season fodder for cattle. Thus, the more-or-less evergreen *Cordia abyssinica* trees are even more severely lopped than *Acacia albida*. In addition, the wood is most highly valued for fuel purposes; however, no advantage is taken of its potential for furniture and construction. Though often cut back to the trunk, *Cordia abyssinica* may regenerate by coppicing. Fair regeneration from seeds has been observed on enclosed fallows, but due to its palatability this tree is most endangered on unprotected plots where it is hardly likely to attain a good size. In the Anglo-Egyptian period, *Cordia* was also protected by law, but plantation trials were given up mainly because the timber quality remained too low to allow commercialization according to European furniture timber demands, and also because frost damage occurred (Ahmed 1979).

Animals

Independent of the Arab pastoral tribes of the surrounding plains, the Fur mountain dwellers keep a number of their own animals, although they are less skilled animal breeders.

Cattle are kept mainly as an investment and saving. Cow milk (production is about 3 litres per day) is a seasonal and minor constituent of the Fur diet. Only where there is no time to visit the market (where nomads sell milk products) during labour peaks in the rainy season is a small proportion of

milk taken from their own cows, the majority being left for the calf. Cattle meat is sold on the market. The best males may be sold for breeding purposes; calves are never slaughtered or sold. Cattle also commonly make up a proportion of bride price. The dung is highly valued for manuring the fields. The number of cattle averages three per family for the whole massif (Watson *et al.* 1977); in Koronga, 3–10 were reported to be usual, with the richest families owning 40–50.

The Fur cattle kept within the massif differ from the Zebu-type prevailing on the plains; they are somewhat smaller and have previously been characterized as "poor" even though they are well fed. But they are well adapted to the cold and cold-wet conditions of the highlands, where the lowland type would suffer. Average stocking rates have been estimated at between 10 and 36 LSU per km^2 in the submontane zone, depending on whether the season is wet or dry (Watson *et al.* 1977).

Goats are kept by each domestic unit (average for the massif: 5; in Koronga, 4 goats are the minimum). They are much more important for human nutrition (milk and meat) than cattle. Donkeys are commonly kept for riding and transport of goods to market (1.4 per compound). They graze on the fallow plots of the village area and are additionally fed with sorghum during the working period. Horses and white mules are kept for the prestige of the household head rather than as well-adapted beasts of burden. Sheep are kept within enclosed grazing grounds in the highlands, usually all over the year, and thus do not belong to the system proper. There are an average of three sheep per family over the entire massif. The animals are sold and the males eaten occasionally, especially during such festivities as those following Ramadhan. Poultry are usually kept in the compound area.

3.2. *Arrangement and interaction of components*

The spatial arrangement of the components is indicated by the schematic projection given in Fig. 22.7 and the photographs given as Figs. 22.4, 22.5 and 22.6. The spatial structure is simple due to the limited number of components, which are arranged randomly according to edaphic or topographic conditions. On the village fields, the only persistent feature is the presence of a tree canopy with an average crown cover of 14% of the total area (range 5–30%), and reaching heights of 7–10 m.

Well-established tarrace fields on ash soils have a tree density of 9–19/ha; these comprise mainly (80%) *Acacia albida* with an average height of 9 m and stem diameter at breast height varying between 0.6 and 1 m. Trees often grow near the stone walls of the terraced fields, but are also retained on the flat portions of terraces. Most trees are mature to overmature, estimated to be at least 100–170 years old.

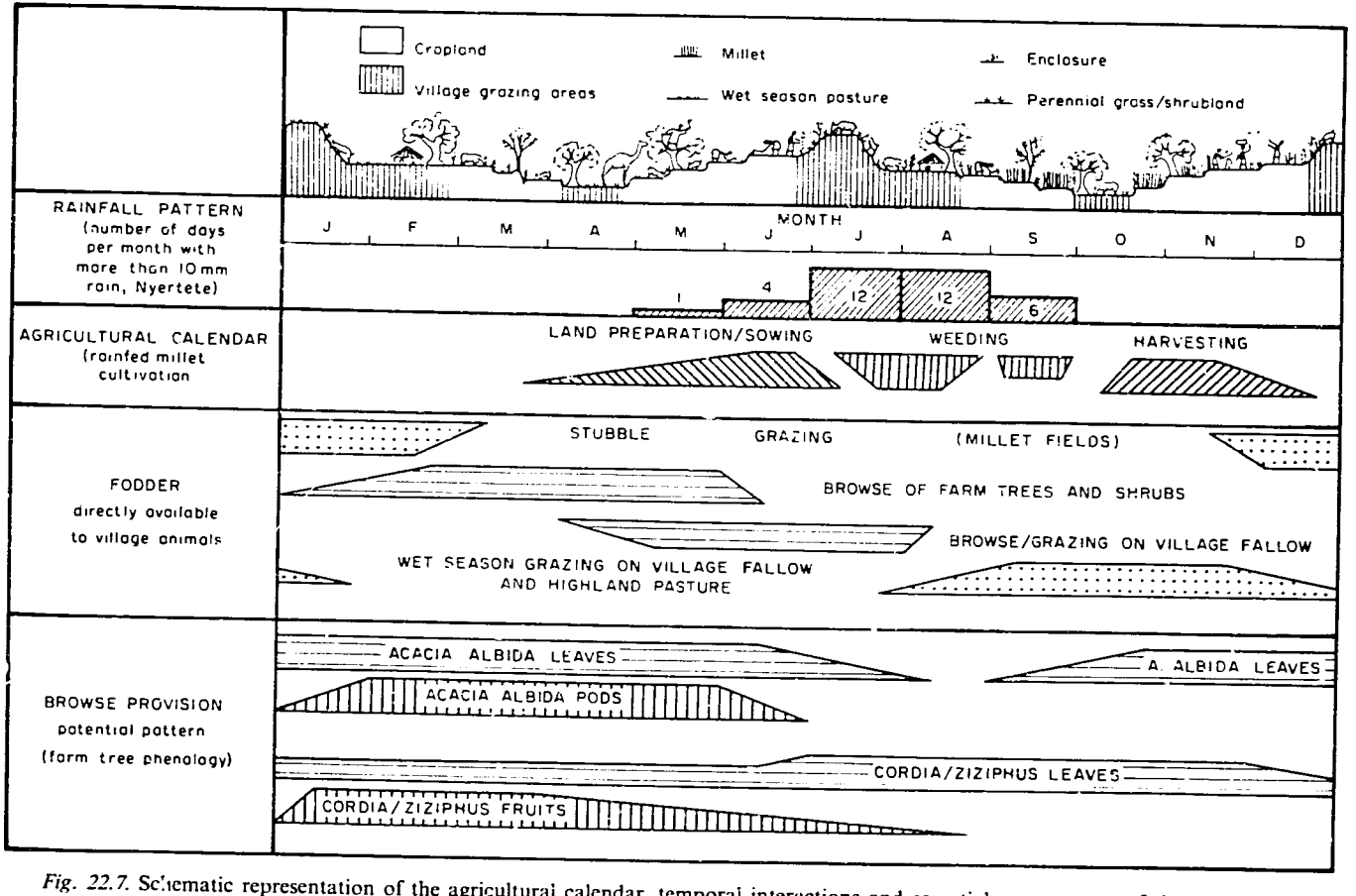

Fig. 22.7. Schematic representation of the agricultural calendar, temporal interactions and essential management of the components.

The temporal arrangement of components is governed by the growing period of millet (90–120 days between July and October). During this time, starting in May with land preparation and sowing, the fields are protected from trespassing of animals by thorn fences. Donkeys, horses, some goats and lactating cows with calves graze on fallow plots during the day (herded by children or old people), returning to the enclosures at night; others such as horses, mules and camels are kept in the compound and fed with collected forage. The larger proportion of livestock migrates to the highland pastures, returning after the harvest (October–December) to graze and manure the fields.

The dispersal of seeds from *Cordia abyssinica* and *Ziziphus spina-christi* is largely due to birds and human consumption of fruits; but *Acacia albida* seeds pass the intestines of grazing animals. Feeding and germination trials in Khartoum (Wickens 1968) showed that the seeds remain up to six days in the cattle's intestinal tracts, 66.5% being excreted undigested. The germination rates and durations are not much enhanced by this treatment. But during the 6 days which the seeds are within the intestines, the cattle may migrate over considerable distances. This fact explains the widespread anthropogenic distribution of *Acacia albida* (Fig. 22.1) and is also assumed to be the reason for its common occurrence in the extensively grazed highlands of Jebel Marra.

Competitive interactions between the components are negligible. Since *Acacia albida* crowns are leafless during the vegetative growing period of millet, they do not shade the millet. The shade produced by the small persistent leaves of *Ziziphus spina-christi* trees is also sparse. *Cordia abyssinica* is the only farm tree with broad, large leaves which potentially produce very compact shade when fully developed in the wet season, but it is generally lopped to such an extent that the crown is reduced to a few isolated branches (this is usually true for *Ziziphus* also) (compare Fig. 22.5).

The extent of competition for water is not fully recognized yet. It might be negligible for *Acacia albida* because it has a reduced demand for water during the rainy season and later it utilizes water reserves from deeper soil horizons by means of its deep taproot.

Competition between trees is generally negligible because of their low density. But several adult *Acacia albida* and *Cordia abyssinica* trees have been observed to be adversely affected by *Ficus thonningii*, a shade and fodder tree, which is usually confined to river banks, valley slopes and compound areas (Table 22.1). It germinates as an epiphyte and kills its host tree by strangulation and shade. Since *Ficus thonningii* is also a useful fodder tree, the farmers do not stop this process of infestation of *A. albida* by *F. thonningii*.

3.3. *Management aspects*

Under present-day conditions, the agroforestry techniques applied by the mountain Fur people appear to be rather poorly developed and exploitative. The most common attitude of the small-scale subsistence farmer is to produce his few sacks of staple millet in the easiest way. Thus, only traces of that skilful management well known from other African tribes sustaining *Acacia albida*-based AF systems (Felker 1978) may be found among the contemporary Fur. The trees are usually not protected or replanted nor are they properly managed.

The common cultivation practices are such that clearing, land preparation and sowing start in April/May when crop residues would have been grazed away leaving only the stalks, animal droppings, some trash and tree litter on the soil. The organic material is heaped on the terrace surfaces in piles a few metres apart and burnt (to destroy seeds of weeds, earwigs and blackworms). The ashes are dispersed and incorporated during the subsequent loosening of the soil, which only scratches the surface to a depth of 10–15 cm.

Simultaneously, the terrace walls are repaired by cleaning the field from eroded stones. The whole family is occupied with this work, especially at the onset of the rains, when sowing (usually broadcast) is combined with tillage. All cultivation work is done with a short-handled hoe in which two types of blades are common, the pointed small one being used on stony soils and a larger truncated one on light soils. After germination, one or two weedings are done, which may be combined with intersowing and thinning. Weeds and remaining stools are pulled up and aligned on the periphery of the plot or heaped at the base of a tree, being used later as manure.

Harvesting of millet starts in October and continues, due to uneven ripening, till December. Selected heads are cut with a reaping knife and collected, most stalks remaining on the plot. Successively, the thorn fences are removed to allow the animals to roam freely about the terraces for stubble grazing.

Information about the duration of cropping periods in Koronga varies considerably: soils basically derived from basalt are cultivated continuously for at least 10 years, e.g., 16–18 years/2 years fallow, whereas ash soils may be converted into fallow after 4–5 years for a period of 3–4 years. Those ash soils which are most intensively manured may be cropped semi-permanently. Crop rotations are not practised.

4. Functional aspects of the system

4.1. *Resource utilization*

Land

Common sizes of rain-fed village fields managed by one domestic unit vary between 0.62 and 1.25 ha, depending principally on the number of active

persons and the degree of their other occupations. A maximum of 2 ha is said to be manageable by large or well-off families.

According to Sudanese law, the State is the ultimate title-holder to all land. Fields revert to the State if a plot lies fallow for more than two years, but more ancient ancestral systems of land tenure and heritage overlap and still govern the practices in Jebel Marra massif, where land belongs to those ancestors who were the first cultivators and is inherited by the collective group of descendants. The local chiefs, as the representatives of the title-holding descent group, decide about land distribution and allocation of usufruct (on the basis of need), which is principally of a temporary nature.

A female child also inherits farm land, though only half of the male child's share. Fallow land (e.g., the rough grazing areas in the Jebel Marra highlands) is *de facto* divided up into four traditional districts confined to different Fur groups. Within each sector, grazing and wood cutting are free to all members of the respective community, whereas cultivation needs the permission of the chief. Grazing rights are obtained through payment of annual head-taxes on animals to the State (represented by the chief). As the village fields in Koronga are semi-permanently cropped and the remaining fallows utilized as well, they have become effectively private lands, consisting of rain-fed fields, the trees growing on them, orchards and "salt-gardens", of the valleys, and enclosed fallow plots. Marginal areas such as uncultivated and "waste" village lands and the supplementary grazing grounds, including their woody vegetation, are communal. Within the village areas, however, trees may only be lopped, harvested and eventually cut by their effective owners. Monetarization of land is actually still confined to irrigated (cash-crop) orchards.

Labour

A special feature of the traditional Fur society is the economic independence of the individual. The expectation among Fur villagers is that each person will cultivate what he or she needs of staple food grains and earn what he or she needs in the way of cash. Husband and wife have their separate grain stores and separate purses. Despite this situation, the "family" is conveniently referred to as an economic unit in socio-economic analyses. An average family unit consists of seven persons. Women are responsible for providing food for unmarried children, thus being forced to cultivate larger areas, but the general sexual division of labour is largely limited to the domestic sphere, where special female services towards men are expected, besides fetching water, cooking or making beer. Women plaster the walls of the huts, clean the floor and share with their children the duty of caring for cattle and goats kept in the village area.

Men build the hut and terrace walls, clear fallow land and thatch the huts. Until half a century ago, they also used to weave home-made cotton cloth.

Only men trade as middle-men and at auction markets and undertake long-distance transport, highland herding and large-scale cash cropping. Administration and public life is also confined to men. Children participate in all agricultural and domestic work, especially collecting wood and herding village animals. Herding is done communally, the surplus of village livestock which is sent for wet-season grazing to the highlands is united to the communal cattle and smallstock herds.

Weeding represents the main bottleneck in terms of labour availability, which, of late, is becoming scarcer because the villagers have started managing additional cash-crop fields in the highlands. On the plots planted late in the season, weed control may therefore be inferior due to failed weedings. Thus, the maximum size of millet fields is limited by labour availability rather than land shortage.

Rough estimates of yields run to 400 kg of grain which may be cultivated per active adult inhabitant per year by means of labour (land preparation and sowing – 10 man-days/ha; weeding – 20 man-days/ha; harvesting – 20 man-days/ha), half of a man's labour and most of a woman's labour being tied up in millet cultivation in the rainy season (Barth 1967; Hunting Technical Services 1977c). On the other hand, there is considerable underemployment during the winter months, especially in Koronga where orchards play a subordinate role, and no special handicrafts are being produced. Women, however, pursue their independent small businesses such as production of salt-cones and diverse ingredients for *asida* which they sell on the markets.

4.2. *Capital and inputs*

Whatever little capital there is in the traditional rain-fed cropping of staple cereals is mobilized by sale of livestock. Besides, savings include grain surplus, which is kept in foodstores, and cash, which is secretly hidden in a pot in the ground under the hut. Investment, however, does not play a crucial role in Koronga where the subsistence economy prevails.

The only traditional investments in cultivation are blades for the hoes which are offered by smiths on the markets. Seed is taken from the "savings" of the previous harvest.

Camel-drawn iron mouldboard ploughs, which had been introduced by 1965 on the piedmont plains and became widespread within the region, are of limited importance for the Koronga farmer because of the small dimensions of the terrace fields. Nevertheless, a Koronga farmer reported that a maximum area of 4 ha (instead of the current 2 ha) may be cultivated in a year by larger, well-off families if soil preparation/sowing and first weeding are done partially by ploughing. In 1982, a locally produced plough cost 50 Sudanese pounds,

but camel prices were between 300 and 800 Sudanese pounds,* and camels need much care and browse provision. Some farmers who do not own camels and ploughs hire them for land preparation at the rate of 40 Sudanese pounds per ha (1982).

Piece and wage work is the dominant form of cash investment for those domestic units which need labourers in addition to the members of the family. Labourers are paid cash and provided with food, beer and tea during the period of work, which in 1982 cost the employer about 80 Sudanese pounds per ha in one cropping period.

The largest amount of cash (or equivalents) is still spent, however, on social functions such as weddings (bride price: the equivalent of about 400 Sudanese pounds), birth, naming, circumcision, funeral and religious festivities (e.g. the Haj).

4.3. *Production*

Information about crop yields within the submontane belt of Jebel Marra is scarce in contrast to the lowlands where extension activities and agricultural stations are concentrated. According to farmers' estimates, millet yields varied from 3 to 4 sacks per feddan (about 650–800 kg/ha) in 1982 which was a rather bad year agronomically. "Good years" allow yields of more than 900 kg/ha. Production of millet straw in Jebel Marra massif in 1976 varied from 5.5 to 6.9 t dry matter per hectare, and that of sorghum straw between 6.8 and 7.5 t/ha, whereas the productivity of the highlands was much lower (675–875 kg/ha); (Hunting Technical Services 1977b). Production levels of the tree component have not been investigated. However, annual litter production of *Acacia albida* in Senegal in a population of 30–80-year-old trees was reported to be (t per ha covered by *Acacia albida* crowns): leaves 2.5, flowers 1.7, fruits 5.4, wood and bark 1.9 (Jung 1979). Foliage production was between 50 and 100 kg per adult unpruned tree, and 12–20 kg for pruned trees (Le Houérou 1980). Most estimates of pod production range between 10 and 75 kg per tree per year. As the adult trees in Koronga only reach half of the dimensions of those in the alluvial valleys, and are more intensely lopped, average production for both pods and leaves is likely to be between 20 and 50 kg per tree annually.

The chemical composition of the products of *Acacia albida*, using mean values obtained within Western Darfur (Hunting Technical Services 1977a, b) and also from other regions, is presented in Table 22.2.

Comparison between nutrient content of *Acacia albida* products and the herbaceous components highlights the high absolute as well as complementary

* 1 US dollar = 0.4–0.5 Sudanese pound (1982/83).

Table 22.2. Available data on chemical composition and nutritive values of the components.

Fraction*	Components of *Acacia albida*									Crop residues		Herbaceous fallow/ Montane grassland	
	Young green leaflets with stalks	Flowers	Mature entire leaves	Pods only	Seeds only	Entire pods	Entire pods	Entire pods	Entire pods	Millet	Sorghum	Below c. 1,600 m a.s.l.	Above c. 1,600 m a.s.l.
Moisture content	63.7	82.2	8.6	8.7	9.4	6.0	9.2	8.0	6.7				
Caloric value												1,824	1,635
Crude protein	17.1	19.0	14.1	13.0	27.2	15.5	10.6	10.4	10.0	2.4	3.8	3.0	3.7
Digestible protein			12.8	7.7	19.7		9.8			1.2	3.5	2.4	2.2
Ether content (oil)	2.3	1.6	5.1	1.4	1.9	0.5	1.4		0.9	0.9	1.5	1.5	1.0
N-free extract	12.4	12.5	49.5	44.0	45.3	22.9	57.7	50.0	56.3	45.4	54.7	52.0	55.0
Crude fibre	59.7	57.2	14.7	28.7	12.2	57.0	26.7	27.4	33.1	43.4	29.2	38.0	35.0
Total ash	8.4	9.7	8.1	4.3	4.2	4.1	3.7	3.3	12.6	7.5	9.8	10.0	9.1
Soluble ash	6.7	7.8	1.7	2.9	1.8		3.4		12.3	2.6**	3.1**	5.6**	5.3**
Silica	0.6	1.9				0.43							
Calcium			1.8	0.4	0.4		0.7			0.1	0.2		
Magnesium										0.1	0.1		
Sodium										0.004	0.006		
Potassium										1.5	1.5		
Phosphorus			0.1	0.2	0.4		0.2			0.03	0.03		
Copper									0.1	3	3	2	2
Cobalt									1.4	2	2	2	2
Manganese									10.7	33	45	65	61
Zinc									11.8	12	32	37	23
Iron									21.4			460	366
Source	Boynes (1940)	Boynes (1940)	Wickens (1968)	Wickens (1968)	Wickens (1969)	Boynes (1940)	Russel (1947)	Codd (1951)	HTS (1977)	HTS (1977b)		HTS (1977b)	

* All are measured in percentage of weight except for copper, cobalt, manganese, zinc and iron which are in parts per million, and the caloric value (in Kcal/g)
** HCL – insoluble ash.

values of this tree within the system, due to the high protein content of its leaves, flowers and fruits. Seasonal availability of carbohydrate and protein produced by the system components has been calculated in 1976/77, evaluating production data of the entire project area of Western Darfur, where *Acacia albida* populations of 20 mature trees per ha were estimated to cover 4% of the area (Hunting Technical Services 1977c). The results are presented in Fig. 22.8, which clearly demonstrates the unusual peak of protein availability in the mid- to late dry season when most extensive livestock systems suffer from a severe lack of protein.

The diagram represents minimum values concerning *Acacia albida* in so far as foliage production has not been considered at all, probably because of lack of reliable data. As *Acacia albida* sheds its leaves in July, lopping will fill the fodder gap in June (Fig. 22.8), as is being practised in Koronga. Here, *Cordia abyssinica*, *Ziziphus* and *Ficus* leaves are still available during the critical period when *Acacia albida* becomes leafless, the fallow herbs not yet fully developed and the fields not accessible to stock.

Even though it is quantitatively different, the production pattern shown by Figure 22.8 is a basic representation of the submontane conditions in Koronga. It should be emphasized that the availability of crop residue and *Acacia albida* products not only depends on the season but also on the farmer's management (fencing and lopping operations).

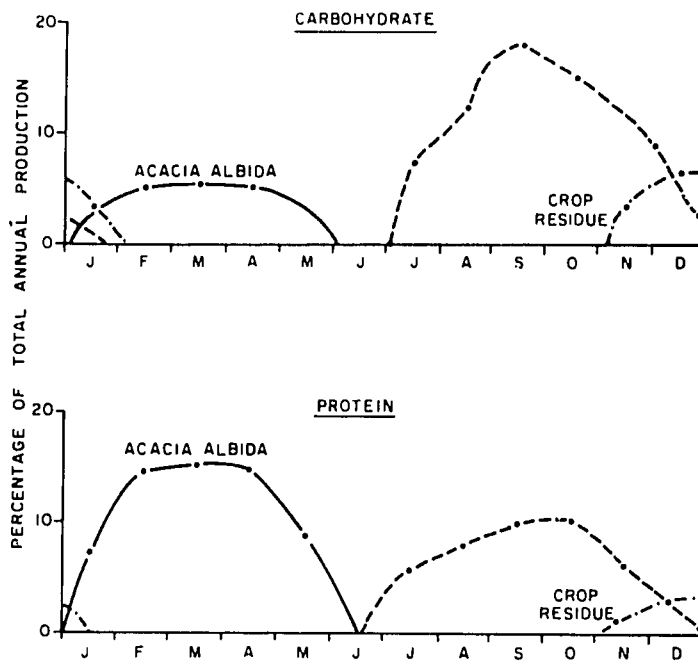

Fig. 22.8. Seasonal availability of animal fodder in terms of carbohydrates and protein, estimated for the entire Western Darfur region.
Source: Adapted from Wilson *et al.* (1980), with kind permission.

Animal production parameters are only available for the whole area of Western Darfur (Wilson *et al.* 1980). According to these sources, financial returns to labour come to 0.68 Sudanese pounds per man-day for both sedentary millet and nomadic livestock production. The conditions in Koronga, where farmers manage their own livestock in an economic way, are quite different. The proportion of people to livestock is larger (about 1:1) compared with the lowlands (about 1:2), and livestock play a minor economic role. Some prices recorded in 1983 on Koronga market are listed in Table 22.3. Agricultural returns for an average family in Koronga (1 man, 1 woman, 3 children) may be outlined as follows: in 1982 (low rainfall), the family harvested 1,530 kg millet from 3.3 ha of which they would keep 450 kg for home consumption and sell 1,080 kg at the rate of 0.5 Sudanese pounds per kg. The financial return per ha from millet production will thus amount to 164

Table 22.3. Recent market prices of some commodities in Jebel Marra/Darfur (Sudanese pounds).

Commodity	1982/83* (drought)	1984** (severe drought)
Cows (4 years old)	max. 200	
Young camels	150–200	
Adult camels	400–>1,000	
Sheep	50–70	40
Goats (male)	max. 20–30	6–10
(female)	15–60	
Meat (1 kg, various qualities)	1.5–3	3
Millet (1 kg)	0.5	max. (September) 2.5
Sorghum (1 kg)	0.6	max. (September) 2.0
Wheat (1 kg)	1.2–1.3	1.6
Rice (1 kg)	0.7	3
Oil (1 kg; groundnut and sesame oil)	max. 4	5.7
Tea (100g)		1.4
Sugar (1 kg)	1.5	3.3
Sardines (1 tin)	0.85–1.1	
Instant milk powder (full fat, 300 g)	3.5	4
1 bundle firewood (10 kg)		0.4
10 poles *Anogeissus leiocarpus*, 1m long/ 5 cm diameter	0.5	
1 pole *Eucalyptus/Cupressus* 6-10 m long, 10 cm diameter (sold from plantation)	10.0	
Wage work (per man-day)	3–8	

* Prices during the rainy season 1982 and dry season 1983 within the massif; results of interviews with farmers in Koronga.

** Prices recorded in the piedmont and foothills of Jebel Marra (F. Ibrahim, pers. comm.).

Sudanese pounds (or a total of 541 Sudanese pounds if all cultivation work is done by the members of the domestic unit). From this income, taxes have to be paid as well as additional food (at least 1,000–1,200 kg millet per year) purchased; in addition, some reserves are needed for donkeys and horses and for seed in the following cropping period. However, eventual income from the sale of animals, irrigated cash crops, salt-cones and processed agricultural products will provide additional income.

5. System dynamics

5.1. *Shrinkage/degradation of the system*

A significant degradation and shrinkage of the system has already taken place, as indicated earlier. The main causes are of a socio-economic rather than environmental nature, although the former might have been accelerated by the recent drought. Monetarization, commercialization and seasonal wage work cause initial inequality and destroy the traditional attitude towards local authorities, values, dietary habits and customs. As in other African countries, political security has caused the mountain population to move down-slope. Due to rapidly increasing monetary values of wage and piece work, it becomes much more attractive for men to follow these occupations. Consequently, the most intelligent and innovative of the population leave those areas where farmers sustained this former intensive AF system; the remaining people switch over to simple extensive bush fallow or shifting cultivation practices because pressure on land decreases.

The rate of the system degradation and shrinkage is very difficult to assess in the area. Aerial photos taken over the past 30 years exist and some evaluation might be possible using these. But this evaluation has not been done yet for the *Acacia albida* system.

The older inhabitants interviewed in Koronga reported that population densities were much higher 50 years ago, and larger areas were cultivated continuously for more than 20 years. Despite the pronounced pressure on land, the density of farm trees was much higher, whereas the species composition remained nearly the same. The inhabitants have no explanation for the present decline of the tree canopy except drought. This indicates that systematic tree-preservation and propagation measures have not been practised over the past 60 years, most of the present mature farm trees being older.

5.2. *Sustainability*

Even though the *Acacia albida* system in Koronga is not yet seriously endangered, the situation becomes more critical with every dying or cut adult

tree. If present management continues, only coppice regrowth and small shrubs will remain. *Acacia albida* and *Ziziphus spina-christi* are not expected to face extinction, as long as regeneration and seed dispersal are abundant within the entire region. *Cordia abyssinica* is apparently more endangered.

The shrinkage of the montane *Acacia albida*-based AF system of Jebel Marra contrasts with increasing demands for agricultural land and animal-grazing resources in the surrounding plains, where rapid population growth rates in the plains force numerous Fur settlers back to the mountains again, or the present mountain population must produce increased quantities of grain to provide the lowland population with their staple food. The 1984 drought already indicated these tendencies.

Despite these promising preconditions for sustainability and extension of the *Acacia albida*-based AF system in Jebel Marra, it is sad that most of the knowledge and management techniques gathered and refined over the ages and handed down from generation to generation have been forgotten with the passage of time. This and several similar cases among other African tribes show that this process is irreversible, and a restoration of AF techniques now depends on external initiatives.

Despite its weaknesses, the *Acacia albida*-based AF system of the Koronga area must be regarded as an optimal land-use alternative in the submontane zone of Jebel Marra: it represents not only a productive and versatile agricultural system, but is also assumed to provide effective protection and conservation of soil and water resources. In order to realize the full potential of the silvopastoral subsystem, lopping and herding practices should be more systematized. *Acacia albida* pods are storable and could thus be collected and kept as a fodder reserve. Potential production of wood within the system has not been assessed yet. The estimates available from Senegal show that 40–60 *Acacia albida* trees/ha produced 1.8–4.7 m^3 of harvestable wood per year, according to rainfall gradient and age of trees (Jensen and Koné 1982). This means that 2–3 ha of cropland containing *Acacia albida* may provide the same amount of wood as does one hectare of a pure *Eucalyptus* plantation in the same environment.

The wood of *Cordia abyssinica* and *Ziziphus spina-christi* is of much higher value, and in view of the general wood demand within the region, considerable economic advantage could be taken of this potential. On the level of smallholder production within this AF system, the ideas and initiatives of the early forestry period in Jebel Marra, namely, the plantation of indigenous *Khaya senegalensis* and *Cordia abyssinica*, could be revived.

Regeneration of trees, especially of *Acacia albida*, can be encouraged by systematic management. Single young trees or entire plots lying fallow must be enclosed with thorn or grass mats, as is usually done with fields during the cropping period. Natural regeneration of *Acacia albida* and *Ziziphus spina-christi* is abundant enough to provide both seedlings and fencing material. For

Cordia abyssinica, transplantation of seedlings may be necessary locally, but once protected it is reported to grow fast (von Breitenbach 1963). In case entire plots are kept enclosed for several years for soil and tree regeneration purposes, the fallow grasses may be harvested to obtain fodder, as is already a common practice in the dry season. During the wet season, the nutritional value of the grasses is much higher, but the labour bottleneck at this time would probably prevent grass harvesting. From this point of view, direct wet-season grazing of fallow fields in combination with individual fencing of selected tree regrowth would be preferred.

In order to reduce labour peaks during the weedings, the introduction of camel-drawn chisel ploughs has been proposed (Hunting Technical Services 1977c). In Koronga, only about 50% of the fields are estimated to be large enough for an economic application of this technique.

6. Extrapolatability

The *Acacia albida*-based AF system described here reaches its climatic limit in Jebel Marra at altitudes between 1,900 and 2,200 m a.s.l. (the temperature limit of sorghum and *Pennisetum*). The uncultivated grasslands in the submontane and lower montane zones provide suitable areas for extending the system. The silvopastoral potential of this area has so far been underestimated and underutilized.

The agrosilvopastoral system as practised on village fields in Koronga may be extrapolated to the montane zones (above 2,000 m a.s.l.) with the following variations of components:

- Introduction of wheat to replace millet and sorghum above 2,000 m a.s.l. Wheat is less appreciated by the Fur for preparation of the *asida* staple, but is partly mixed with millet for this purpose, or with sorghum to prepare the flat traditional bread (*kisra*).
- Trees such as *Ziziphus spina-christi* and *Cordia abyssinica* may be extended to the highlands up to at least 2,300 m a.s.l., where mature trees have been seen in the village areas. *Olea laperrinei*, adapted to higher altitudes, is another useful tree species. The tree is very resistant to fire, drought and grazing and its wood is of outstanding value for fuel and construction purposes.

Considering a wider extrapolation of the Jebel Marra types of *Acacia albida*-based AF systems, the wide ecological adaptability of this tree must again be emphasized: although its natural occurrence was probably restricted to gallery forests, it is now spread all over the African savanna zones in a wide range of habitats (Fig. 22.1).

Table 22.4. Examples of present AF practices and remnants of historic cultivation systems in Africa and Agro-Oriental mountain areas, which include the tree species dominant in the Jebel Marra systems (from arid to humid climatic conditions, roughly).

Location	Tree species and uses	Sources
Israel: Upper Jordan valley	*Acacia albida*, *Ziziphus spina-christi*: spreading on arable lands (root suckers coppice regrowth)	Karschon (1961)
Cape Verde Islands 200 m (NNE-expos.)/1,400 m (SSW-exp.) – max. 1,900 m a.s.l.	*Acacia albida* remnants on maize/beans croplands, at present silvo-pastoral over-exploitation. *Ziziphus mauritiana* accompanying fallow invader. Very rare wild olives (*Olea europaea*). All species may have been introduced by man	Chevalier (1935); Da Silva and Barbosa (1958); White (1983)
Yemen A.R. –Humid aspects, valleys 1,000–2,000 m a.s.l.	*Cordia abyssinica*: shade tree for indigenous (Mocha) coffee	Hepper and Wood (1979)
–Humid aspects, above Ibb, above 2,500 m a.s.l.	*Cordia abyssinica*, *Ziziphus spina-christi*: with *Acacia* spp. (other than *A. albida* spp. remnants of former intensive cultivation systems	
Cameroon (NW)/Nigeria (NE) Mandara Mountains, 800–1,400 m a.s.l.	*Acacia albida*, *Ziziphus spina-christi* among many other trees preserved/cultivated on terraced millet/sorghum/legume fields; permanent cropping and stall-fed cattle, population densities reaching 300/km^2. *Cordia abyssinica* not mentioned, but might be present	Hallaire (1976)

Sudan Kordofan, Nuba Mountains 1,000–1,500 m a.s.l.	*Acacia albida* (also grown as a live fence), *Ziziphus spina-christi* and *Cordia abyssinica* among many other multipurpose trees: similar to Mandara mountains (above)	Lebon (1985); Wickens (1968)
Ethiopia Rift Valley, 1,600–2,200 m a.s.l.	*Acacia albida* abundant between 1,800 and 2,000 m a.s.l. and *Cordia abyssinica* in farmed parklands created by Galla and Arussi tribes: *Cordia* is cultivated in an orchard-like manner and retained on farmlands (natural montane forest remnants). *Ziziphus spina-christi* probably present as fallow invader	Le Houérou (1980); v. Breitenbach (1963)
Nigeria Jos Plateau 1,000–2,000 m a.s.l.	*Acacia albida* retained (or spontaneous fallow invader) in *acha* (*Digitaria exilis*) – millet cultivation of Biron tribe, with cattle present (Fulani herders). Trees rare	Gosden (1978)
Tanzania –Mbeya district, Southern Highlands Province, 750-1,500 m a.s.l.	*Acacia albida* on arable lands; regarded as an indicator of fertile soil. Shade tree for coffee	Wickens (1969)
–Northern District, 900–1,900 m.a.s.l. Mt. Kilimanjaro	*Cordia abyssinica* in Chagga homegardens as shade tree for coffee, fuel, construction wood, beehive construction. *Acacia albida* recorded on the northern flanks of Kilimanjaro	Fernandes *et al.* (1984) Wickens (1969) (compare Fig. 22.1)
Guinea Fouta Djallon 500–1,500 m a.s.l.	*Cordia abyssinica* in afro-montane forest remnants; utilization other than silvopastoral (Fulani cattle) unknown	Aubreville (1950)

Although *Acacia albida*-based AF systems may have their greatest potential in the drier savanna areas, where cattle play a major role, they are flexible enough to be practised almost all over Africa, and to be adaptable to winter, summer, monomodal and bimodal rainfall regimes and tropical and sub-tropical climates.

Traditional AF systems similar to the Jebel Marra example occur in various other places (Table 22.4), which also gives an idea of its potential extrapolatability.

Acacia albida-based agrosilvopastoral land-use systems thus appear to be well suited for restoration, conservation and increase of productivity in degraded, over-exploited African highlands. Even though such highlands cover a relatively unimportant percentage of land within tropical Africa (6.8% above 1,500 m a.s.l.; Getahun 1979), they are favoured for their potential productivity.

7. Research needs

1. In order to improve the *Acacia albida*-based AF system as practised at present in Korongo/Jebel Marra, and to assess its true potential, the following data need to be gathered:

- Basic hydrology of the ash- and basalt-derived soils prevailing in the area in order to estimate the optimum densities of *Acacia albida* (is the degree of crown coverage limited by water supply?);
- The effects of closed *Acacia albida* stands on agronomic factors affecting crop growth, and crop yields, compared with open stands;
- Productivity of *Acacia albida* (pods, foliage) under the specific conditions within the area; influences of lopping techniques and intensity;
- Beneficial or competitive role of the other farm trees (*Cordia abyssinica*, *Ziziphus spina-christi*): their shading and fertilizer effects on crops, competition for soil moisture within those layers rooted by the crops;
- Crops: selection and improvement of local millet varieties, trials with more systematic legume mixed cropping;
- Animals: determination of optimum size and composition of village herds;
- Labour: possibilities of rationalizing weeding procedures; and
- Socio-economic/ethnologic preconditions: assessment of the possibilities of introducing tree planting and protection measures by means of economic/ecologic motivation.

2. In order to transfer the system to the Jebel Marra highlands, it is essential to undertake:

- Trials to assess the climatic (temperature/aridity) limitations for the tree components;

- Agronomic studies concerning the interactions between the highland crops, transferred trees, *Acacia albida* and *Olea* spp.;
- Determination of effective carrying capacities of the highland pastures regarding different kinds of animals, without *Acacia albida* and with integration of lopping and browse utilization;
- Socio-economic and technical considerations regarding the introduction of rotational grazing/conservation of plots and fire control, in order to increase the woody resources in the area, besides the ecologic investigations mentioned above; and
- Trials to develop optimal crop associations/rotations which reduce the weed competition (bracken invasion).

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23. An evaluation of the *Acacia albida*-based agroforestry practices in the Hararghe highlands of eastern Ethiopia*

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Abstract. Growing *Acacia albida* as a permanent tree crop on farmlands, with cereals, vegetables and coffee underneath or in between, is an indigenous agroforestry system in the Hararghe highlands of eastern Ethiopia. However, there are practically no data on the merits and benefits of this practice.

The paper presents the results of an investigation into the effects of the presence of *A. albida* on farmlands on the yield of maize (*Zea mays*) and sorghum (*Sorghum bicolor*). Twenty-seven plot pairs, each consisting of one plot under the *A. albida* foliage cover and the other in the open away from the trees, on fields in a 40-km radius around the Alemaya College of Agriculture were sampled and the yield components analysed. An increase of 56% in crop yield was found for the crops under the tree canopies compared to those away from the trees. The improvement was in 1,000 grain weight and number of grains of plants under the trees, indicating that the trees ennanced the fertility status of the soil and improved its physical conditions in terms of crop growth.

Additional benefits from the *A. albida* trees include supply of fuelwood and fodder. Quantitative estimates of these outputs, as well as their monetary values, are presented in the paper. However, in order to realize significant benefits, stand densities of the tree should be higher than at present.

Based on an enquiry about farmers' attitudes towards *A. albida*, the prospects for extension of this promising agroforestry technique are discussed against the background of the state and trends of development of agriculture in the area. It is surmised that despite some shortcomings, such as the relatively slow and highly variable growth of *A. albida* and a conflict with the spreading cultivation of *ch'at* (*Catha edulis* Forsk.), the prospects for extension of this technique are good. It is recommended that its propagation should be incorporated into the programmes of the extension agencies of the various governmental agencies concerned with land use.

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1. Introduction

A. albida is well known as a tree crop grown with agricultural crops such as sorghum, maize, groundnuts and others in the mid-altitude, low-rainfall areas of western Africa. Research findings on many aspects of this traditional agroforestry technique are available from this region (Charreau and Vidal 1965; Felker 1978). The extensive presence of the tree on farmlands has also been reported from other areas such as Israel and the Near East, Eastern Africa and the Horn of Africa. Recent reports reveal that the tree thrives well in highlands up to 2,300 m a.s.l. (Miehe 1986; Chapter 22).

Acacia albida also occurs extensively on the Hararghe highlands of Ethiopia, where it forms the basis of a traditional agroforestry practice. However, there is no systematic record on the merits and benefits of the practice. Information available from other ecosystems, such as the West African *Acacia albida* system, may not be extrapolatable to the highland conditions of Hararghe region. At the same time, detailed information on the functioning of this system became necessary in the context of developing appropriate agroforestry models for the Hararghe highlands, a task initiated by the Alemaya College (Forestry Section) in co-operation with the Ethiopia Forest Authority (FaWCDA). Therefore an investigation was undertaken to study and document the system with special emphasis on:

1. The influence of trees on crop yields;
2. The extent of farmers' motivation to use/accept the tree and the conditions hampering or facilitating the incorporation of the tree into cropping systems;
3. The shortcomings of the current practice, and ways of overcoming them; and
4. The reasons for the limited distribution of species and agroforestry techniques at the moment, and the scope for the extension of this technique in particular and agroforestry models in general.

This paper focuses on the first aspect, followed by a general discussion on the other aspects.

2. General description of the area

2.1. *Geographic location*

The study area is situated in the Hararghe Administrative Region in eastern Ethiopia. It represents the eastern part of a mountain chain which on maps usually appears as "Ahmar mountains". The town of Alemaya, where the

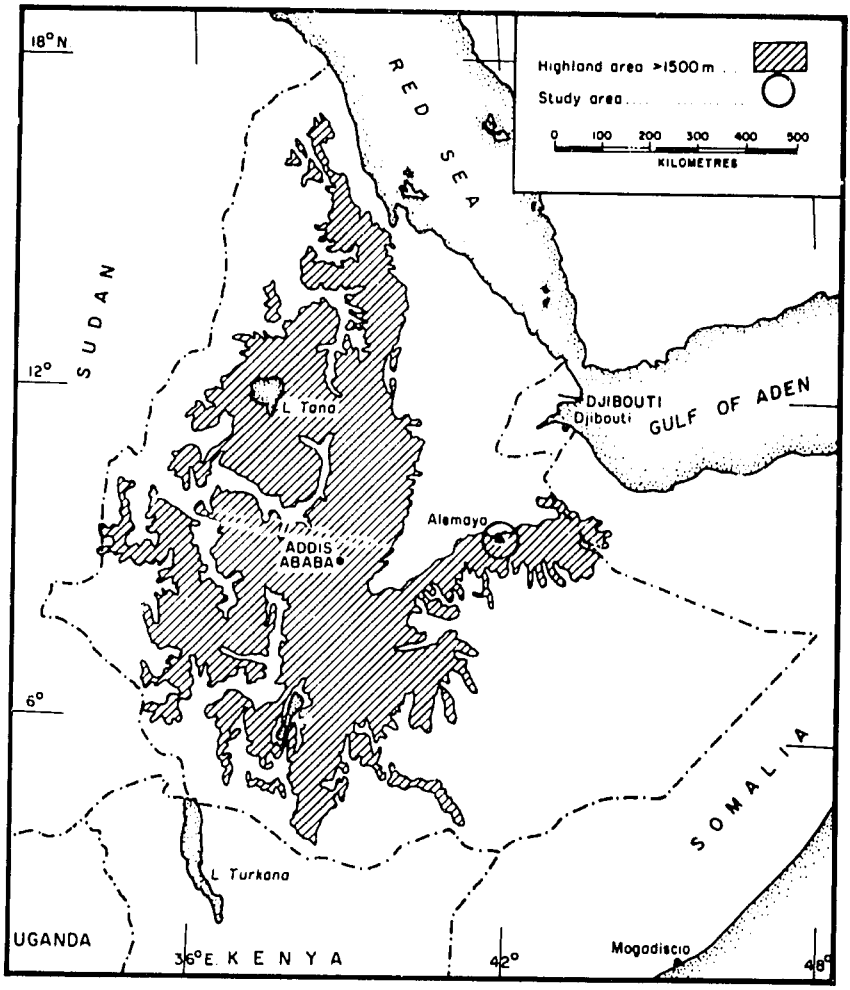

Fig. 23.1. A map of Ethiopia showing the location of the study area.

Alemaya College of Agriculture is located, is in the centre of the study area at 9°26′ N latitude and 42°03′ E longitude (Fig. 23.1).

2.2. *Biophysical environment*

Most of the highland area of Hararghe is situated at altitudes between 1,800 m and 2,400 m a.s.l. On parent materials consisting of granites and partly sand or limestone, six major soil types have developed, four of which are important in extent: Entisols (Regosols) – (50–60% of the area); Entisols (Fluvisols) – 10–15%; Lithosols (10%) and Inceptisols (Cambisols) – (5–10%). While the fertility status of Cambisols and Fluvisols is relatively better,

Regosols are low in organic-matter content (1.5–2.3%), total nitrogen, available phosphorus and cation exchange capacity (Tamirie Hawando 1982).

Rainfall in the region varies from 600 to 900 mm per year on average but is subject to large variations. With mean monthly temperatures of 16–17°C and rainfall concentrated from March to September, the annual growing period is 210–270 days (FAO/UNDP 1982). The area is very densely populated. Alemaya and K'ersa districts support the highest rural population densities in the whole of Ethiopia with more than 400 inhabitants per sq km. The rate of population growth is about 2.3% per annum.

2.3. *Agriculture*

As a consequence of the high population density, as much as 90% of the land is cultivated in the central part (Poschen 1983). The size of holdings varies generally from 1 to 2 ha. The most common crop is sorghum, covering 50–60% of the total area under cultivation. It is sometimes grown mixed with maize (5–20% of the stand). Both sorghum and maize are also usually intercropped with beans. *Ch'at* (*Catha edulis*), is a very important crop of the locality both in terms of the extent of area under cultivation and its contribution to the cash economy. It is a shrub, the leaves of which are chewed as a stimulant. Sweet potato, potato and vegetables are the other common crops. *Ch'at* and vegetables are the principal sources of cash income (Ministry of Agriculture 1974; Poschen 1983; Tamirie Howando 1982).

On average, a family keeps two head of cattle, a goat and a sheep. This livestock population is much smaller than in the central highlands of Ethiopia (Agro-economics Department 1980). The main reason for the low livestock population is the overall shortage and/or non-availability of fodder, the situation being particularly serious during the dry season, making animal rearing uneconomical and time consuming.

As a consequence of this low livestock population, oxen draught is inadequate, which often results in failure to do timely sowing and weeding. Moreover, the amount of manure produced is far too little to meet the agricultural needs for sustainable crop yields. Sorghum appears to be the crop that is best adapted to the climate. Each part of the crop is economically useful: grain for human consumption, thinnings, leaves and thin stalks for fodder, and stubble for fuel. However, because of the prevailing land scarcity, sorghum is cultivated continuously in monoculture; crop rotations and fallowing are hardly possible, and less than 10% of the cultivated land is left to fallow.

At the same time, of all the cereals, sorghum removes from the soil the highest amounts of nitrogen and potassium per unit yield (Rehm and Espig 1976). With all parts of the crop and all weeds removed from the fields year

after year, soil under the crop is continuously being depleted of nutrients. Moreover, sorghum takes a long time to cover the ground adequately after sowing, and during this period the soil is exposed and prone to rain erosion. Consequently most of the Hararghe highlands are badly degraded by erosion and gullying.

The present trends in land use are characterized by decreasing size of holdings, diminishing numbers of livestock per household, and conversion of the remaining, marginal, communal land from grazing to arable land. Emphasis on cash needs as well as intercropping is on the increase in order to provide for cash needs and simultaneous production of several products from the same plot. Some efforts are also under way to intensify production of potatoes, vegetables and *ch'at* through irrigation and adoption of soil- and water-conservation measures such as terracing.

3. The effect of acacia trees on understorey crops

3.1. *Method of investigation*

The only feasible approach to assessing the effect of the acacias on the yield of crops grown beneath them in farmers' fields was to select a series of "paired plots" representing a range of factors likely to influence the outcome. The factors considered were: length of the growing period, soil type, size, density and shape of the trees. At each site, a pair of plots consisting of one under the canopy of a tree and one in the open away from the tree, were demarcated. Plot size varied from 30 to 80 m^2. The paired plots were equal in all respects except for the presence of the tree. A total of 27 sites (pairs of plots) spread over a distance of 80 km were selected.

In the study area, *Acacia albida* is not confined only to alluvial plains with access to ground water, but can be found on all soil types. Seven sample pairs were from Fluvisols, eight from Cambisols and 13 from Regosols, the latter being at various stages of degradation. Tree densities in the plots varied greatly from 1 to 10/ha. Ten samples were taken from fields where the tree densities were higher, and 17 from single-tree plots. Size and shape of trees also were very variable, ranging from small-sized trees with dbh 20 cm, height about 5 m, total volume 0.8 m^3 and crown projection area 49 m^2, to large ones with dimensions of 67 cm, 10.6 m, 2.65 m^3 and 155 m^2, respectively. It was difficult to assess the age of the trees. Based on interviews with older people, and using the period of Italian occupation of 1939–1941 as the reference date, it was estimated that trees with 40–45 cm dbh were around 40 years old.

Of the 27 plots included in the sample, 12 had a sole stand of sorghum as the crop, two a sole maize stand and 13 a sorghum and maize mix.

Fig. 23.2. A photograph of one of the study sites showing an *Acacia albida* tree with the crop underneath.

Figure 23.2 shows one of the study sites. From each pair of plots, observations on crop-growth parameters were recorded prior to crop harvest in October–November 1983. Site conditions and tree size were also recorded. From each plot, 20 plants were harvested randomly and each plant analysed individually. Based on plot yield, the yield per ha was calculated: yield/ha = no. of plants/ha × no. of grains/plant × weight/grain. Yields per hectare refer to gross area for crops under the tree canopy, i.e., including the area occupied by trees. In addition, weight of stalk and root, and extent of stalk-borer infestation and bird damage were assessed.

The data were analysed statistically using Fisher's *t*-test (Fisher 1970; Snedecor 1956). For each pair of plots, the differences were tested for significance. From the total of all pairs, plot means were used to calculate the overall mean and standard deviation as well as to compare these overall mean values.

The method had some drawbacks and disadvantages. For example, it is difficult to persuade the farmers to allow 40 plants (or 80 in a mixed stand) to be taken out for observation. On the other hand, a smaller number of plants per plot would not allow precision in statistical comparison. Furthermore, direct comparison between different sites is very difficult because of several other variable site factors. There were, however, no means to overcome these shortcomings and limitations. Nevertheless, the trends in yield response of crops as influenced by the presence of trees could be identified based on the significance tests for individual plot pairs. The results of the investigation were

complemented by an inquiry into farmers' treatment of the plots, their opinion about the acacias and their use, and some socio-economic information on the farmer and the farms.

3.2. *Influence of acacia on crop yield*

Crop yields are expressed on a per-hectare basis to facilitate comparisons both between plot pairs and with regional yield data. While comparing the data, it has to be borne in mind that usually the canopy cover is limited to a fraction of a field only.

Table 23.1 and 23.2 present an overview of the influence of *Acacia albida* cover on crop yields. The yields of both crops were, on average, substantially higher under the tree canopy than outside. Averaged over all the 27 plot pairs, the grain yields (consisting of sorghum and maize) under the tree were 2.42 t/ha (gross area occupied by the tree) compared with 1.55 t/ha in "without-tree" plots, an increase of 56% under the canopy. Table 23.1 shows that this increase was higher (relatively as well as absolutely) for maize than for sorghum. In order to express the difference on a unit-area basis, yields of pure stands were calculated based on the total density of plants and grain weight per plant from both mixed and pure-crop stands. Compared this way, maize yield under the trees was 3.4 t/ha as against 1.92 t/ha in the "open", the figures for sorghum being 2.13 and 1.57, respectively, representing a 76% increase in grain yield for maize and 36% for sorghum under the canopy over that in the open. All differences were statistically significant (Tables 23.1 and 23.2).

This improvement seems moderate compared to the published data from Senegal, where the reported increase in yields under acacia trees is 250% for millet (Charreau and Vidal 1965) and 100% for sorghum (Poschen 1983). In absolute terms, however, the increase of almost 1 t/ha of sorghum under the trees over the "no-tree" plots in Hararghe is twice as high as that in Senegal, where the recorded yields without and with tree cover were only 0.5 and 1.0 t/ha, respectively.

Analysing the yield components, it appears that the increase in yield under the trees is caused by the cumulative effects of slight improvements in 1,000-grain-weight and the number of grains per plant coupled with the somewhat higher plant densities under the tree. Increases for maize are higher than for sorghum both in absolute and relative terms. The vegetative growth of sorghum was also stimulated under the acacias, with stalk weight being about 50% more and roots almost twice as heavy (Table 23.2), as compared to the plants in the open.

Although the average data (Table 23.1) showed a very clear trend regarding the difference in crop yields under and away from the trees, the data from

Table 23.1. Grain yield of maize and sorghum under and away from *Acacia albida* trees in Hararghe highlands, Ethiopia.

Crop	No. of samples	Computation of	Density (plants/ha)		Grain wt/plant (g)		No. of grains/plant		1,000 grain weight (g)		Yield (t/ha)	
			A	B	A	B	A	B	A	B	A	B
Maize (1) (2)	15	mean	33,800	31 600	99.9**	63.1	328**	221	305	277	3.39**	1.92
		s.d.	8,100	8,000	30.9	35.8	70	93	52	49	1.29	1.04
Sorghum (1) (2)	25	mean	31,100	29,800	72.0	55.2	174	153	39	36	2.13*	1.57
		s.d.	8,200	7,200	36.8	23.3	69	68	8	8	1.07	0.60
All plots (2)	27	mean	31,100	29,900	—	—	—	—	—	—	2.42**	1.55
		s.d	7,900	7,000	—	—	—	—	—	—	1.06	0.57
Maize (1) (2)	Increase (%) of		7		58**		49**		10		76**	
Sorghum (1) (2)	A over B		4		31**		13		9		36*	
All plots (2)			4		—		—		—		56**	

1. Yield data per ha for maize have been recorded from 13 mixed stands of sorghum and extrapolated based on the density of the mixture and from two pure stands. Yield data for sorghum are from 12 pure sorghum stands and 13 mixed stands with yields extrapolated as for maize above. All yield data at 15% moisture content (dry weight basis).
2. There were 12 plots of sorghum alone, two of maize alone and 13 of sorghum + maize mixture.
3. Abbreviations: A = under canopy (gross area including the area occupied by the tree); B = in the open (away from canopy) s.d. = standard deviation
4. * Significant at 5% level; ** significant at 1% level
5. Yield range: sorghum A 0.6–5.2 t/ha B 0.6–3.0 t/ha maize
   A 1.3–5.5 t/ha B 0.6–4.2 t/ha

Table 23.2. Comparison of maize and sorghum stalk and root weight under and outside the canopy cover of *Acacia albida*.

Crop	No. of samples	Statistics	Weight of stalk per plant (g)		Weight of roots per plant (g)		Increase of A compared to B (%)	
			A	B	A	B	Stalk	Root
Maize	12	mean	66	53	—	—	24	—
		s.d.	22	29	—	—		
Sorghum	25	mean	145*	97	29*	15	49*	95*
		s.d.	41	43	15	7		

A - under the tree; B - away from the tree.
* significant at 1% level of probability.

individual pairs of plots were more divergent. Table 23.3 gives a summary of the variations. For maize, the range varied from no difference to an almost six-fold increase in yield under the canopy. For sorghum, the highest increase in yield under canopy amounted to 400%, but there was one instance when the yield was significantly higher in the plot away from the tree. Further analysis of the data indicated that maize yields showed the highest comparative advantage for the plots under trees where no manure had been applied, and particularly where drainage problems were prevalent, suggesting that enrichment of the soil with organic matter and improvement of drainage by the tree's roots were the key factors. The observation that the number of grains per plant was 48% higher under the canopy suggests that moisture availability to plants was substantially greater just before and during flowering

Table 23.3. Grouping of pairs of plots according to relative increase or decrease in sorghum and maize grain yields under and away from the tree canopy.

Range of % increase in grain yield in plot under the canopy over that away from the canopy	Number of cases	
	Sorghum	Maize
+ 200	2	3
+101 + 200	3	2
+ 51 + 200	5	5
+ 21 + 50	4	3
− 20 − 20	9	2
− 21 − 50	1	0
− 51 − 100	0	0
−101 − 200	0	0
− 200	1	0
Total no. of cases	25	15

and grain development. Previous studies have reported soil structure and microclimate to improve under *A. albida* (Dancette and Poulain 1965; Dugain 1960; Jung 1967).

The morphology and shape of the tree apparently exert a decisive influence on crops, especially sorghum. Yields under the tree are most favourable when the canopy is dense to medium dense, i.e., organic matter and nitrogen influx are high from leaf-shedding at the onset of the rains. It is important, however, that the tree branches should be well above the sorghum heads; very low tree crowns can lead to depressions in sorghum yields. This was identified as the likely cause in six cases out of eleven in which yields were not influenced or were actually reduced by the presence of trees. Only in one of the remaining five cases was a higher damage by birds the likely reason. Another farmer on whose farm the yield under the tree foliage was lower admitted to having neglected weeding in his plot and attributed the outcome to this.

3.3. *Additional benefits from trees*

While crop-yield improvement constitutes the most important single benefit of having acacias on crop lands, some other advantages such as supply of fuel and fodder are of substantial importance as well.

Fuel from *A. albida* is obtained through pruning and eventually by felling old trees. The pruning yield comes to c. 0.4–0.5 m^3 per mature tree, when about 20–35% of the total tree volume is removed. Most farmers prune once every 4–5 years; thus an average 0.1 m^3 of fuelwood is obtained per mature tree annually. This wood is almost exclusively used as fuel for home consumption. Felling acacias is not very common; only seven out of 17 farmers admitted to felling the trees in the past. Two of them mentioned the need for fuel as the motive, five others used it for sale, mostly to cover unforeseen expenses. For a number of farmers, the acacias also fulfil an insurance function: acacia wood is in high demand, particularly as fuel for local bakeries. Prices on the farm range from 30 to 40 Eth. Birr (= US$ 15–20) per m^3. The wood is also well suited to making house utensils like mortars or containers to store food. However, the amount of wood actually consumed for these purposes is negligible.

The fodder value of the acacias is realized mostly by letting livestock eat the pods from the fields during the off-season. The farmers do not regard leaves as a particularly valuable fodder. Moreover, the amounts that could be obtained are perceived as being too insignificant to cover a seasonal shortage due to drought. The pods, on the other hand, are highly valued. Almost all farmers use them for feeding; some even collect them from the fields for this purpose. They are not stored, however, as a reserve fodder, although this can easily be done.

Table 23.4. Estimates of annual gross returns per hectare of sorghum and maize crops with and without *A. albida* cover.

	Without *A. albida* A		With 6 trees/ha = 9% cover B		With 20 trees/ha = 31% cover C		With 65 trees/ha = 100% cover D	
Outputs	Physical returns (t)	*Monetary value	Physical returns	*Monetary value	Physical returns	*Monetary value	Physical returns	*Monetary value
Crop								
– grain yield	1.55	1,085	1.63 t	1,142	1.82 t	1,274	2.42 t	1,694
– stalk yield	2.34	600	2.42 t	621	2.60 t	667	3.18 t	628
– fertilizer savings	—	—	0.02 t	15	0.07 t	51	0.24 t	163
Wood								
– fuel (pruning)	—	—	0.4 m^3	14	1.4 m^3	47	4.4 m^3	152
– fuel (stems)	—	—	0.2 m^3	5	0.6 m^3	18	2.2 m^3	77
Fodder								
– pods	—	—	0.6 t[2]	30	2.0 t	100	5.0 t	250
Total		1,685		1,827		2,157		2,929
Amount				142		472		1,399
Increase over case A (%)				8%		28%		82%

Baseline data:
1. Production of cereals and trees corresponding to study sample mean.
2. Canopy area of a mean volume = 155 m^2
3. Fuelwood price: *A. albida* wood 35 Eth. $/100 kg.
4. Grain prices: sorghum, maize 70 Eth. $/100 kg.
5. Fertilizer response: 8.5 kg grain yield increase per kg urea (Murphy 1959; Tamirie 1983), urea price 70 Eth. $/100 kg.
6. All monetary figures in Ethiopian Birr; 1 Eth. $ = 0.48 US $ (1983).

3.4. *Evaluation of benefits derived from* A. albida *in fields*

To compare the benefits derived from the trees on a common scale, local costs and prices were inserted as shadow prices or opportunity costs to express the value of physical units in monetary terms; the results are given in Table 23.4. The calculations show that one *A. albida* tree produces goods worth 25 Eth. Birr (= US$ 12.9) per year. This return is high enough to almost double the gross return per ha of a sorghum and maize mixture if the field were fully stocked with trees. Harvesting of wood is the only activity that involves substantial inputs of labour in a plot with trees compared to one without trees. But considering the difference in returns from the two, it is safe to assume that the net returns per ha and per unit labour input increase much more in the plot with trees. Nonetheless, the density of *A. albida* in most parts of the study area is rather low, and therefore the perceivable impact of the practice is limited. Densities of about 20 trees per ha, i.e., a coverage of one-third or more of the cultivated land, are found in some areas (e.g., in villages east of the town of Harar). This density seems a reasonable target for an extension programme.

4. Factors affecting the incorporation of acacias into cropping patterns

4.1. *Motivation and attitudes of farmers*

The farmers of the study area have a very positive attitude towards the species. Seventeen out of 19 farmers stated that the advantages far outweighed the disadvantages, two felt they were equal and none said that the disadvantages were overwhelming.

However, this observation cannot immediately be extrapolated to large areas. From an earlier study (Poschen 1983), it was clear that only those farmers already having acacias in their fields took a positive view. For example, in the Alemaya catchment, which is situated in the centre of the study area but largely devoid of the tree, the acacias do not have a good reputation. The Alemaya farmers have another species, *Cordia africana*, in their fields and of which they are rather fond. It offers shade for the farmer to rest underneath (one of the most compelling reasons for the farmers to retain trees in their fields); it has no negative effects on crop yield; its leaves are used as fodder and the pruned branches as fuel.

A. albida is exceptional, however, in that once its positive effect on crop production is recognized in an area it is allowed to become established in densities much higher than of any other tree species growing in fields. Farmers' views about a particular tree species tend to depend on the experience gained with it personally rather than anticipation based on abstract

reasoning. To a certain degree this will make extension work difficult in some parts of the highlands.

4.2. *Development trends in agriculture*

Another difficulty arises from the importance of *ch'at* and the probably well-founded contention of farmers that *A. albida* is detrimental to *ch'at*. While the unusual phenology of the tree (leaf setting at the beginning of the dry season, growth throughout the dry season, shedding of leaves at the onset of the small rains) and the deep root system largely avoid competition with shallow-rooted, rain-fed annuals, this does not hold true for a shrub of which the leaves are the product. *Ch'at* thrives best at moderate fertility levels, it seems to be susceptible to leaf diseases under shade and its growth phases overlap too much with those of the trees'. The constant "shrinkage" of holding size will force farmers to increase intercropping of *ch'at* with vegetables and cereals because cash and subsistence production have to take place on the same plot. This might reduce the potential area for intercropping with acacias. So far, however, a gradual, but steady increase of area interplanted with acacias is observed all over the study area, including centres of *ch'at* production.

4.3. *Silvicultural problems*

An efficient method of propagation of *A. albida* is a problem that has not yet been satisfactorily resolved. The problem has two facets: one is the survival of seedlings, the other the growth rate of those that survive. The species is very sensitive to mistakes during seedling production and outplanting. Conventional methods can result in high survival rates if proper care is taken. A trial in the Alemaya College showed 50–90% survival nine months after planting and 75% after two years (Poschen 1983). Slight mistakes in timing, however, can reduce survival rates to 60% in the first year and to 0% in the second. Better results in this regard may be attained by using extra-long plastic containers with a length of 30 cm, instead of the normal 20 cm, for raising seedlings (Giffard 1964). Yet another problem that would remain even with satisfactory survival rates is the vast differences in the performance of seedlings from one and the same batch because of the heterozygosity of *A. albida* (Felker 1978). This can perhaps be overcome, for example, by propagation from cuttings or by evolving appropriate methods for early testing in nursery beds. *A. albida* is generally slow growing. However, some genotypes can grow as fast as 1.6 m per year in height and 2.9 cm in diameter. Assuming a mean annual increment of 1.2 m in height and 2 cm in diameter, it would

"only" take 20 years to let a tree grow to a size at which it can substantially improve yields of under-planted crops; this would still be an improvement over the 35–40 years that they probably take at present.

4.4. *The sparse stand of* A. albida

The distribution of the species is rather limited in the highlands of eastern Ethiopia. This could be a result of the almost exclusive reliance on the natural spreading by migration which is a slow process given its moderate growth rate, relatively late flowering and heavy-sized pods. The rate of spreading is enhanced by animal droppings, but drastically affected by browsing goats. It is only in areas with high densities of human population, where most of the land is cultivated and free grazing restricted, that the acacias can gain ground. In the neighbouring Chercher highlands, where these favourable conditions do not exist, the acacias are hardly found despite the seemingly favourable site conditions as evidenced by the vigorous growth of a few surviving trees. Thus, it is obvious that a good stand of acacias can be maintained only if rigorous and concerted efforts are made to plant and nurture the trees.

4.5. *Proper tree management practices*

Pruning as practised at present, often results in unsatisfactory size and shape of the tree crowns. The lowest branch of the tree should be at a height of not less than 4 metres. Low-level pollarding leads to competition with crops and reduces much of the potential wood and fodder production. Regular pruning is desirable as it allows for the harvest of fuelwood and improves leaf production, the main source of benefit from the tree.

4.6. *The slow growth rate of the trees*

The time lag between the establishment of the trees and the time they begin to have an impact is an obvious disadvantage. However, given the benefits which can be obtained, and the cost-benefit ratio, which certainly compares very favourably with those of other land-use options in the region, this time lag is not a serious drawback. Besides, it is not so different from what is generally accepted for other extension items. For example, attempts to introduce chemical fertilizers in the region were started more than 20 years ago and yet a major breakthrough has still not been accomplished.

From an economic point of view a long time-lag would only be prohibitive if heavy investment at the outset entailed high interest costs during the

maturation phase. With very low establishment cost for acacia, even an extended period of compounding interest does not have much of a bearing. Farmers' reactions and decisions confirm this.

The long maturation phase need not be an obstacle to popularizing the technology as long as the farmers can be convinced that this agroforestry technique will not be obsolete by the time the newly planted trees become fully effective. The technology does not conflict with likely future developments or innovations, *ch'at* and irrigation being the two exceptions. Increased food production is an urgent need in Ethiopia, but most of the modern innovations in agriculture, such as improved varieties, use of pesticides, and mechanization are fully compatible with this agroforestry technique. The use of renewable organic fuel is also likely to continue, hopefully in a more economic way. There is no reason why Ethiopia should wish to replace cheap natural sources of fertilizer with expensive industrial ones, even if this could be externally financed. Livestock keeping will be continued for a long time to come, entailing the need for fodder for the animals. All these point to the importance of *A. albida*-based agroforestry systems. It is heartening to note here that farmers' reaction to a limited extension effort to popularize *A. albida* in 1984 were very encouraging; there was a great demand for the limited stock of seedlings that was available for distribution.

5. Conclusions

A. albida offers as much promise for agroforestry in the Hararghe highlands of Ethiopia as it does in West Africa where it is more popular and extensive, and in other places where it is less extensive yet very important and promising (Miehe 1986). The tree is fully complementary to crop and animal production; it increases yields of crops grown underneath and enhances the overall returns from farmland. It also supplies fodder and fuel and simultaneously constitutes a form of savings and security for the rural population. The incorporation of the tree does not require any substantial change in farming practices and involves practically no additional cost and labour. The presence of the tree on the farm does not present any impediment to the intensification and development of rain-fed agriculture. Nor is it a "second class" alternative meant for those farmers who cannot afford the "first class" innovations. Planting *A. albida* in the Hararghe highlands is desirable on poor grassland, for the reclamation of wastelands and on soils with impeded drainage. In general, it can be extended to all arable lands except on *ch'at*-dominated fields and irrigated land. From a practical point of view, it seems particularly advantageous on plots further away from the cattleshed. This minimizes the need to cart manure over long distances and thus saves the manure to intensify production around the homestead.

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24. The shamba system: an indigenous system of food production from forest areas in Kenya*

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Abstract. The shamba system, a form of taungya where agricultural crops are grown together with forest tree species, has been quite widespread in the "high-potential" agricultural areas of Kenya since the early 1900s, and is still very popular. When properly practised, the system allows sustained, optimum production of food crops along with forestry species from the same land and thus meets most of the social and economic needs of the shamba farmer. This paper briefly describes the system's productivity and functioning and analyses its ecological as well as socio-economic characteristics.

1. Introduction

The taungya system is a method of planting forest trees in combination with food crops. Its origin can be traced back to the 1850s in Burma, where it was used as a means of replanting teak plantations on badly degraded land (King 1968). It is essentially a modification of the traditional shifting cultivation, but various forms of the practice can be found in different parts of the tropics (Nair 1984). A highly developed form of this agroforestry system, known as the shamba system, is being practised on government (state) forest land in Kenya, the main difference between this system and many other forms of taungya being the considerable integration of the cultivators into the Forest Department (civil service status) in the former. This short paper describes the salient aspects of the shamba system.

2. Development of the shamba system

2.1. *Origin*

Licenced cultivation in Kenya's forests started in 1910, and since then the number of such cultivators has been increasing rapidly. The main objective of permitting such farming in forests was to establish exotic forest plantations

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with minimum establishment costs. Several types of participants, such as serving and retired forest workers, landless peasants and those who live within the immediate vicinity of the forest area, used to be involved in the practice. Under the traditional shamba system, the resident workman would agree to work for the Forest Department for a period of nine months each year, to clear, in his own time, the cut-over, indigenous bush cover from a specified area (usually between 0.5 and 0.6 ha each year). That would enable the Forest Department to plant trees in the cleared land (the "shamba") within two years. Each participant would have four shambas each of about 0.5 ha area at different stages of establishment, ranging from recently allocated (cleared) bush to those with two-year-old trees. The farmers would be allowed to cultivate crops (usually maize, potatoes, cabbages, carrots, etc.) for up to two or three years, the farmers having the sole right to all such produce.

The system continued fairly successfully, mainly because of four factors:

1. The availability of sufficient cultivable land;
2. The presence of a willing land-hungry farming population;
3. The availability of a market for surplus produce; and
4. Security protection against wild animals.

2.2. *Changes over the years*

The shamba system has undergone substantial changes since its beginning in the early 1900s, the most significant being the increase in the number of participants. Table 24.1 shows the situation in terms of the average area of the shamba and the number of people involved in each in 20 Forest Stations in Kenya during 1981 and 1983. In some areas the demand for shambas is extremely high, so that the problem is not in finding enough people to clear land but to control their number (Mburu 1981). The most radical change occurred in 1976, when the resident workman status of the shamba was changed; instead of working as casual workers for nine months a year, they were made full-time employees of the Forest Department (civil servants). This change in work status had two effects: first, there was a significant increase in the direct tree-establishment cost incurred by the Department; secondly, the workers' status as civil servants did not oblige them to cultivate the land nor would the land be allotted to them automatically. If they wanted land they would have to rent it from the Forest Department. This caused a considerable drop in the number of participants in some areas.

2.3. *Extent of the system*

The spread of the system is limited by the country's ecological conditions. About 75% of the country is arid or semi-arid. The shamba system is confined

Table 24.1. Average size and number of people involved in some forest shambas in various areas of Kenya.*

Location	Total area planted (ha)	Average size of shamba (ha)	Number of households involved	Total number of people involved
Elgeyo	300	2.0	900	4,500
Gathiuru	644	0.7	2,444	12,220
Hombe	265	0.4	199	995
Kamae	69	0.1	330	1,650
Kaptagat	232	0.8	240	1,200
Kericho	85	0.3	157	785
Kerisoi	108	0.5	216	1,080
Kitalale	1,100	0.5	104	520
Maji Mazuri	350	1.0	340	1,700
Molo	553	1.4	402	2,110
Mucheene	165	1.0	165	825
Nabkoi	660	2.0	282	1,410
Nessuit	526	0.7	512	2,560
N. Kinangop	20	1.0	163	810
N. Marmanet	245	1.0	446	2,230
N. Mt. Elgon	30	1.0	160	800
Nzoia	232	1.4	192	962
Sorget	213	1.0	621	3,105
S. Marmanet	220	0.4	361	1,580
Wanjerere	15	1.0	80	400
Total	5,831.8		8,269	41,440
Mean		0.9	413	2,072

Average number per household = 5 people.
* Based on surveys conducted in 1981 and 1983.

to the "high-potential" forest areas which occupy about 3% of the country and represent 12% of the total agricultural land (Fig. 24.1). These areas are at elevations of 1,000–2,000 m a.s.l. just south of the equator, and receive an average annual rainfall of over 1,000 mm (bimodal: approximately 60% in March–May and the rest in October–December). The soils in the areas where the system is practised are, in general, of volcanic origin, deep, well textured and of medium-to-high fertility status.

3. Functional aspects of the system

3.1. *Production aspects*

The shamba system has been used extensively for the establishment of many forest plantations in Kenya. To date about 160,000 ha of forest plantations of

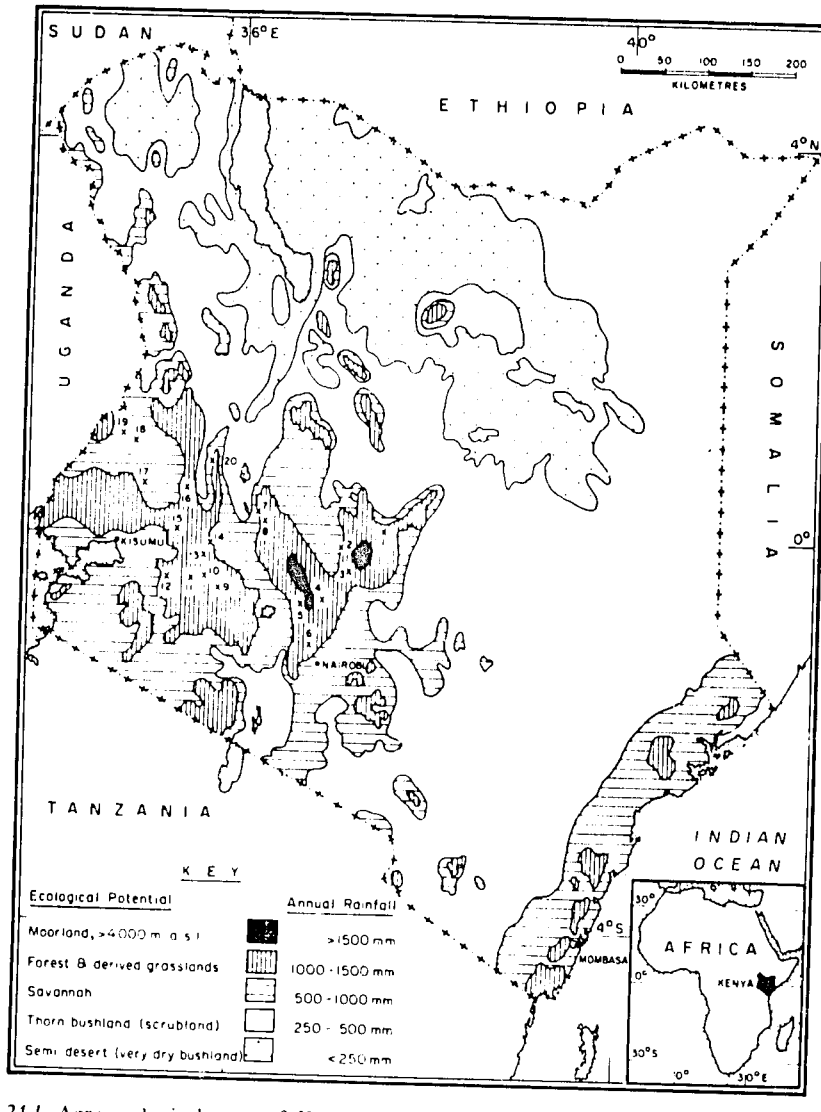

Fig. 24.1. Agro-ecological map of Kenya showing the spread of the shamba system (forest locations from where data on the system were collected).

1. Mucheene
2. Gathiuru
3. Hombe
4. Wanjerere
5. North Kinangop
6. Kamae
7. North Marmanet
8. South Marmanet
9. Nessuit
10. Molo
11. Kerisoi
12. Kericho
13. Sorget
14. Maji Mazuri
15. Nabkoi
16. Kaptagat
17. Nzoia
18. Kitalale
19. North Mt. Elgon
20. Elgeyo

Fig. 24.2. The shamba system – agricultural crops (maize and cabbage in the picture) being cultivated during the early period of establishment of a *Cupressus lusitanica* plantation (Photo: ICRAF).

exotic species have been established through this method in the country. The tree species commonly found in these plantations are *Cupressus lusitanica*, *Pinus patula*, *Pinus radiata*, *Eucalyptus* spp., *Araucaria*, *Acacia* spp., *Vitex keniensis* and *Fagara macrophylla*. Examples of the shamba system in practice are shown by the photographs given in Figs. 24.2 and 24.3.

Fig. 24.3. Harvesting of the agricultural crops from a shamba plot (Photo: ICRAF).

Surveys conducted by the Forest Department in 1981 and 1983 to assess the benefits and costs of the Departmental shambas revealed that forest shambas made a significant contribution both in terms of cash and food production, locally as well as nationally. The locations of the forest stations sampled in this survey are shown in Fig. 24.1.

The main agricultural crops produced are maize, potatoes, beans, cabbages, carrots, peas, wheat, pyrethrum and kale, which form the staple diet for most people in Kenya. Table 24.2 shows the annual production figures from some forest stations (e.g., Gathiuru) are fairly high, thereby reflecting the large number of people who practise the system. In some stations (e.g., Kamae) certain crops are grown twice a year.

The major input is seeds, supplied by the participating farmers; fertilizers are rarely used. The major source of power is human labour. It is estimated that in the 1960s the shamba system accounted for about 18 million kg (200,000 bags) of maize, which formed about 16% of the total national production. Similarly, 38% of the potatoes produced in the country were grown in the forest reserves (Wanyeki 1981). A comparison of crop yields from agricultural land and forest lands (Table 24.3) shows that forest land yields are almost the same as those of agricultural land. It has to be pointed out that the production figures for individual crops are apparently low,

Table 24.2. Total agricultural production from the shambas in different districts (t/yr).

Location	Maize	Potatoes	Beans	Cabbages
Elgeyo	1,215	81	162	162
Gathiuru	4,392	21,960	1,317	—
Hombe	34	591	107	—
Kamae	237	1,485*	—	1,584*
Kaptagat	216	—	—	—
Kericho	141	42	14	56
Okerisoi	194	2,333	11	19
Kitalale	384	—	15	—
Maji Mazuri	254	275	49	—
Molo	543	181	36	—
Mucheene	148	2,376	—	—
Nabkoi	507	761	28	—
Nessuit	2,765	1,152	230	338
N. Kinangop	75	293	—	—
N. Marmanet	803	—	80	—
N. Mt. Elgon	432	—	43	—
Nzoia	223	—	34	—
Sorget	1,118	3,353	6	—
S. Marmanet	482	170	16	94
Wanjerere	72	—	29	29
Total	14,235	35,051	2,177	2,292

* Two crops per year.

Table 24.3. Average yield of maize and potatoes in agricultural land and Forest Department shambas* in different districts (kg/ha).

District	Forest station	Potatoes		Maize	
		Agricultural land	Forest land	Agricultural land	Forest land
Nakuru	Nessuit	—	—	2,700	1,800
Elgeyo	Elgeyo	8,500	—	2,700	1,350
Laikipia	Gathiuru	—	9,000	—	1,800
Meru	Mucheene	11,520	7,200	1,800	—
Nyeri	Hombe	6,930	2,970	1,350	—
Kiambu	Kamae	6,300	4,500	2,790	—
Uasin Gishu	Nabkoi	9,000	2,700	3,150	1,350
Kericho	Sorget	—	5,400	3,150	1,800
Trans Nzoia	N. Mt. Elgon	—	—	3,600	2,700
Nyandarua	S. Marmanet	1,800	—	3,150	1,530
Murang'a	Wanjerere	3,600	—	1,800	900

Sources: Ministry of Agriculture, District Reports for 1981 and 1984; Ministry of Environment and Natural Resources, Forest Department Reports, 1982 and 1984.
* Intercropping.

especially in forest lands, because of intercropping. The same plot produces maize, potatoes and beans, though not in sole-crop stands. For example, a farmer at Mucheene in Meru District produced 7,200 kg of potatoes, 1,800 kg of maize and 900 kg of beans all from the same hectare of forest land. Overall, the system contributes substantially to food production in Kenya.

3.2. *Biological aspects*

The trees and crops compete for the resources available. In a study conducted at Muguga in the early 1960s, it was found that trees grown on bare fallow soil showed a 15% increase in growth over those grown with maize (Mburu 1981). This difference may be lower in areas with high rainfall and greater in areas with less rainfall. But in economic terms the substantial saving in cost of clearing and weeding easily offsets this initial setback in the growth of trees.

3.3. *Socio-economic aspects*

The economic advantages of the system are derived from the sale of agricultural products. Table 24.4 shows the average revenue per hectare for each family for the sampled stations. Family income is greatly improved, as they save cash which would have been spent on food. Table 24.4 also shows that

Table 24.4. Average monetary returns per hectare from the shambas (KSh/year).

Location	Size of shamba (ha)	Costs/ha	Gross	Net	Total income per family
Elgeyo	2.0	1,035	1,425	390	780
Gathiuru	0.7	5,300	6,675	1,375	1,375
Hombe	0.4	1,096	2,100	1,004	401
Kamae	0.1	2,445	3,000	555	55
Kaptagat	0.8	360	1,425	1,065	852
Kericho	0.3	680	1,440	760	228
Kerisoi	0.5	310	9,180	8,870	4,435
Kitalale	0.5	1,645	4,981	3,336	1,668
Molo	1.4	1,240	1,822	582	815
Mucheene	1.0	4,315	8,000	3,685	3,685
Nessuit	0.7	1,380	7,700	6,320	4,424
N. Marmanet	1.0	2,105	2,497	392	392
N. Mt. Elgon	1.0	1,629	2,850	1,221	1,221
Sorget	1.0	1,550	2,700	1,150	1,150
Wanjerere	1.0	575	1,530	955	955

Average revenue per hectare = KSh 3,220.20
Average cost per hectare = KSh 1,834.15
Total average revenue per family = KSh 1,290.30/ha
1 US $ = KSh 16.00 (approx.: April 1986)

the establishment cost per hectare varies: this is mainly due to differences in labour costs from area to area. Moreover, the farmers in different areas use some inputs, but in varying quantities, in order to sustain or increase yields. The system also provides more or less full-time employment to most participants who have no other sources of income. For the Forest Department, this is a cost-effective method of tree establishment: apart from providing a weed-free area for tree planting, it also ensures weeding around young trees for 2–3 years so that tree survival rates increase.

Other social benefits provided by the Department are:

1. A free house or free building materials for the participant;
2. Forest districts with welfare centres, schools, dispensaries, churches and shops, and free water supply; and
3. Help with cutting down the large trees on the allocated plots.

The participants thus benefit from free housing, medical facilities, schools, welfare and infrastructural development. The combination of arable farming and timber crops offers considerable scope for development of sustained rural communities and is more profitable than growing food and forest crops separately.

The shamba system seems to be the most appropriate land-use system for rural development programmes. The combination of agriculture and forestry

when properly implemented reduces environmental degradation and also provides means of reconciling the often conflicting interests of tropical foresters and farmers. The system also satisfies most social and economic needs of subsistence farmers who participate in it, and saves the forest from the destruction caused by shifting cultivation.

4. Disadvantages

The shamba system also has several drawbacks. Notable among them are:

1. About 40% of the reported forest fires in Kenya originated in these forest shambas, mostly at the time of clearing (Wanyeki 1981);
2. The possible damage to crops by wild animals such as elephants, buffaloes, etc., discourages some participants, particularly in remote areas;
3. The cultivation of glades (grasslands) in forest areas has reduced grazing land for both livestock and wild animals;
4. The system requires high levels of supervision, otherwise the laid-down regulations would not be followed, thereby affecting tree establishment adversely;
5. In some areas the number of participants far exceeds the available land, thus leading to illegal clearing.

5. Prospects

The shamba system will continue to play a major role in forest plantation establishment in Kenya *vis-à-vis* tackling the food and fuelwood shortages. With high rates of population growth, unemployment and food shortages the system will continue to play a leading role in the economy. The continuing threat to natural forest is noticed in most areas but compensatory forest planting (clearing indigenous species to plant exotic species) should relieve the pressure in some areas. Crop yields in the system are bound to drop as most of the cultivation is now in second-rotation plantation areas. In view of the importance of the system, and the large number of people supported by it, it is essential to undertake research to evolve appropriate technologies to improve the productivity and sustainability of the system. One of the immediate areas for research could be the management of various crops, including fertilizer application to them, which could improve the productivity not only of the crops but also the trees and thus enhance the overall performance of the system. The provision of easy credit facilities to the farmers for the purchase of fertilizers and other inputs also needs to be properly organized.

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25. The compound farms of south-eastern Nigeria: a predominant agroforestry homegarden system with crops and small livestock*

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Abstract. Compound farms are a homegarden-type of agroforestry system involving the deliberate management of multipurpose trees and shrubs in a multistoreyed association with agricultural crops and small livestock within the compounds of individual houses. In addition to the advantages of diversified production, risk minimization, improved labour and nutrient-use efficiencies and soil conservation, compound farms represent germplasm banks containing many of the useful tree/shrub species currently disappearing due to indiscriminate clearing of forests and woodlands.

1. Introduction

South-eastern Nigeria is a region comprising Anambra, Imo, Cross River and Rivers States with a population density approaching 500 people per square kilometre. This high population pressure on the limited land resources has led to a breakdown of the traditional land-use practices of shifting cultivation and bush fallow which would need periods of up to 15 years to maintain stability (Floyd 1969).

Compound farms are a traditional land-use system that appear to have evolved concomitantly with the shifting cultivation and bush-fallow systems. Recent observations by the authors in the sparsely populated rain-forest zone of the Central African Republic indicate the spontaneous establishment of compound farms by shifting cultivators seeking to establish land tenure alongside new roads.

Compound farms are found within the vicinity of the homesteads and comprise numerous multipurpose woody species in intimate multistoreyed associations with annual crops and small livestock. The multistoreyed structure and species diversity allow almost complete coverage of the soil by plant canopies, thereby promoting soil conservation. Soil fertility is maintained by the use of household refuse, crop residues and animal manure.

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The system has been recognized as a potentially sustainable form of land use (Lagemann 1977) with possible application for the entire humid tropics. Over the last 15 years, the Forestry Development and Investigation Branch (FDIB) of the Forestry Commission, Enugu, and more recently the National Institute for Horticulture (NIHORT), have been undertaking systematic research and development of the traditional food and fruit-producing tree species commonly found in the compound farms.

This paper identifies the major components of compound farms and describes their uses, environmental variation, interactions and management practices. The prospects for and the implications of improvements to the system are examined.

2. General description of the area

South-eastern Nigeria stretches from 4°15′ to 7° N and 5°49′ to 9°39′ E occupying an area of about 75,500 km^2. The land surface is dominated by plains under 200 m a.s.l.

Rainfall is high on the coast, usually monomodal and may reach 4,000 mm yr^{-1}. Further inland, the annual bimodal rainfall ranges from 1,250–2,500 mm with up to three months of dry season. Rainfall intensities are high, often above 50 mm hr^{-1}, with short-interval intensities in excess of 100 mm hr^{-1} (Kowal and Kassam 1977).

The region has high insolation with uniformly high temperatures throughout the year. Mean annual temperatures range from 25° C to 27° C. In coastal areas, mean annual radiation is low due to constant cloud cover.

Major soil groups include:

- Ultisols and Oxisols derived from intermediate and acidic rocks. These are the major soils in the low-altitude forest zone. They are susceptible to compaction, low in nutrients and high in exchangeable Al.
- Alfisols and associated Inceptisols and Entisols. They have a higher base status than Ultisols and Oxisols but are susceptible to erosion.

3. Land-use systems

Agriculture is the major form of land use in south-eastern Nigeria. Approximately 90% of the farms, however, are less than 4 ha in area and about 55% are less than 1 ha (Okigbo and Greenland 1976). This small area of farmland is usually made up of two or more plots which are often scattered around the village.

Both natural and plantation forests exist. Major plantation species include *Gmelina arborea* L., *Tectona grandis* L.f., *Nauclea diderrichii* (De Wild. Th.

Dur.) Merril., *Terminalia ivorensis* A. Chev. and *Pinus caribaea* Morelet. These are planted for fuelwood, poles and pulpwood. To a lesser extent, *Cassia siamea* Lam. and *Eucalyptus* spp. are planted on poorer sites.

In Imo, Cross River and Rivers States, timber is exploited from natural forests within forest reserves. The species extracted include *Entandrophragma* spp., *Khaya ivorensis* A. Chev., *Mitragyna ciliata* Aubrev. & Pellegr., *Nauclea diderrichii*, *Chlorophora excelsa* (Welw.) Benth., *Gossweilerodendron balsamiferum* (Verm.) Harms. and *Cylicodiscus gabunensis* Harms.

Traditional cropping systems range from shifting cultivation in isolated parts of Ogoja Province (near the Cameroon border) to intensive sedentary cultivation. Floyd (1969) reported the following predominant farming systems in south-eastern Nigeria:

(a) Shifting cultivation (periodic movement of both cropland and settlement)
(b) Bush fallowing (periodic shifting of farmland only)
(c) Rudimentary sedentary cultivation (one- or two-year fallow rotations)
(d) Intensive sedentary cultivation
  - terrace farms
  - compound farms.

Compound farms are a good example of the homegarden type of agroforestry as defined by Fernandes and Nair (1986). Due to the fragmented nature of land holdings, attempts to combine cash cropping with a regular supply of food for household use have led to the operation of different field systems and diversified production units:

(a) Compound farms involving multistoreyed cropping of staple food crops with multipurpose trees and small livestock in the immediate vicinity of the house;
(b) Near fields close to the compound but with fewer crops than compound farms;
(c) Outlying and distant fields.

Associated fields are a common feature of the homegarden type of system (Fernandes and Nair 1986; Jacob and Alles 1986; McConnel and Dharmajala 1973; Michon *et al.* 1986; Nair and Sreedharan 1986; Soemarwoto *et al.* 1976). These fields are often used to produce food or cash crops that are not suitable for growing within the multistoreyed homegardens, e.g., maize (intolerant of shade), rice or millet simply to supplement homegarden production.

4. Structure of the compound farm

The compound farms are predominant throughout south-eastern Nigeria where most homesteads have them. Variation of the composition and diversity

of tree species is noticeable, however, as one moves north from the rain forest to the drier savanna zone (Okafor 1982).

4.1. *Crops*

The dominant staple species include yams (*Dioscorea* spp.), cassava (*Manihot esculenta* Cranz), cocoyams (*Xanthosoma sagittifolium* Schott. and *Colocasia esculenta* L.), bananas (*Musa* spp.), plantain (*Musa paradisiaca* L.) and maize (*Zea mays* L.). These are usually grown in mixtures with several subsidiary crops such as okra (*Hibiscus esculentus* L.), pumpkin (*Cucurbita pepo* L.), melon (*Colocynthis vulgaris* Schrad.) and leafy vegetables (*Amaranthus* spp., *Corchorus olitorius* L., *Telfairia occidentalis* Hook f. and *Solanum* spp.).

4.2. *Trees and shrubs*

Several trees and shrubs are deliberately planted and managed on the compound farms for a variety of products or functions. Table 25.1 provides a li of recorded species and their uses or functions. A surprisingly high number of tree and shrub species (at least 60) in the compound farms provide food products. Other woody species providing edible products almost certainly exist: Okafor (1981) identified a total of 171 indigenous woody plants of nutritional importance in the forest zone of Nigeria. The list comprised 53 families with 119 genera and included 95 fruit-tree species. Table 25.2 presents available data on the nutrient composition of the edible portions of some of these trees and shrubs and their potential contribution to human nutrition.

4.3. *Livestock*

Goats, sheep and poultry are commonly kept for meat, for sale and/or home consumption. Other animals occasionally kept include cattle and pigs. Livestock are fed with fodder from trees and shrubs, crop residues, grasses and herbaceous species growing in the compound farms or near fields. The animals are either confined in pens and stall fed or tethered in fields. Trypanosomiasis is a major constraint to livestock rearing.

4.4. *Arrangement/interaction of components*

As is common in the homegarden system, the spatial arrangement of the various components appears haphazard. Nevertheless, the trees, shrubs and

other crops in the compound farm are positioned where they can be protected, watered and harvested with ease.

Trees and shrubs that are regularly used for food, such as *Treculia africana*, *Chrysophyllum albidum*, *Dacroydes edulis*, *Pterocarpus* spp. and *Vernonia amygdalina* Del., occur at a higher frequency within and around the compound farms. Species that are not used regularly or are difficult to harvest occur at a higher frequency in the outlying and distant fields.

The number of crops decreases as the distance from the house increases. The highest diversity occurs on the compound farms and is lowest on the outlying fields. This minimizes the time spent visiting distant fields. In a study of crop distribution on fields at increasing distances from the houses, it was found that 17.8 of 20 important crops were on the compound farm, 12.2 on the second, 11.8 on the third, 8.0 on the fourth and 5.6 on the fifth most distant field (Igbozurika 1978). Figure 25.1 shows the intensity of cropping encountered in compound farms.

Vertically, several relatively distinct strata (canopy layers) can be distinguished in the compound farms. Figure 25.2 is a schematic representation of the vertical strata in compound farms. The lowest zone (0–1.5 m) comprises food crops like cocoyam, beans, cucurbits, okra and regeneration of overstorey trees and shrubs. The next zone (1.5–3 m) consists of cassava, maize, yams (on stakes), *Vernonia amygdalina* hedges and castor. Next is the plantain banana layer (3–6 m) with pawpaw, *Moringa oleifera*, *Ficus capensis*, *Ricinodendron heudelotii* (usually pollarded), *Psidium guajava* and *Crescentia cujete*. Above this comes the fruit vegetable tree layer (6–30 m +) comprising *Pterocarpus* spp., *Cola acuminata* and *Elaeis guineensis*, and other species for timber, fuelwood and cultural uses, such as *Albizia ferruginea* Benth., *Canarium schweinfurthii*, *Chlorophora excelsa* and *Hannoa klaineana*.

4.5. *Variation in compound farms*

A survey of traditional farming sytems in southern Nigeria (Okafor 1981) revealed that compound farms are rare or absent in most of south-western Nigeria. In south-eastern Nigeria, the intensity of cropping with compound farms generally increases with population pressure and land scarcity. Thus, in the densely populated parts of Anambra such as Aguata, Idemili, Nnewi and Njikoka, cropping intensity is greater than in the northern parts of the State.

Differences in species composition of compound farms invariably reflect changing environmental conditions and former land use. Compound farms in the rain-forest zone are characterized by a greater diversity of woody species and a certain predominance of forest species such as *Treculia africana*, *Irvingia gabonensis*, *Dacroydes edulis*, *Chrysophyllum albidum*, *Cola acuminata*, *Elaeis*

Table 25.1. Woody species recorded in compound farms of south-eastern Nigeria and their functions and uses.

Species	Functions/uses
Acioa barteri (Hook. f. ex Oliv.) Engl.	Fodder leaves, stakes, fallow species for restoring soil fertility
Afzelia bella Harms var. bella	Fermented leaves as vegetable, stakes
Albizia spp.	Fodder leaves, stakes, building material, soil-fertility restoration
Alchornea cordifolia (Schum. & Thonn.) Muel. Arg.	Leafy vegetable, stakes, structural material
Anacardium occidentale L.	Edible fruit, food nut, fuelwood
Annona muricata L.	Edible fruit, beverage
Anthonotha macrophylla P. Beauv.	Leaf wrappers, stakes, soil-fertility restoration
Artocarpus communis Forst.	Fruit cooked and eaten, fodder leaves, fuelwood
Baphia nitida Lodd.	Comwood of commerce, fodder leaves, live fence, chewing sticks
Blighia unijugata Bak.	Leafy vegetable
Canarium schweinfurthii Engl.	Fruits eaten after softening in hot water, timber, veneer
Cajanus cajan (L.) Millsp.	Food seed, fodder leaves, fuelwood, leaves used for measles cure
Carica papaya L.	Edible fruit, leaves as vegetable and used to cure malaria
Ceiba pentandra (L.) gaertn.	Leaves as vegetable, fodder leaves, timber, fibre, for mattresses and pillows
Chlorophora excelsa (Welw.) Benth.	Timber, leaves and female catkins as fodder, young leaves as vegetable
Chrysophyllum albidum G. Don	Edible fruit, tree has religious significance as "god of maternity"
Citrus sp.	Edible fruit
Cocos nucifera L.	Edible fruit, thatching, wood as structural material
Cola acuminata (Beauv.) Schott. & Endl.	Seeds eaten, of great importance in social functions
Cola gigantea a. chev. var. gigantea	Seeds used to thicken soups, timber
Cola lepidota K. Schum.	Seed testa eaten fresh, stimulant, socio-cultural importance
Cola nitida (Vent.) Schott. & Endl.	Seeds eaten, stimulant, socio-cultural importance
Cola pachycarpa K. Schum.	Seed testa eaten fresh, stimulant
Crescentia cujete L.	Fruits used to make calabashes, fuelwood
Dacryodes edulis (G. Don) H.J. Lam.	Fruit eaten after softening in hot ashes or hot water, fodder leaves
Daniellia oliveri Hutch. & Dalz.	Timber, structural material, fodder leaves, tender leaves as vegetable, soil-fertility restoration
Dennettia tripetala Bak. f.	Peppery fruits eaten with kola
Dialium guineense Willd.	Vitamin C-rich fruits eaten, beverage, fodder leaves, wood for tool handles, stakes, fuelwood, charcoal
Elaeis guineensis Jacq.	Palm oil extracted from kernels, sugary exudate from cut flower fermented into "palm wine", fronds as thatching, fodder and mulch
Ficus spp.	Leaves as vegetable, fodder leaves
Garcinia kola Heckel	Seeds eaten, chewing sticks, seeds as snake repellant
Gnetum spp.	Leaves as vegetable
Gongronema latifolium Benth.	Leaves as vegetable

Hannoa klaineana Pierre & Engl.	Timber, fuelwood
Hildegardia barterii (Mast.) Kosterm	Seeds as condiment or roasted and eaten, stem provides fibre for ropes, gum
Hymenodictyon pachyantha K. Krause	Leaves as food wrappers, fodder leaves, live stakes
Irvingia gabonensis var. *gabonensis*	Edible fruit, kernel as soup condiment, fodder leaves, wood for tool handles, utensils, carvings, roots, leaves and bark medicinal uses
Irvingia gabonensis var. *excelsa*	Kernel highly valued as soup condiment and source of oil, wood for tool handles and utensils
Jatropha curcas L.	Live fence, leaves for ringworm treatment, seeds fermented and used as soup condiment
Kigelia africana (L.) Benth.	Flowers as vegetable, bark used medicinally for treating sores
Landolphia owariensis P. Beauv.	Acidic fruit pulp eaten
Lasianthera africana Beauv.	Leaves as vegetable
Macsobotrua spp.	Fruit edible, suitable for jams and jellies
Mangifera indica L.	Edible fruit, fodder leaves, fuelwood
Mondia whitei (Hook. f.) Steels	Edible fruit, bark provides fibre for ropes
Monodora myristica Dunal.	Seeds used as substitute for the spice nutmeg
Moringa oleifera Lam.	Flowers, leaves and young pods as vegetable, fodder leaves, live stakes used in boundary demarcation. Seeds used for purification of water.
Myrianthus arboreus P. Beauv.	Leaves as vegetable, seeds edible after cooking
Napoleona imperialis P. Beauv.	Edible fruit pulp, fodder leaves, leaves used medicinally as anti-emetic, wood a chewing stick
Nauclea latifolia Smith.	Edible fruit, fodder leaves, wood as stakes, fuelwood
Neuboulda laevis seem.	Trees used for boundary demarcation, live fence, wood used to build yam stores, fodder leaves, stem and roots used medicinally
Ocimum gratissimum L.	Leaves as vegetable
Parkia biglobosa Benth.	Seeds fermented and used as condiment, fodder leaves and pods, timber, fuelwood, fertility restoration
Penthaclethra macrophylla Benth.	Seeds processed and used a condiment, fodder leaves, wood for tools, utensils, staking or structural materials, leaves as mulch
Persia americana Mill.	Edible fruits, fodder leaves
Prosopis africana Taub.	Seeds used as condiment, fodder leaves, fuelwood
Psidium guajava L.	Edible fruits, fodder leaves, fuelwood
Pterocarpus milbraedii Harms.	Leaves as vegetable, camwood, dye
Pterocarpus santalinoides (P. & D.) L'Her. ex. d.c.	Leaves as vegetable, trees for boundary demarcation, fodder leaves
Pterocarpus soyauxii taub.	Leaves as vegetable, timber, camwood, dyes, sacred tree
Ricinodendron hendelotii (Bail.) ex Pax.	Fodder leaves, live stakes, seeds as condiment and oil
Spondias mombin L.	Edible fruit, jams, jellies, fodder leaves, live stakes, boundary marking, fences
Sterculia tragacantha Lindl.	Wood for building material
Tetracarpidium conophorum (Muell. & Arg.) Hutch. & dalz.	Edible seeds (raw or cooked), source of canophor oil
Tetrapleura tetraptera (Schum. & Thonn.) Taub.	Pods used as spice, fuelwood, bark and pods used medicinally
Theobroma cacao L.	Seed processed into cocoa, leaves as vegetable
Uvaria chamae P. Beauv.	Edible fruit pulp, leaves as vegetable, fodder leaves, fuelwood
Vitex doniana Sweet	Leaves as vegetable, edible fruits, timber, fuelwood
Xylopia aethiopica (Dunal)	Seeds used as spice, substitute for pepper, timber, fuelwood

Table 25.2. Nutrient composition of the edible portion of some tree/shrub species in compound farms.

Species	Edible part	Calories	% Fresh weight (unless otherwise stated)				mg per 100 g fresh weight (unless otherwise stated)				Vit. A (in international units)	Thiamin (kg gamma)	Riboflavin (kg gamma)
			Water	Protein	Fat	Carbohydrate	Ca	Fe	Nicotinic acid	Ascorbic acid			
Annoca muricata	Fruit pulp												
Artocarpus communis	Fruit pulp	109	70.0	1.5	0.3	25	25	1.0	—	15	35	200	—
Carica papaya	Fruit pulp	38	89.0	0.6	—	9	10	0.5	0.1	60	2,500	20	20
Cola acuminata	Nut	309	12.0	9.0	1.0	66	—	—	—	—	—	—	—
Cola nitida	Nu	—	83.0	1.5	0.6	—	3.1	1.4	0.7	9.8	31	11	47
Daniellia oliveri	Dried leaves	—	9.4	5.5	—	—	—	—	—	—	—	—	—
Ficus gnaphalocarpa	Dried leaves	—	11.6	13.8	—	—	—	—	—	—	—	—	—
Irvingia gabonensis	Dried kernel	—	—	—	54.0	—	—	—	—	—	—	—	—
Monodora myristica	Residual seed meal	212	1.0	17.6	2.8	29	—	—	—	—	—	—	—
Moringa oleifera	Fresh seeds												
Moringa oleifera	Fresh leaves												
Pentraclethra sacrophylla	Kernel	569	10.0	22.0	45.0	17	90	—	—	—	—	—	—
Prosopis africana	Pod pulp	279	9.6	9.2	3.0	53	160	70	—	—	—	—	—
Prosopis africana	Dried stems + leaflets	300	7.9	10.2	6.8	50	—	—	—	—	—	—	—
Pterocarpus spp.	Dried leaves	218	10.1	17.1	2.4	32	500	70	—	—	—	—	—
Spondias mombin	Fruit pulp	—	72.8	1.3	0.1	—	31.4	2.8	0.9	46.4	71	95	50
Telfairia pedata	Kernel	517	6.6	19.6	36.0	28.5	—	—	—	—	—	—	—
Vitex doniana	Dried leaves												

Source: Irvine (1961).

Fig. 25.1. High intensity, multistoreyed cropping in compound farms (Photo: E.C.M. Fernandes).

guineensis, *Pterocarpus soyauxii*, *P. santalinoides*, *Ficus capensis*, *Spondias mombin* and *Garcinia kola*.

In the derived savanna zone, *Adansonia digitata*, *Ceiba pentandra*, *Moringa oleifera*, *Tamarindus indica*, *Prosopis africana*, *Parkia biglobosa*, *Detarium microcarpum*, *Anogeissus leiocarpus*, *Daniellia oliveri* and *Erythrophleum suaveolens* are more common.

Differences in species composition within compound farms result in substitution of species for particular uses. For example, kernels of *Irvingia gabonensis* used as a soup condiment in the first zone are substituted by kernels of

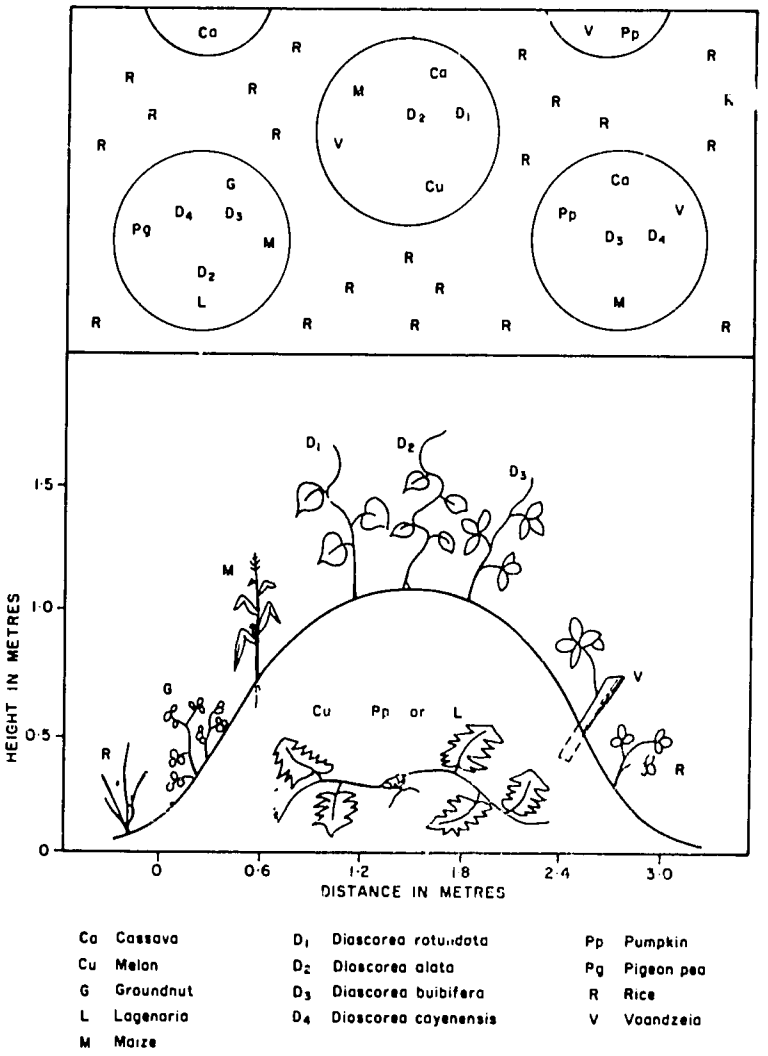

Fig. 25.2. Spatial distribution of crops on mounds in Abakaliki, Anambra State, Nigeria.

Detarium microcarpum in the savanna areas. Similarly, fermented seeds of *Ricinus communis* are commonly used as a condiment in the forest zone while *Parkia biglobosa* and *Prosopis africana* are used for the same purpose in savanna areas.

5. Management aspects

Farmers make use of changes in soils and topography and this results in definite planting patterns within compound farms. Root crops are usually planted on ridges and mounds and climbing crops such as yams and cucurbits

Fig. 25.3. Ricinodendron hendelotii trees as live stakes for yams (*Dioscorea* spp.) (Photo: E.C.N. Fernandes).

are usually staked or planted close to trees which act as supports. Figure 25.3 shows the use of trees like *Ricinodendron heudelotii* as live stakes for yams. Maize is usually planted in furrows on the lower sides of the ridges or mounds. Figure 25.4 shows the distribution of crops on mounds. Creepers such as *Colocynthis vulgaris* Schrad. and pumpkin are used to provide ground cover. Fruit species such as oranges, avocado and pineapple may be planted along pathways of the compound farm. Cowpeas and lima beans are often planted along fences to facilitate harvesting.

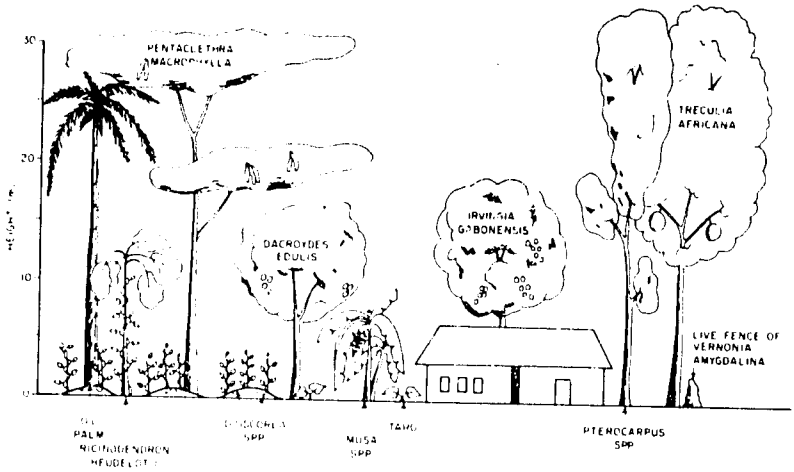

Fig. 25.4. Schematic presentation of vertical strata in compound farms.

Due to different maturity periods, crop species are invariably planted and harvested at different times. Yams, for example, are planted before the onset of the rains, while maize and millet are planted a few months after the rainy season has begun. Cassava is planted about four weeks after maize and harvested the following year. This diversified and continuous production of food is important not only nutritionally, but also because storage of harvested products is difficult and post-harvest losses are high (Ruthenberg 1980).

Planting patterns are also related to the light requirements of component crops. Thus, the great majority of crops in the compound farms are at least moderately shade tolerant, e.g., yams, cocoyam and beans. Heliophytes (light lovers) such as maize, and to some extent cassava, are usually planted in the outlying fields where tree and shrub density is lower and hence shading is less.

6. Evaluation

6.1. *Merits*

Numerous advantages are inherent in the multispecies, multistoreyed cropping systems such as those of the compound farms. These include diversified production, risk minimization, enhanced labour efficiency, continuous production (thereby minimizing post-harvest losses due to poor storage facilities), better nutrient cycling and nutrient-use efficiency than in monocropping systems and good soil conservation due to continuous ground cover.

In addition to being nutritionally important, many of the tree/shrub species provide products with considerable economic value. It has been estimated that the total revenue from a single mature tree of *Irvingia gabonensis* var.

gabonensis (valued for its kernel) is around US$ 300 annually (Okafor 1982). The high local demand for *Irvingia* kernels, coupled with the scarcity of supply, illustrates the cash-generating potential of some of these tree/shrub species.

The genetic diversity of the compound farms is important not only for risk minimization but also because some of the species present have potential to substitute for currently imported products. Thus, *Monodora myristica* is a good replacement for imported nutmeg (*Myristica fragrans*). *Piper guinense* can substitute for *P. nigrum* (black pepper). The drying oil obtained from *Tetracarpidium conophorum* compares very favourably with linseed oil. Seeds of *Treculia africana* can substitute for or supplement rice with considerable nutritional advantage.

Due to the high rate of forest clearing in southern Nigeria, a large number of potentially valuable species are currently being lost (Denton *et al.* 1983). This enhances the importance of compound farms as invaluable germplasm banks of at least the traditionally important multipurpose tree/shrub species that are currently being destroyed in the forest zone.

Although the present system is believed to have originated approximately ten centuries ago (Okigbo, pers. comm.), and remained relatively stable over the intervening period, rapidly increasing population and scarce land resources are now putting increasing pressure on the system. In order to meet the needs of the people, the emphasis in land use is turning to current productivity as opposed to sustainable productivity.

Recently acquired wealth (during the "oil boom") resulted in some farmers clearing their compound farms with bulldozers and engaging in high-input monocropping. Removal of the canopy cover over the erosion-prone Alfisols and compaction by heavy machinery on the sandy Oxisols and Ultisols have resulted in soil degradation and poor yields.

The presence of tsetse flies and trypanosomiasis is a major constraint to livestock rearing in the compound farms. Livestock could play a major role in enhancing the productivity of compound farms both directly via the production of meat and milk and indirectly in nutrient cycling.

Perhaps the biggest constraint of the compound farm or homegarden type of system is that it is perceived as a primitive form of substistence land use. This view is common both at international and local levels of land-use policy and decision making and has resulted in little, if any, resources being devoted to the study and improvement of the system as a whole.

6.3. *Potential for increasing the productivity of compound farms*

Current research on crops and animals being undertaken by national research programmes, the International Institute for Tropical Agriculture (IITA) and

the International Livestock Centre for Africa (ILCA) has relevance to the compound-farm system. It is important, however, that suitable on-farm trials be carried out to test the suitability of new species, varieties and/or technologies.

Funds for systematic research into the tree/shrub components of compound farms are scarce and much needs to be done. The large-scale production of seedlings of improved multipurpose tree and shrub species currently available at FDIB, and the efficient supply of these to farmers, would be one method of achieving improved productivity in the short term.

The abundant but seasonal availability of fruits, widespread waste of fruits during seasons of plenty, and lack of storage mean that the effectiveness of production in compound farms could be significantly enhanced by adequate processing and/or preservation methods. For example, several of the indigenous fruit species can be processed into jams or jellies (e.g. *Chrysophyllum albidum*, *Irvingia gabonensis* var. *gabonensis*, *Dialium guineense* and *Spondias mombin*).

In the long term, exploitation of variation in phenology, both within and between species, could result in the longer availability of a desired product. For example, the use of adult stem cuttings to propagate *Pterocarpus* spp. varying in pattern of leaf flushes could result in availability of *Pterocarpus* vegetables for home consumption or sale throughout the year. Similarly, intensive selection methods could result in increased yields and quality products.

The possibility of importing species currently used in homegardens elsewhere in the tropics should be actively pursued. For example, the homestead gardens in the south-western coastal parts of India (Nair and Sreedharan 1986), Kandy gardens of Sri Lanka (Jacob and Alles 1987) and the agroforests of Indonesia (Michon *et al.* 1986) can offer a wide variety of plant species that might be quite adaptable to the conditions of south-east Nigeria and other humid lowland tropics. Numerous food, fruit and other multipurpose species have been identified in these and other such studies (e.g., Fernandes *et al.* 1984), which could play a significant role in enhancing productivity and profitability of this system.

The potential of integrating genera such as *Derris*, *Adhatoda* and *Lonchocarpus* within compound farms for green manuring should be investigated. The species identified are recognized sources of natural insecticide and nematicide compounds and could play an important role in minimizing pre- and post-harvest crops losses due to pests.

It is important that a well co-ordinated and systematic research programme is undertaken to obtain information relevant to enhancing the productivity and sustainability of the compound farms. Fernandes *et al.* (1984) identified several areas of research important to the homegarden system as a whole.

6.4. *Extrapolatability*

As described previously, the compound farm or homegarden system is already widespread in many areas of the tropics. The system permits a considerable amount of flexibility of management options allowing subsistence and/or commercial production. The high species diversity inherent in the system also allows for conservation of species which are at present being destroyed through improper land use.

This concept of compound farms (homegardens) as multipurpose gene banks requiring little input but enjoying protection by farmers who derive benefits from them, may be the only way to minimize the current genetic erosion occurring in the tropics. In this context, the system would be invaluable in areas such as the Amazon basin.

Acknowledgement

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26. The dehesa: an agrosilvopastoral system of the Mediterranean region with special reference to the Sierra Morena area of Spain*

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Abstract. A multidisciplinary team undertook a six-year investigation on the agro-ecological and socio-economic aspects of the dehesa system in the Sierra Norte area, a part of the Sierra Morena of Sevilla Province, Western Andalusia, Spain. This paper summarizes its findings on the various agro-ecological features of the system and evaluates the system's functional aspects *vis-à-vis* the trends and developments in land use in the region over the past few centuries. The synergistic effects of tree cover on understorey grassland vegetation are discussed in terms of soil fertility build-up and favourable micro-climatic and hydrological features, and the potential use of this information in future research and development programmes to improve the dehesa system in the Mediterranean region is outlined.

1. Introduction

In south-western Spain the word "dehesa" is used to denote the land-use system in rural areas, mainly rangelands, which are occupied by scattered oak trees (*Quercus rotundifolia, Q. suber, Q. faginea*). The system has been known for many centuries for its multiple, mainly silvopastoral, use of renewable resources, and its strong linkages to recurrent cereal cropping in rangelands.

There are many bibliographical references to the past importance of the oaks in producing sweet acorns both for human consumption and to feed domestic animals such as pigs (see, for the Roman period, Bauer 1980). Early livestock farmers in south-western Spain had legal rights over grazing resources belonging to rural areas "with trees". These indicate the long history of the land-use system involving oak trees in the appropriation of rural areas in the Iberian peninsula.

The scattered tree layer dominated by sweet acorn oaks has a strong link

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with animal husbandry and, as such, the dehesa could basically be considered as an orchard system which produces feedstuff for domestic animals. But looking more carefully, we can say that this orchard-like system is also a producer of forestry resources, such as timber for various uses, charcoal, tannin, cork (*Q. suber*), etc. Besides, it plays a very important role in improving soil conditions, and also in giving shelter for grazing animals. The system also contributes to the comprehensive ecological equilibrium of the rural area and to its environmental quality and stability, both at regional and very local levels. These various characteristics of the dehesa system are described and evaluated in this paper based on the results of a six-year study undertaken in the Sierra Norte area, northern Sevilla, Western Andalusia, Spain.

2. The importance of the dehesa

The dehesas cover approximately 5,000,000 hectares in south-western Spain (Campos Palacin 1983) (Fig. 26.1, Table 26.1) and more than 500,000 ha in Portugal (Balabanian 1980) where they are called "montados".

The study area from which results are reported in this paper, has an area of about 140,000 ha of the Sierra Norte (Fig. 26.1), which is a part of Sierra Morena (Province of Sevilla). The organization of the whole rural area dominated by the dehesas could be described as follows:

2.1. *Agricultural lands of Ruedo*

These are very specific intensive agricultural areas close to the rural villages. They look like a cluster of polyculture units and are represented by many small fields under horticulture (mainly vegetables) and intensive fodder production (presently for dairy cows), mainly on fertile alluvial soils.

Table 26.1. Surface of grazing lands in south-western Spain (in thousands of hectares).

	Open grasslands (1)	Dehesas str. s. (open oak woodland) (2)	Matorrales (3)	Dehesas s.l. (1 + 2 + 3)
Extremadura	998	760	246	2,004
West. Andalusia	394	722	281	1,397
Other Provinces	913	402	251	1,566
Total	2,305	1,884	778	4,967

Source: Superficie occupados por los cultivos agricolas (1981) Ministerio de Agricultura, Madrid.

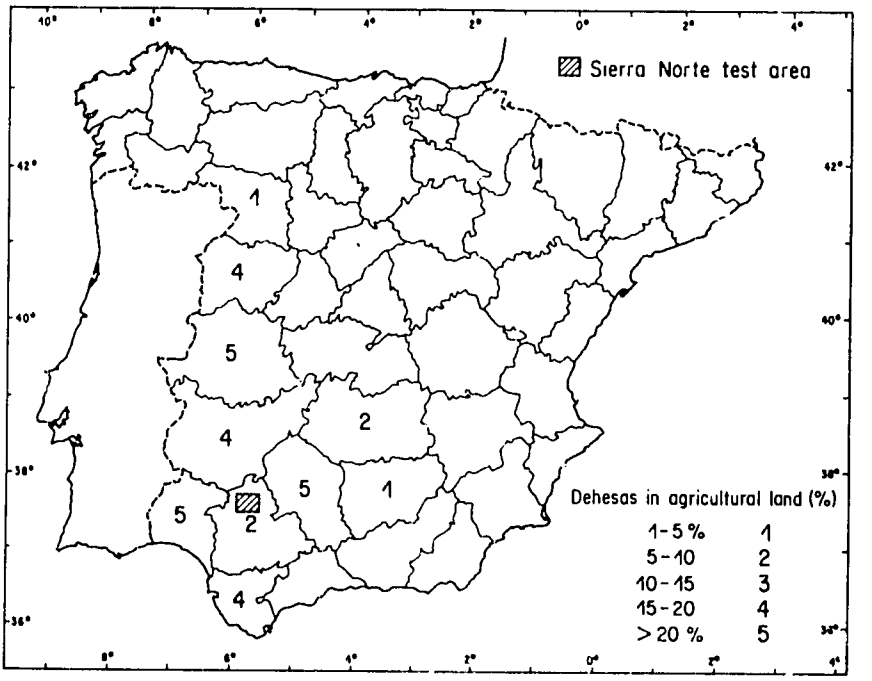


Fig. 26.1. Distribution of open oak woodland (dehesa *stricto sensu*) in Spain as percentage of agricultural land, and location of the Sierra Norte study area (Western Andalusia).

2.2. *Olive-tree plantations*

A typical form of landscape in Andalusia, extended sometimes to large areas in the vicinity of the villages, on red ferrallitic soils. They constitute the main source of income for the small land owners and employment for daily agricultural workers. Some of these olive-tree plantations are currently being abandoned for various reasons, and, consequently, they show some features that are quite similar to typical oak dehesas.

2.3. *Dehesas* (stricto sensu)

They represent the dominant landscape of the rural areas in the Sierra Norte. They look like very open oak forests, with a density of 20–40 mature trees per hectare. The ground surface is covered either by cultivated cereals (oats, barley, wheat) or, more commonly, by native vegetation dominated by annual species used as grazing for both wild and domestic animals. Land-use maps (Vacher *et al.* 1983) show that 80% of the dehesas have a tree cover of between 5 and 20%. These statistics are used by the Ministry of Agriculture in Spain to identify three categories of grazing lands:

Fig. 26.2. Photograph of a typical dehesa landscape of the low hills of the Sierra Norte. Scattered oaks (*Quercus rotundifolia*), 30–40 mature trees per hectare, are especially pruned to increase acorn production, the understorey is a post-cultural annual grassland dominated by *Bromus hordeaceus*, *Vulpia vesiculata*, *V. bromoides*, etc. (Photo: G. Long.)

post-cultural fallow annual grasslands without trees,
dehesas *str. s.*,
grazed open oak forests (tree cover more than 20%).

Quercus rotundifolia is the only tree component in 45% the dehesas *str. s.* (Fig. 26.2) and *Q. suber* in 5%; 50% of the dehesas *str. s.* have a mixture of the two species, but *Q. rotundifolia* always dominates *Q. suber* in the Sierra Norte (Fig. 26.3).

2.4. *Matorrales*

These are represented by dense evergreen shrublands, typical Mediterranean vegetation types, composed mainly of *Cistus* spp., *Erica* spp. and *Arbutus unedo*. They are the result of the forest degradation, especially in very shallow and poor soils which are quite frequent in the hilly areas of the Sierra Norte, or part of the progressive ecological succession after a few years of bad management of cropping and grazing lands.

2.5. *Plantation forests*

In Sierra Norte, these are represented mostly by monospecific plantations of *Eucalyptus* (*E. rostrata*, *E. globulus*) and *Pinus pinea*. The localization of such

Fig. 26.3. Photograph of an oats field as understorey to mixed oaks (*Q. suber* and *Q. rotundifolia*) dehesa. (Photo: G. Long.)

forests corresponds to more specific social and land-tenure conditions than to soils with good forestland capabilities. They represent areas that were originally under either dehesas *str. s.* or matorrales, owned by absentee farmers belonging to the "*latifundist*" class.

Considering the evolution of the main land-use types in relation to three periods between 1750 and 1956 (Table 26.2), there has been very little change in the areas occupied by each type. The dehesas have remained the most important aspect of rural land use in the Sierra Norte over the last two centuries. Madoz (1850) in his dictionary describes such dehesas and emphasizes the quality of their grazing function. Based on these facts, on the one hand, and the presence of the trees in most of the dehesas of the Sierra Norte,

Table 26.2. Evolution of the land-use units of the Sierra Norte of Sevilla (percentage of the whole area; sampled area: 140,000 ha).

	18th century 1750	19th century 1850–1956	20th century 1956
Agrosystems of ruedo	1	1.5	1
Olive tree plantations	6	4.5	7
Dehesas	53	60	60
Matorrales	38	33	32
Plantation forests	2	1	0

Source: Vacher *et al.* (1983).

on the other, we can say that the agrosilvopastoral dehesa system has been stable for many centuries.

The evolution of this agrosilvopastoral system between 1956 and 1977 was studied by Vacher *et al.* (1983). Aerial photographs (1956 – scale 1:33,000; 1977 – scale 1:18,000) were used to determine the main changes. Table 26.3 shows the most significant data, of which the following can be emphasized:

- 20–25% of the 1956 dehesas (various types) have been transformed, mainly to the advantage of the matorrales; and
- The area under matorrales increased from 14,624 to 25,234 ha, i.e. 80% increase.

The changes indicated in Table 26.3 are the result of three main anthropogenic factors:

(a) Decreasing the agropastoral management practices in the dehesa areas;
(b) Increasing the deforestation and clearing process in order to extend cropping lands; and
(c) Reforestation over about 10% of the total area surveyed.

In summary, the most prominent changes in the dehesa landscapes have occurred in the past 20–30 years. There is a strong evolutionary process called "matorralization" linked with a process of increasing cropping lands with heavy machinery. This is still not as common in the hilly region of the Sierra Norte as in the other dehesa regions (i.e., Salamanca). To some extent, the relief and poor soils of the Sierra Norte have preserved the dehesas in spite of the general tendency of tree eradication to produce cropping areas. But, on the other hand, social and land-tenure conditions have favoured forestry and less care for many dehesa rangelands.

Table 26.3. Evolution of the land-use units (in hectares) of the Sierra Norte of Sevilla between 1956 and 1977 (sampled area: 140,000 ha).

	1956	1977
Open grassland (without trees)	16,770	11,026
Oak dehesa rangelands	63,890	50,268
Matoralles (shrublands)	14,624	25,234
Shrubby oak woodlands (dehesas-matorrales)	31,437	27,714
Olive tree plantations	6,317	6,681
Agrosystems	1,306	2,385
Plantation forests	0	11,036

Source: Vacher *et al.* (1983).

Systems such as dehesas and "montados" also exist in various other Mediterranean countries, including Morocco, Algeria, Tunisia, Southern France (mainly Corsica), Italy (Sardinia) and Greece. But the system in those countries is usually not as well managed as in the Sierra Norte area. Moreover, in the warmer semi-arid parts of the Mediterranean regions, especially in limestone areas, the carob tree, *Ceratonia siliqua* (Leguminaceae), takes the place of the oak tree.

3. Analysis of the dehesa farming system

3.1. *Traditional farming system in the dehesa regions*

Many reports are available on the changes in the function of the dehesa farming system during the sixties (Fourneau and Roux 1974, Gomez Gurtierrez *et al.* 1982, 1966, Romero Candau 1981, Tanago 1982). Enquiries were made by the research group of the Casa of Velazquez in order to collect basic information at the farm level and the information gathered was checked against documentary sources (such as Galindo 1966, Garcia Fernandez 1977, Gomez Gurtierrez *et al.* 1982, Parsons 1966). Based on these, the following characteristics of the system in the Sierra Norte test area can be emphasized:

Livestock management

The livestock systems, either sheep, goats, cattle or pigs, are very flexible. Most of them have zonal variability of pastoral and stubble resources and are adapted to various forms of migration, for instance transhumance from Sierra Norte to the fertile cereal cropping area near the Guadalquivir river. Sheep (for mutton, meat and wool) are the main category of grazing animals (Figs. 26.4 and 26.5). Pigs are also associated in all dehesa farms. The sheep production system is shown in Fig. 26.6. There is only one lambing every year in the autumn. Lambs are marketed and old ewes eliminated from the flock in early summer, which means just before any shortage of natural grazing resources or before taking the sheep to the stubble area of the lower plains. Destocking of the rangelands, which means a long rest period, is a key factor in the management of the grazing lands. Thus, the maximum feeding requirement corresponds to the maximum potential availability of the green grazing resources, between mid-autumn and late spring.

As regards pigs, the key question is how to make the best use of seasonal acorn production, between October and February, in order to get the maximum liveweight increase. Ruperez (1957) reported that 9 kg of *Q. rotundifolia* acorns can lead to the production of 1 kg of fat pork meat. The period considered for acorn feeding is called "montanera". During 75 days of

Fig. 26.4. Photograph of sheep (Merinos) grazing the grassland (annual grasses) associated with scattered trees (*Quercus rotundifolia*). (Photo: G. Long.)

Fig. 26.5. Photograph of cattle (mainly Retinta breed) in a *Q. rotundifolia* dehesa. The picture shows that during the hot part of the day cattle are attracted by the shade of scattered oak canopies. Here the grassland is dominated by *Phalaris aquatica* and *Dactylis glomerata*, two perennial grasses. (Photo: G. Long.)

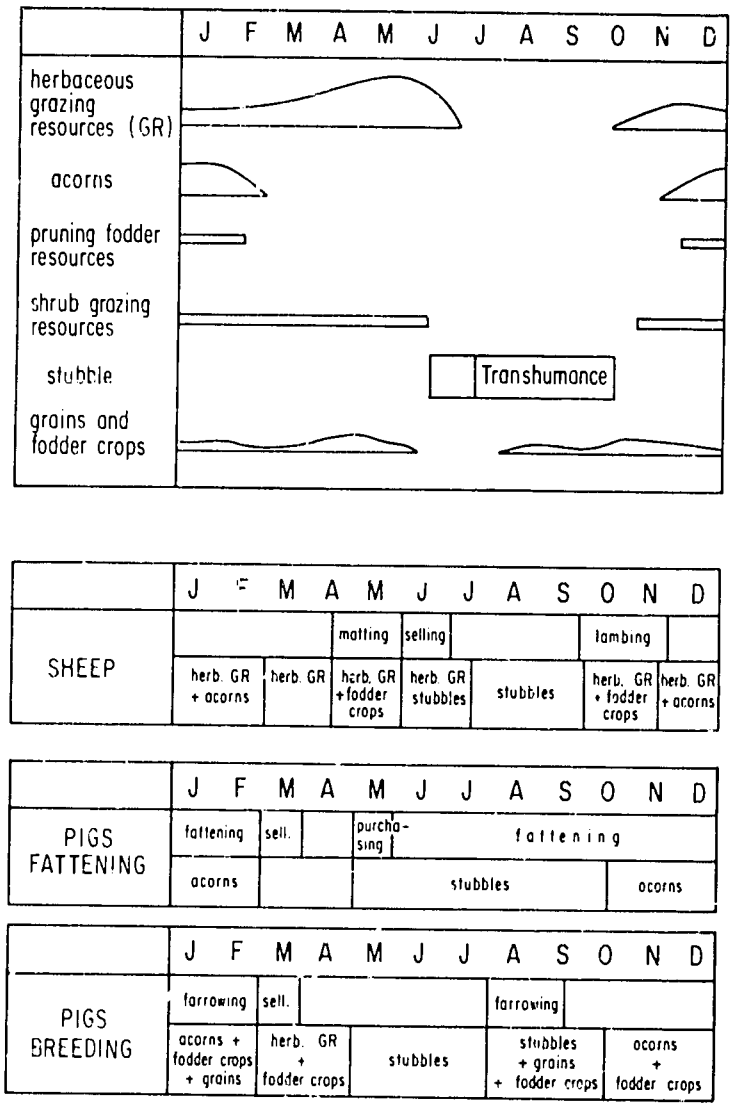


Fig. 26.6. Seasonal variations of grazing and fodder resources in sheep and pig livestock systems in a traditional farming area of the dehesa region, before 1960.

montanera a pig can gain 60 kg liveweight before it is sold in the spring. On average, there is a stocking rate of 1 adult pig for every 2 hectares of mature oak dehesa with 20–40 trees per ha. Pigs are also grazed with herbaceous fodder and, as such, are competitors of sheep. That means a minimum rotating system is implemented in such a way that the two main categories of grazing animals are present at different times on a given piece of rangeland. Sheep, goats and pigs are all herded. There are no fenced areas, except for night corrals.

Optimization of the traditional feeding systems for the two dominant categories of grazing animals – sheep and pigs – is done as follows:

- The more fertile lands in the dehesa region are cropped with cereals (grain, straw and stubble are considered as feeding materials) and fodder legumes (*Lupinus*, *Vicia*, *Medicago sativa*) unless facilities for summer irrigation are available;
- Summer stubble grazing in the Guadalquivir plains is a very important part of the livestock system, mainly for sheep.

The necessity of improving soil fertility in the medium-quality grassland area led to the practice which corresponds to the "majadales". These are areas which correspond to the size of small corrals frequently moved from place to place and in which sheep are kept some nights in order to increase natural organic turn-over, thus leading to a significant improvement of grazing quality the following year. Fences were quite absent before the sixties and the rule was herding during the day and penning (majadales) at night. All the grazing areas were grazed more or less continuously with the exception of the night enclosures and the rest period during the transhumance time.

Establishment and maintenance of the dehesa

Sowing of sweet acorns is undertaken if the native oaks have too poor initial conditions. Young oak stands are protected against grazing for about five years.

Trees are pruned, first during their early stages to give them their special architecture, with a verticil of 2–7 main branches at 1–2 m above ground when the tree is mature and then to favour the horizontal spread of the fruiting branches. This allows opening of the canopies and facilitates increase in canopy size and better acorn production. An oak tree of the dehesa is pruned many times during its life with the objective of continuous control of the shape of the tree, to improve its fruiting capabilities and also to collect wood for fuel or charcoal, which is one of the main "forest" incomes from these very open forests.

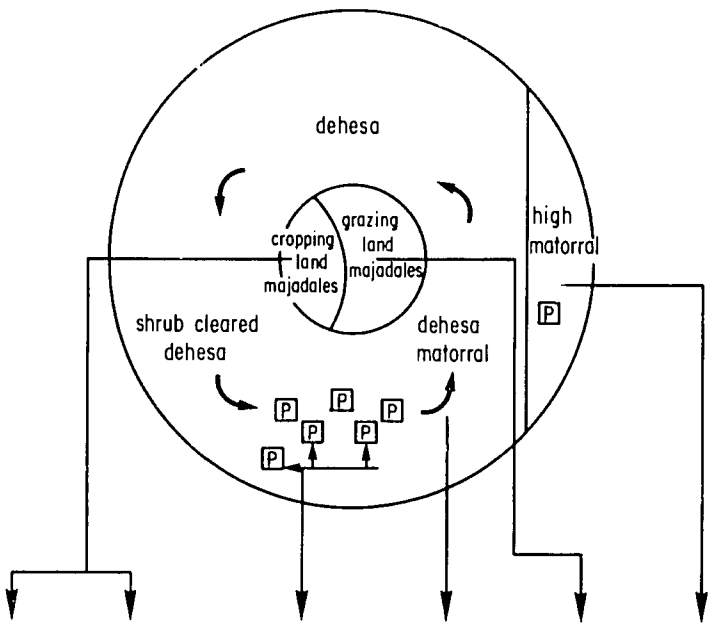
A mature *Quercus suber* tree also gives the opportunity for cork production. A *Q. suber* dehesa of 40–50 trees per ha produces 600–1,000 kg of cork every nine years.

Oak dehesas are considered good rangelands unless they are invaded by the shrubs of the adjacent matorrales, which is a natural ecological succession if the farmer gives little care to his lands. The fight against the invasion of shrubs, especially *Cistus* spp., a regular operation on the farm, is carried out by hand pulling of the individual young plants from the areas that are close to the farm. In more distant areas this process is done through special

contracts between the farmers and groups of peasants, the "pegujaleros", who are allowed to clear the lands invaded by matorrales for their own fuel needs and then to plough these lands for cereal cropping. In doing so, native oak trees are selected and protected in such a way that they contribute to the build-up of a dehesa-like landscape.

All these establishment and maintenance techniques are possible when manpower is available, and because most of the rural population concerned are poorly paid and have little security. The long-term strategy of the production system could be considered a testimony to the compatibility between the rules proposed at the national level (cf. legal rignts given to the latifundists) and the traditional heritage of the families who have been the owners of the big farms for centuries.

A summary of the functioning of a traditional farming system in the dehesas of the Sierra Norte is given in Fig. 26.7, emphasizing the production of renewable resources.



irrigated zone	cropping land majadales (4-8 years rotation)	shrub cleared dehesa (15-20 years rotation)	dehesa	grazing lands majadales	high matorral
• fodder crops	• fodder crops • cereals (grains) • stubbles • herb. GR	• cereals (grains) • stubbles • herb. GR • charcoal	• herb. GR • acorns, pruning GR • Timber • charcoal • cork	• herb. GR (only for lambs)	• shrub fodder resources • charcoal

herb. GR = herbaceous grazing resources

Fig. 26.7. Schematic representation of the functioning of a traditional farming system.

3.2. *Recent developments in the Sierra Norte*

The main features in the early 1960s

These can summarized as follows:

- Emigration of more than 30% of the total population of the Sierra Norte, mainly the daily workers depending on big farmers;
- Rapid increases in the wages of agricultural workers;
- Higher rate of incidence of pig diseases;
- Decreasing demand for charcoal because of the development of other energy sources at the level of small urban systems; and
- Breakdown of the transhumance system between the Sierra and the cereal growing plains according to big changes in cropping systems (industrial agriculture, sugarbeet, sunflower, etc.) and also because the cereal culture itself was modified (wheat cultivars with short straw led to low stubble productivity; burning of stubble was preferred to using it for sheep grazing).

New trends during the past two decades (1965–1985)

The weakness of the socio-economic situation in the dehesa areas led the Ministry of Agriculture, represented by its Agency for Animal Husbandry Development, to try to implement a programme for improvement of animal production. The targets were mainly animal products, but very little rangeland management. The scenario can be summarized as follows:

- Partial substitution of small grazing animals by cattle;
- General efforts to improve cattle breeds by crossing local Retinta cows with Charolais or Limousin bulls which are better for meat production;
- Sheep production (local Merinos crossed with many other improved breeds) oriented to a system which is characterized by three lambings in two years for every mature ewe; and
- Health improvements in all categories of domestic animals.

These animal production systems, which are relevant to fertile grassland or farmland areas, are a result of a policy of increasing animal products for the benefit of regional and national markets. As a consequence, there is an increase in the demand for grazing and fodder resources from cropping areas, or foodstuffs from agro-industry, and greater areas are brought under a ley-farming system based upon Australian cultivars of *Trifolium subterraneum* (see below). The prerequisites for such a ley-farming system are good cultivation of the soil surface, availability of commercial seeds at fair cost, and fertilization by grazing animals in order to guarantee the perennial nature

(more than two years) of the ley. Along with these efforts, all the farmers are encouraged to use fences, mostly in large size plots (10–50 ha), in order to control the grazing animals with the minimum of manpower. But, unfortunately, the grazing-management system did not change: it remained a "year-long continuous grazing system", and much less care has been taken for most of the areas not considered cropping lands.

All the components of this national and regional programme were accompanied by very substantial subsidies from the government. Some farmers, being incapable of controlling the intensity of the new system of production, disappointed with the programme, or often absent from their farms, preferred to change their production system drastically. Some of them decided to plant pure stands of forest trees (*Eucalyptus*, *Pinus*); others developed wildlife and game resources for hunting.

The situation in the mid-1980s

The dehesas represent about 50% of the whole surface of the study area of the Sierra Norte. They correspond to livestock farms, mainly cattle, sheep, and rarely goats (for milk) and pigs. Grazing resources are poorly managed (if managed at all). Average size of the farms is about 500 ha. Stocking rates are 1–2 equivalent sheep units per ha per year (De los Llanos 1983). The sheep population decreased from 240,000 to 87,000 head during the 1970s, mainly because of the disappearance of many livestock farms. The goat population also decreased from 77,000 to 34,000 head, although there might have been an increase of productivity in some livestock farms. At the same time the cattle population increased from 28,000 to 41,000 head (all these figures, from Agencia de Desarrollo Ganadero, 1983). Cattle are linked with the farms which are more than 500 ha.

In the present management practices for sheep production, relations between feeding resources produced on the farm and those from outside are taken into consideration. To meet the new target of at least three lambs in two years for every mature ewe, there is a requirement of an average of 30 kg of improved feedstuff produced outside the farm for every lamb, so as to adjust the lamb growth rate to the present conditions. Furthermore, lambing can be at different times of the year, even in a season when there are no grazing resources.

A summary of the functioning of the present dehesa farming system is given in Fig. 26.8. The main aim of the new cattle livestock system is to raise young steers and market them 5–7 months after calving. Here again, the improvement of the growth rate depends mainly upon artificial feedstuff.

Consequently, the dehesa systems are neglected; they become areas mainly to confine the grazing animals and to feed at minimum levels. Continuous grazing is the rule. Range rotation with corrals at night, leading to an

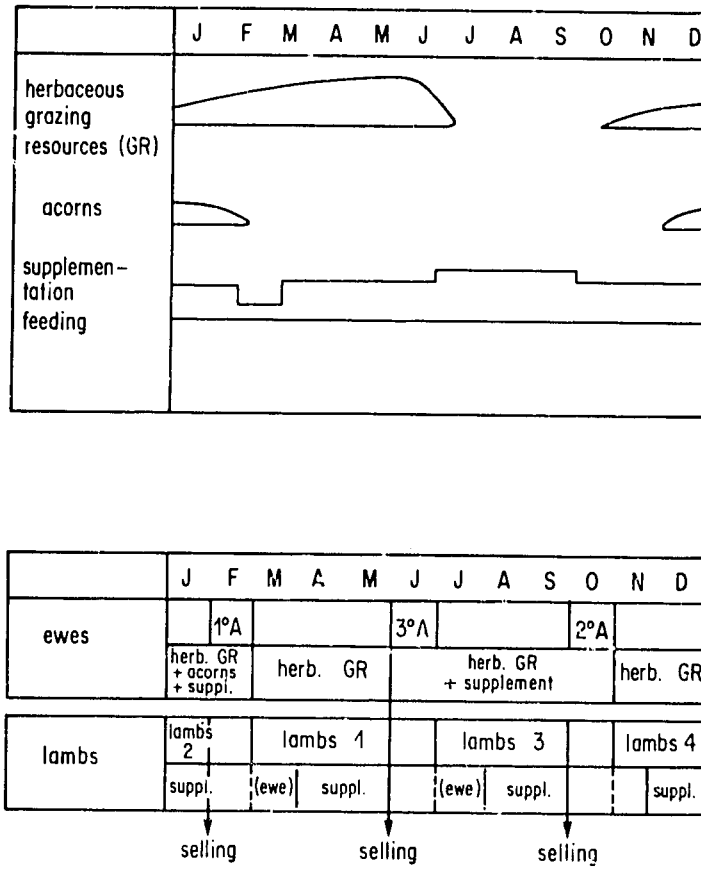


Fig. 26.8. Seasonal variations of grazing and fodder resources according to sheep production in the present dehesa farming system (1980).

improvement of the value of the grassland (see majadales), is no longer practised. Furthermore, some of the dehesa lands are converted into cropping lands for ley farming with *Trifolium subterraneum* cultivars (such as Clare, Mount Baker, Woogenellup, from Australia). The more-or-less total failure of this new cropping system is quite obvious in the Sierra Norte area for many reasons: low persistence capability of the cultivars used, bad management of the ley, a succession of years with low rainfall, etc. Most of the areas cropped with *T. subterraneum* are today grasslands with very poor grazing value. There is still a controversy in Spain about this question, but based on the authors' observations, the ley-farming system as presently practised in the study area of the Sierra Norte has serious inadequacies. Other ways have to be explored for improving grazing value and persistence of the natural grasslands belonging to the dehesa system.

The failure of the ley system is unfortunately linked with less care for the tree layer of the dehesas. Because of higher costs and scarcity of manpower

the trees are neglected even when the farmers are using more sophisticated pruning techniques. The gathering of pruned material is a very expensive task with a small return; sometimes this leads to burning on the spot, especially if the demand for charcoal is high. Eradication of invader shrubs is only done with heavy disk ploughs which adversely affect the most fertile soil horizons and lead to the extinction of all stands of perennial grasses with good grazing value. But still the matorral continued to be extended (matorralization) during the past few years, with an increasing fire risk. Techniques for the regeneration of the tree layer in the dehesas are no longer available at farm level.

In conclusion, the new system of production, with elements of modernization, has many bad effects on the management and reproduction of the renewable resources of the dehesas. Ecological deterioration of this very specific agroforestry system is today an acute problem which requires careful attention, both at research and technical-managerial levels.

4. Agro-ecological analysis of the dehesa landscapes of the Sierra Norte

Though not immediately obvious, there is a considerable amount of regional as well as local heterogeneity in the dehesas. The relationships between ecological variables at regional levels, such as topography and climate, and the vegetation of the dehesa landscapes, are not very easy to investigate. It has been proposed to consider the dominant species composition and the distribution of matorrales associated with the dehesas *str. s.*, to determine the links between the main ecological variables and natural vegetation of the Sierra Norte taken as a test area.

Morrales are frequent in all areas, from lowlands to upper altitudes. They have climatic gradients from semi-arid (600 mm/year rainfall) and warm winter mesoclimatic conditions at lower altitudes (100–300 m) to more rainy (more than 800 mm) and cold winter mesoclimatic conditions at higher altitudes (550–770 m). There are three types of matorrales, viz. motorral-dehesa, matorral-jaral, matorral-alto, and they represent three land-use conditions associated with five vegetation series and regional environmental variables. The five vegetation series from low altitude to high altitude are: (a) *Olea europea*, (b) *Quercus rotundifolia* + *Olea europea*, (c) *Quercus rotundifolia*, (d) *Quercus faginea* + *Q. rotundifolia*, (e) *Q. faginea*. The matoralles linked with these series are described in Table 26.4 according to decreasing cover for the 2–4 dominant evergreen shrub species among the 13 types of matorrales that have been identified. Thus, matorrales are indicators for regional ecological zoning, but they indicate very little about the ecological interactions between tree and grassland layers of the dehesa *str. s.*

Available literature (Garcia Novo 1968, Gomez Gutierrez *et al.* 1978, Gonzalez Bernaldez and Pineda 1980, Gonzalez Bernaldez *et al.* 1976)

Table 26.4. Schematic distribution of 13 types of matorrales belonging to five vegetation series in respect to main abiotic factors and present land use conditions, in the Sierra Norte of Sevilla. (In each block representing one type of matorral, dominant shrubs species are listed according to decreasing cover.)

Vegetation series	*Olea europea*	*Quercus rotundifolia* *Olea europea*	*Quercus rotundifolia*	*Quercus faginea* *Quercus rotundifolia*	*Quercus faginea*
Range of altitude (m)	100–300	200–400	300–500	550–700	550–700
Mesoclimatic gradient	from "less rain/warm winters" to "more rain/cool winters"				
Matorral-dehesa: grazing main use	1. *Cistus monspelienses* 2. *Chamaerops humilis*	1. *Cistus salviaefolius* 2. *Cistus monspeliensis* 3. *Phlomis purpurea*	1. *Cistus salviaefolius* 2. *Daphne gnidium* 3. *Phlomis purpurea*	1. *Cistus salviaefolius* 2. *Daphne gnidium* 3. *Cistus populifolius*	
Matorral-jaral: no present use	1. *Cistus ladaniferus* 2. *Cistus monspeliensis* 3. *Quercus coccifera*	1. *Cistus ladaniferus* 2. *Rosmarinus officinalis* 3. *Genista hirsuta*	1. *Cistus ladaniferus* 2. *Lavandula stoechas* 3. *Rosmarinus officinalis*	1. *Cistus ladaniferus* 2. *Lavandula stoechas*	1. *Cistus populifolius* 2. *Erica arborea* 3. *Erica umbellata*
Matorral-alto: game for hunting	1. *Olea europea* 2. *Pistacia lentiscus* 3. *Quercus coccifera*	1. *Myrtus communis* 2. *Olea europea* 3. *Arbutus unedo*	1. *Quercus coccifera* 2. *Pistacia terebinthus* 3. *Arbutus unedo*	1. *Quercus coccifera* 2. *Viburnum tinus* 3. *Cytisus grandiflorus*	

emphasizes the interaction between grassland composition of dehesas and local ecological conditions, mainly soil conditions. But very little has been reported on the role of human action in changing the floristic composition, structure, function and evolution of the grasslands.

Based on the ecological responses of grasslands in different sites, the distribution of the main species according to their grazing or fodder values in ecological groups along a gradient of variation for trophic and hydric conditions have been determined (Fig. 26.9a). These grazing categories are:

G: Grasses, with G1: very good; G2: medium; G3: bad.
Leg: Leguminous (mostly annuals)
DF: Species of various families, with good fodder value.
NF: Species of various families, with no fodder value.

Figure 26.9b shows how the agricultural use of the rangeland and the intensity of grazing-land management can have an impact on the quality of the grassland associated with a dehesa. It is also obvious in such a situation that the floristic composition is quite variable. One of the main variables which is important for differentiating floristic components (and consequently grazing value) at site level is the "date of the last ploughing" (for cereal cropping); that means the age of the present grassland vegetation, after cereal culture, combined with grazed stubble and then fallow. Due to continuous ploughing during the last decades, most of the plant species belong to the therophytes category – annuals – and the chances of observing a plant succession with good perennial grasses are meagre. The perennial grasses are

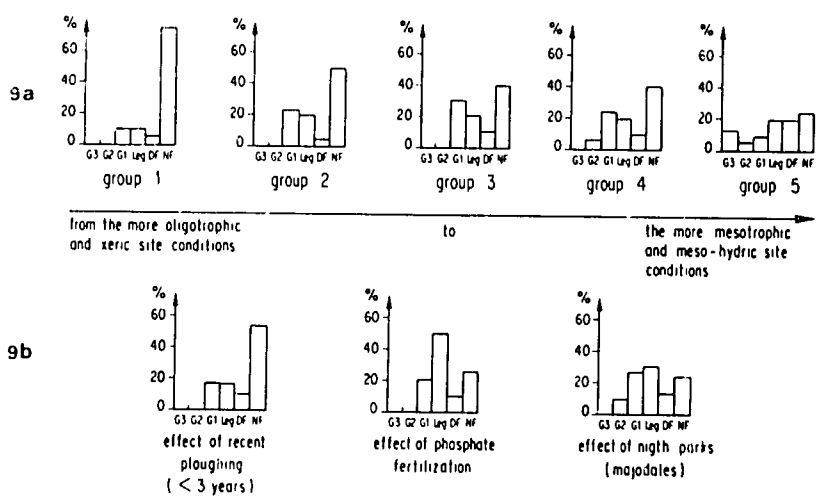


Fig. 26.9. Responses of species composition according to species fodder values, considering two sets of main variables. (a) Responses of five groups of species (frequencies of species fodder values) according to a tropo-hydro gradient. (b) Effects of management practices on the frequencies of species fodder values.

only present in areas where no ploughing has been done for many decades and only if invasion of the shrubs from the matorrales has been prevented. Such areas where the soils have good water-holding capacity and where grazing resources are used with a minimum seasonal rotating grazing system, have a perennial grass cover (*Lolium perenne*, *Dactylis glomerata*, *Agrostis castellana* etc.). This suggests that the very low yields of the unstable annual grasslands, a characteristic of the post-cultural succession, could be replaced by more stable and productive grassland vegetation, i.e., with perennial grasses having a good fodder value. Unfortunately all the techniques recommended for agricultural development during past decades were in favour of *Trifolium subterraneum* ley farming, and since these have failed, it is important to understand the place of perennials in the dehesa and how they could contribute to the productivity and stability of this complex system.

Before analysing the responses of perennials, it is essential to understand the effects of tree canopies, taking into account the horizontal patterns of floristic composition in a grassland associated with scattered oak trees. Some information is available in the literature on this aspect, for example:

- Changes in floristic composition and species frequencies (Gonzalez Adama and Allue 1982; Gonzalez Bernaldez *et al.* 1969; Montoya and Meson 1982; Peloche and Puerto 1969; Puerto *et al.* 1980; Yavitt and Smith 1983);
- Species phenological variations (Gonzalez Aldama 1982, Montalvo *et al.* 1980, Montoya and Meson 1982);
- Variations of the chemical composition of the herbaceous layer (Montalvo *et al.* 1980);
- Influence of the tree in relation to the ecological variables which determine the functioning of the herbaceous layer;
- With specific reference to soil properties (Gonzalez *et al.* 1969; Montoya 1982a; Peloche and Puerto 1979; Puerto *et al.* 1980; Zinke 1962);
- Microclimatic conditions (Montoya 1982a; Parker and Muller 1982);
- The effects of grazing animals (Montoya 1982b).

Analysing the above information on the dehesas of the Sierra Norte, Vacher (1984) concluded the following:

- There exists an important tree effect on the herbaceous layer: two different kinds of phytocenosis can be described, one under the tree canopy cover and the other outside the direct effect of canopies; the pattern is more of a mosaic than a continuum.
- Limits between the two phytocenosis areas are approximately at the vertical projection of the limits of the tree canopies. Considering exposure, this can vary to some extent: the northern limit is situated a little outside the vertical projection; the southern limit is situated more inside the vertical projection. This demonstrates the microclimatological effects of the tree canopy.

- The heterogeneity of the herbaceous vegetation is of the same magnitude under the tree canopies as outside the tree canopies.
- Under tree canopies, plants show better adaptation to soil conditions (both for fertility and water balance); outside tree canopies xero-oligotrophic conditions lead to more xerophytic responses in annual grasses and Compositae.

  Perennial grasses, i.e., *Agrostis castellana*, *Dactylis glomerata*, *Phalaris aquatica* and *Lolium perenne*, are more frequently present under the tree canopies than outside. This has also been observed in the dehesas of Extremadura and Salamanca (Gonzalez Aldama and Allue 1982; Montoya and Meson 1982; Puerto *et al.* 1980; Romero Candau 1981).

5. Contribution to the knowledge of soil fertility and hydrological balance in the sub-systems of a dehesa

5.1. *Some changes in soil properties*

Thirty-two sets of samples (one each under the tree canopy cover and outside the canopy cover of the same mature tree) were collected for two soil horizons 0–5 cm and 5–20 cm – each, and the samples analysed. Some soil analysis data are shown in Table 26.5, from which the following conclusions can be made:

- Under the tree canopy cover, the values for organic matter content, total exchange capacity, potassium, phosphorus, total nitrogen and carbon contents are twice those of the same variables outside the tree canopy cover;
- Exchangeable calcium and magnesium values are 1.5 times higher under than outside the canopy;
- Such trends are observed both for the surface horizon (0–5 cm), which is the most biologically active, and for the second horizon (5–20 cm);
- The role of trees in the improvement of soil conditions is more marked in very poor soil conditions such as in the El Pedroso area, in comparison, for instance, with Castilblanco area.

The increase of organic and mineral components in soils located under the tree canopies is due partly to leaf shedding and other litter fall but also to animal excretion because grazing animals are always attracted by isolated trees in a grassland (cf. behaviour responses to the environmental conditions). Consequently, if a rest period is allowed to the grassland under the canopy cover, a very obvious improvement of soil fertility is observed under the tree-canopy cover. Such observations had been reported for *Quercus*

Table 26.5. Main characteristics of soils in the two dehesa subsystems.

	El Pedroso				Castilblanco			
	Oak canopy		Grassland		Oak canopy		Grassland	
	0–5 cm	35–20 cm	0–5 cm	5–20 cm	0–5 cm	5–20 cm	0.5 cm	5–20cm
Organic matter (%)	7	5.2	4	3.2	9	5.8	5.8	4.2
Cationic exchange capacity (ppm)	14	9	8	6.5	19.5	15	13.5	11.2
Exchangeable K (ppm)	0.75	0.50	0.34	0.32	0.90	0.29	0.60	0.12
Exchangeable Ca (ppm)	10	6	5.1	3.8	14.5	11.7	8.4	7.4
Exchangeable Mg (ppm)	2	1.2	1.3	1	2.8	2.1	2.6	2.3
Organic C (%)	42	24	24	15	52	30	26	17
Total N (%)	3	1.65	1.8	1.1	3.5	2.1	1.8	1.2
P_2O_5 (%)	0.16	0.09	0.07	0.06	0.89	0.73	0.51	0.46

rotundifolia (Escudero *et al.* 1985; Gonzalez Bernaldez *et al.* 1969; Montoya 1982a). The oak trees also extract minerals from the deep soil layers and concentrate them into the surface horizons, which renders them available for nutrition of herbaceous plants, and consequently to grazing animals, depending on management practices.

These data for the dehesas of the Sierra Norte confirm the beneficial effect of isolated oak trees on soil conditions in semi-arid and sub-humid Mediterranean areas of south-western Spain.

5.2. *Production and utilization of mineral nitrogen*

Production of N

A research programme was undertaken to study the N cycle related to the herbaceous-layer requirements under the tree canopy and outside.

The following sub-systems were studied:

(a) Grassland dominated by annuals such as *Vulpia geniculata* and *Bromus hordeaceus*;
(b) Grassland dominated by perennials such as *Phalaris aquatica* (an area which is managed with a rotation grazing system) outside the tree canopy cover;
(c) Grassland dominated by perennials such as *Phalaris aquatica*, *Lolium perenne*, under the tree canopy cover.

The N production was determined *in situ* and in laboratory experiments (incubation of soil samples and measurement of the ammonium and nitrate production), and the net N absorption by plants calculated.

Variations of mineral N with *in situ* measurements for the 0–10 cm horizon, after four weeks of incubation, show that:

- Higher N mineralization is observed in grasslands with perennials; and
- Higher N mineralization is observed under the tree canopy cover.

These results are indicative of better biological activity in the soils under the tree canopy cover than outside.

The results of *in vitro* experiments are similar to those of *in situ* measurements. We observed that all year round the N mineralization is weak in areas with annual grassland outside the tree canopy cover. Conversely, high N content is observed under tree canopy cover, especially during the December-February period. Maintenance of fairly good conditions is also observed all year round; this allows perennial grasses to grow better in conditions of water availability.

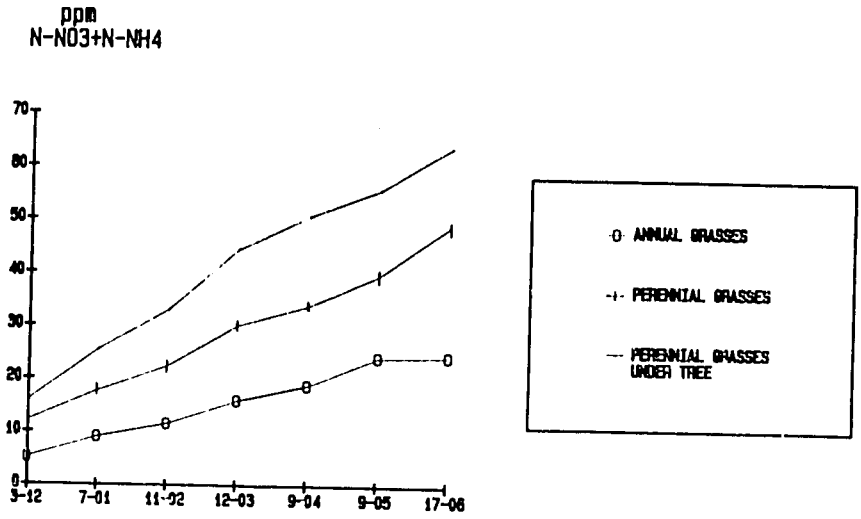


Fig. 26.10. Mineral nitrogen uptake for the 0-10 cm soil layer under three types of grassland cover during the vegetation growing period (data in ppm).

Utilization of N

By comparing *in situ* N production for the same time increment, the same period and same soil samples, we can get a good idea of the plant N utilization. Figure 26.10 shows how this varies according to the three grassland sub-systems we have dealt with. The curves show very clearly that perennial grasses are always more N-efficient than annuals, and that perennials under the tree canopy cover are the most efficient for N utilization. Seasonal variations in N utilization by herbaceous plants show a definite advantage for the complex "tree – perennial grasses" system.

5.3. *Efficiency in the use of water*

Measurements (by the neutron probe technique) of water availability in various soil conditions and grassland sub-systems under the tree canopy and outside were undertaken in some dehesa systems of the Sierra Norte (Joffre *et al.* 1987).

Table 26.6 shows how the water balance varies according to measurements of various water parameters. We observed the following:

After the third year, the percolation is six times higher for annual grassland than perennial ones. This means that there is a loss of 200 mm for plant production in the former because the rooting systems of annuals are not capable of utilizing such percolated water in the deep soil horizons.

Table 26.6 Value of some water-balance parameters (in mm) during the vegetation growing period of 1985-1986. The values are expressed for the whole soil profile from ground surface to 150 cm depth. Comparison between open habitat and oak canopy habitat.

	Open habitat*		Isolated oak canopy** habitat: perennial grasses
	Annual grasses	Perennial grasses	
Rain	602	602	602
Actual evapotranspiration (AET)	334	543	539
Deep drainage	250	40	20
Soil water storage change	18	18	43

* Outside the canopy cover, annual grassland efficiency vs. perennial grassland efficiency.
** Under the tree canopy cover.

Conversely, perennials use more water and are capable of deep-water utilization. Consequently:

- The total dry-matter production, on an annual basis, is higher for perennials than annuals;
  The growth period (green photosynthetic stage) for the perennials is five weeks longer than for annuals which dry out earlier.

The percolation is also reduced to the same magnitude as with perennials outside the canopy cover. Considering the data obtained for perennials outside canopy cover, the perennials under the tree canopy show better water efficiency; more water is used, but the improved soil structural conditions lead to a better response of the soil water reservoir and also better water diffusion into the whole soil profile. Furthermore, the microclimatic conditions under the tree canopy (shade and shelter effects, which result in a reduction of evapotranspiration and an early rewarming just before spring) favour a better growth of perennials during a longer period than outside the tree canopy.

6. The future of the dehesas

Considering, on the one hand, the very rapid ecological changes during the last two decades, and the powerful techniques available today to contribute to these changes, on the other, the dehesas become a very sensitive agro-ecosystem. Looking at the ecological advantages, in terms of biological productivity and metastability, as we have demonstrated in the case of our Sierra Norte research programme in south-western Spain, it can be said that some positive synergetic effects can be observed when scattered oak trees are associated with

various components of grassland vegetation, unless management practices favour mainly tree and perennial grass associations. However, much more research is required in order to provide substantive data for decision-makers, managers and farmers.

Taking into consideration the new socio-economic opportunities of Spain as a member of the EEC, and its participation in the international Man and the Biosphere programme of UNESCO, we hope that our results, however preliminary, could help in the conception and implementation of an interdisciplinary R + D programme dealing with sustainable rural development and the long-term conservation of renewable resources in dehesa areas.

The dehesa-like systems could be considered for adoption as potential multiple use agro-ecosystems for all the fragile areas of the Mediterranean region (Fig. 26.11), from semi-arid to sub-humid conditions. This means millions of hectares in the countries bordering the Mediterranean basin, as well as millions more hectares in the rest of the world where Mediterranean climates occur. For instance, in Chile the dehesa-like *Acacia caven* system in semi-arid and sub-humid regions has the same ecological and socio-economic

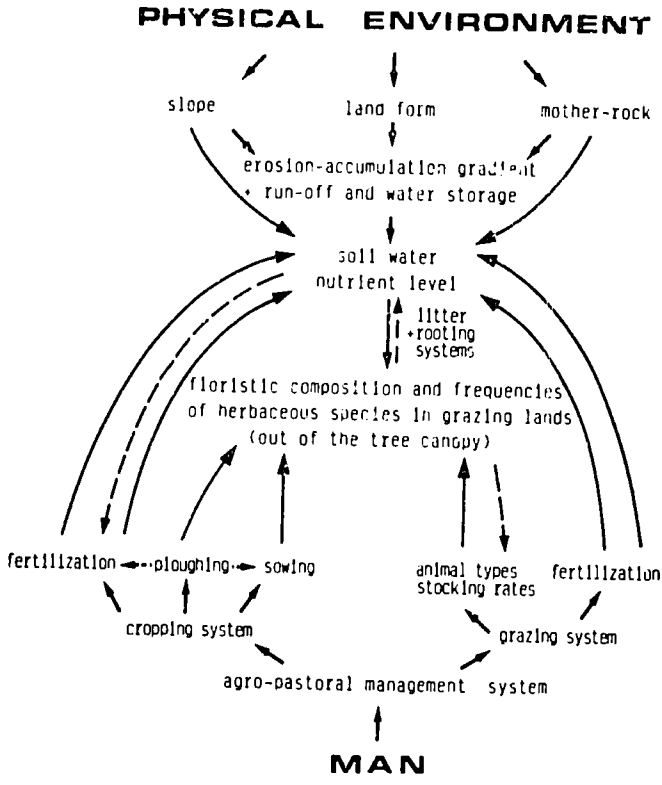


Fig. 26.11. Schematic representation of the relationship between land utilization pattern and environmental variables in a dehesa farming system.

role as that of oak dehesas in the Old World. Positive synergetic effects between the tree canopy of *A. caven* (a legume tree) and the best grassland conditions (*Lolium multiflorum*) have been demonstrated in farm systems with sheep and cattle (Ovalle 1986).

More experiments at farm level need to be undertaken with a new set of management practices applicable to the complex phytocenosis of the dehesas, both for the benefit of environmental conservation and of the farmers and the countries concerned. New management-technique packages must be implemented. They will comprise, for instance:

(a) Examining carefully the biological potential of local or native species, both trees and herbs;
(b) Adoption of grazing systems which allow rest periods, either for the reproduction of the tree layer or for the maintenance of many perennial species with high fodder value;
(c) Fertilizer application to the impoverished rangelands according to their past utilization;
(d) Relevant livestock systems;
(e) Appropriate training of decision-makers, managers and farmers.

Adoption of these management techniques could lead to better conservation of renewable resources, land, water and genetic pools. The socio-economic benefits from such a programme should be considered on the basis of long-term benefits for the whole society, rather than being vitiated by the high cost of early investments.

Acknowledgements

The results presented in this paper were obtained during a six-year bilateral research programme (1980–1986) co-ordinated by Francis Fourneau of the Casa of Valezquez, a French institution based in Madrid. The University of Sevilla, especially its Laboratory of Ecology (Prof. F. Garcia Novo and has colleagues and students), the Centre Emberger of the Centre National de la Recherche Scientifique, Montpellier (Dr G. Long and his colleagues), and the Institut National de la Recherche Agronomique of Paris (Dr B. Roux and his colleagues and students) were the main research institutions involved in the study.

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Part 5

Agroforestry systems in Latin America

457

27. Paraiso (*Melia azedarach* var. "Gigante") woodlots: an agroforestry alternative for the small farmer in Paraguay*

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Abstract. This paper describes the salient aspects and analyses the potential of the "Paraiso Woodlot" System which is becoming popular as an agroforestry alternative to land use in the degraded acid sandy soils of the humid sub-tropical Guayaybi area of Paraguay. The system consists of a combination of paraiso (*Melia azedarach* var. "gigante") with other trees, especially *Leucaena leucocephala*, and annual crops.

The fast growth habit, deep root system, addition of large quantities of organic matter through leaf and litter fall, compatibility with agricultural crops, high value of the sawlogs and production of substantial quantities of poles and firewood make paraiso an excellent species for agroforestry combination. Preliminary results of the trials indicate that the "woodlots" are successful, and with increasing efforts of the extension agencies they are being accepted as a viable alternative to traditional agricultural systems.

Besides discussing the potential of these "woodlots" based on initial results, the paper identifies the constraints of the system and highlights the priority research areas.

1. Introduction

The Paraguay Agroforestry Extension Project is a co-operative effort between Paraguay national agencies and international technical assistance organizations. Initiated in June 1981, the project aims to better address the problems of rural farmers in Paraguay by introducing new, more sustainable systems of land culture.

The most promising system developed by the project is a mix of "paraiso" (*Melia azedarach* var. "gigante") with other trees and annual crops and is popularly known as "paraiso woodlots". Where well tended, the paraiso woodlots have performed with excellent results. With increasing popular acceptance through the efforts of the extension agencies, the woodlots seem

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to be establishing themselves as a viable alternative to traditional agricultural practices. This paper describes the salient aspects and projects the potential of paraiso woodlots as an agroforestry alternative for land use in Paraguay.

2. General description of the area

2.1. *Geographical location*

The longest established paraiso woodlots are located in the Department of San Pedro, in the locality of the town of Guayaybi (24 S latitude, 56 W longitude). This area was first settled 20 years ago by small farmers moving from older, more crowded regions. With no electricity, running water or paved roads, Guayaybi remains a simple, undeveloped area.

2.2. *Biophysical environment*

Guayaybi lies within the Paraguay River watershed. The topography is gently rolling, with almost flat valleys drained by slow-moving rivers. The average elevation ranges between 200 and 250 m.

Climate

Guayaybi has a humid, sub-tropical climate. The annual rainfall averages 1,500 mm and is well distributed throughout the year. Much of the precipitation occurs as intense downpours. The yearly temperatures in the area average 24 C. Frosts are variable; some years are frost free and others have several light freezes, the average being two frosts a year.

Soils

The soils in the area are sandy red-yellow podzols derived from Triassic and upper Permian red sandstones. Most of the soils are acidic sandy loams with a variable clay fraction and pH in the range of 4.2–6.5. Soils of the areas that have been cleared for agriculture are more acidic, have a lower organic-matter content and are more extensively leached than corresponding soils under forest cover. Bedrock is encountered at depths of 15–25 m.

Vegetation

A tall, humid, semi-deciduous forest forms the climax vegetation of the Guayaybi area. This forest contains many hardwoods highly valued for their

quality lumber. Scattered emergent trees, such as "tajy" (*Tabebuia ipe*), "yvyra-pyta" (*Peltophorum dubium*) and "kurupay-kuru" (*Anadenanthera macrocarpa*) rise above a layer of co-dominant species, characterized by "guatambu" (*Balfourdendron riedelianum*), laurel (*Ocotea* spp.) and "yvyrapepe" (*Holocalyx balansae*). The understorey is dense and woody.

2.3. *Land-use systems*

Agriculture

The land around Guayaybi is owned by small farmers. Most of the farms in the area are 10–20 ha in size. The farmers practise agriculture at a rudimentary level. They cultivate maize (*Zea mays*), groundnut or peanuts (*Arachis hypogaea*), cassava (*Manihot esculenta*) beans (*Phaseolus vulgaris*) and bananas (*Musa* spp.) for their own consumption or to sell locally. In addition, cotton and tobacco are planted as cash crops for export. The families depend greatly, but not entirely, upon their farms for subsistence. Sour orange (*Citrus aurantium*) is grown in plantations for a fragrant oil used in perfumery.

Typically a form of slash-and-burn agriculture is used. To start, forested land is divided into lots. Each farmer periodically clears a portion for his lot and plants cotton or tobacco as the first crop on the new land. These crops grow well for 2–4 years; thereafter their yields decline sharply. Subsistence crops are then planted on such "old land" and more forest is cleared to plant cash crops. Eventually, when the cash crops have to be planted on the leached, nutrient-depleted soils which had long since had their forest cover removed, the farmer either sells his land at a low price and moves to a new area, or stays, faced with the prospect of steadily dwindling crop yields.

Each family has a small number of pigs, cattle and chickens. Pigs are fed table scraps and allowed to roost in the fields. Cattle are crowded on small over-used pastures. They gain weight slowly on forages high in roughage, low in protein and insufficient in quantity. Milk yields are low. Chickens yield small amounts of meat and eggs. They graze around the houses and occasionally are thrown some corn, but are otherwise left uncared for.

Forestry

Thirty percent of the Guayaybi area is covered with natural forests, the rest having been cleared for agriculture. In the 1960s this forest was selectively cut. The valuable species such as "tajy" (*Tabebuia ipe*), "peterevy" (*Cordia trichotoma*), "yvyra ro" (*Pterogyne nitens*) and "cedro" (*Cedrela tubiflora*) were removed. The remaining forest contains species for which there is little or no market outside local use. For this reason the cut-over forest is not valued. There are few industries based on wood products from the natural forest in Guayaybi.

3. Structure of the paraiso woodlot system

Drops in productivity to as little as a third of what was harvested previously indicate agriculture, as currently practised in the area, is not sustainable in the long term. This drop in productivity is primarily due to soil and climatic conditions that predispose the land to fertility loss after deforestation:

- The sandy soil is readily leached;
- Organic matter, abundant in the natural forest soils, diminishes rapidly after forest clearing;
- Intense, erosion-causing rains are common; erosion losses range from 30 to 100 t ha^{-1} of soil, or even more.

In an effort to rebuild soil fertility and use their degraded lands farmers are turning towards agroforestry (paraiso woodlots) as a land-use alternative.

3.1. *Components*

Crops

Common subsistence crops grown in the woodlots include bananas (*Musa* spp.), beans (*Phaseolus vulgaris*), cassava (*Manihot esculenta*), maize (*Zea mays*) and groundnut (*Arachis hypogaea*). Vegetable crops for urban markets are also sometimes grown, such as onion (*Allium cepa*), bell pepper (*Capsicum annuum*), tomato (*Lycopersicon esculentum*) and watermelon (*Citrullus vulgaris*).

Crop management consists primarily of weeding with a hoe. Two crops are grown each year: one in early summer and another in the fall. Groundnut, pepper, tomato, onion and watermelon are early crops. Maize, beans and cassava are grown year round except in the cold months (June–August). Beans are often grown in combination with cassava and/or maize.

Trees

Paraiso (*Melia azedarach* var. "gigante") is the main tree component of the system. It is a fast-growing exotic with an erect growth form. Little shade is cast by the crown. Paraiso produces an attractive wood that can be used in furniture making, plywood, veneers and interior carpentry.

- *Planting*. Paraiso is planted as a bare-root stump. The planting site should be freshly ploughed. A crop is planted between the tree rows and the trees are kept weed free through the periodic weedings done for the crop.

- *Pruning*. The tree requires pruning for the first two years, enough time to develop a limb-free 6 m bole.
- *Thinning*. Paraiso is shade-intolerant and should be maintained at low densities for fast growth. At a 4 × 3 m spacing at least two thinnings will be required: first in year 3, and next in year 6, 50% of the trees being removed with each thinning.
- *Harvest*. In 12 years, 200 trees will be ready for harvest, with an average DBH of 40 cm. All the trees may be harvested at this time, or 50% may be removed and the remaining trees harvested in year 15, with an average DBH of 50 cm.

Leucaena (*Leucaena leucocephala* var. K-67, K-28 and Cunningham) is also planted to produce forage, firewood, posts and poles. Leucaena has failed to nodulate in the Guayaybi area, probably due to high soil acidity. Nonetheless, it grows well.

- *Planting*. Leucaena is planted as a bare-root stump, either inter-mixed with paraiso or in separate rows.
- *Pruning*. If the leucaena is to be used as posts or poles it is pruned for the first four years. If it is to be used as forage the top is cut off periodically at 1.5 m.
- *Harvest*. The leucaena is harvested on an as-needed basis for firewood, posts and poles.

"Peterevy" (*Cordia trichotoma*), "timbó" (*Enterolobium contortisiliquum*), "yvyraro" (*Pterogyne nitens*) and "yvyra pyta" (*Peltophorum dubium*) are native hardwoods valued for high-quality lumber. "Timbó" and "yvyra pyta" fix nitrogen and are good soil improvers. All produce posts and firewood as secondary products.

- *Planting*. They are planted as bare-root stumps, either intermixed with the paraiso or in separate rows.
- *Pruning*. The native species (with the exception of "peterevy") grow with poor form. Constant pruning is required to ensure the formation of a single trunk. The paraiso overstorey, once formed, will shade the native hardwoods, inducing superior growth form (but slower growth).
- *Thinning*. Trees with poor form or slow growth should be thinned out.
- *Harvest*. The native species should be of harvestable size (40 cm) in 25–35 years.

"Yerba maté" (*Ilex paraguayensis*) is a small, shade-tolerant evergreen tree. The leaves and small branches are dried, ground up and used to make a mildly stimulating tea (terreré, the national drink).

- *Planting.* "Yerba maté" should be raised in containers and planted during winter one year after the paraiso has been established.
- *Harvest.* After five years of growth "yerba maté" is ready for its first harvest. The foliage and twigs are cut, leaving the trunk and larger branches. Trees are harvested once every two years and harvest continues for about 30 years.

Animals

On average, each farm supports an average of six head of cattle. Of these, two are oxen used to work the fields and haul the produce to market, two are milk cows, and the remaining two are young animals. The cattle – unimproved crosses between Zebu-type and European breeds – are not good producers of meat or milk, but are resistant to diseases and are adaptable to the local climate.

3.2. *Arrangement of components*

The arrangement of the woodlot components is flexible; it varies according to the needs of the farmer. Two combinations will be explained in detail.

Paraiso with "yerba maté" and bananas

- *Year 1.* Paraiso is planted at 4 × 3 m spacing. At the same time four rows of groundnut are planted between the paraiso rows, to be followed by beans.
- *Years 2–4.* "Yerba maté" is planted in the paraiso rows in the second year at 3 m spacing. Maize, beans and cassava are planted between the tree rows.
- *Years 5–14.* One row of bananas is planted in the fifth year with 3 m between each banana plant. Paraiso can be cut in year 12.
- *Year 15.* Final harvest of paraiso for sawlogs.

Schematic presentations of this arrangement in years 1 and 7 are given in Fig. 27.1.

Paraiso with leucaena and "timbó"

- *Year 1.* Rows of paraiso are planted 3 m apart from rows of leucaena (var. K-67) mixed with "timbó". Trees within the paraiso rows are spaced 3 m apart, trees in the leucaena rows are spaced 2 m apart. Three rows of groundnut are planted between the trees, to be followed by beans.
- *Years 2–3.* Maize, beans and cassava are planted between the trees.

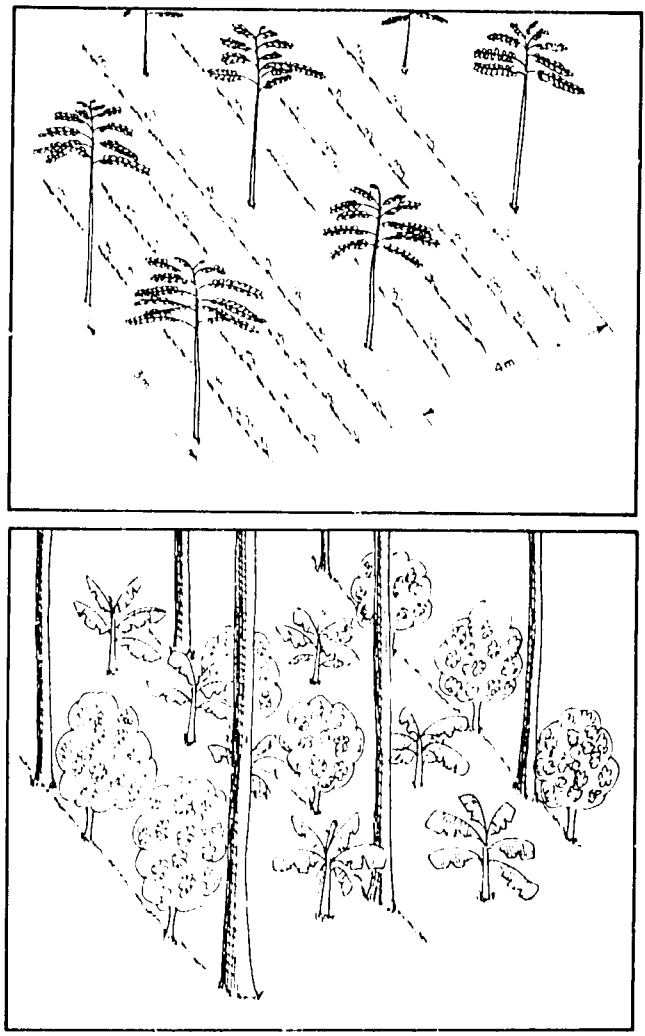
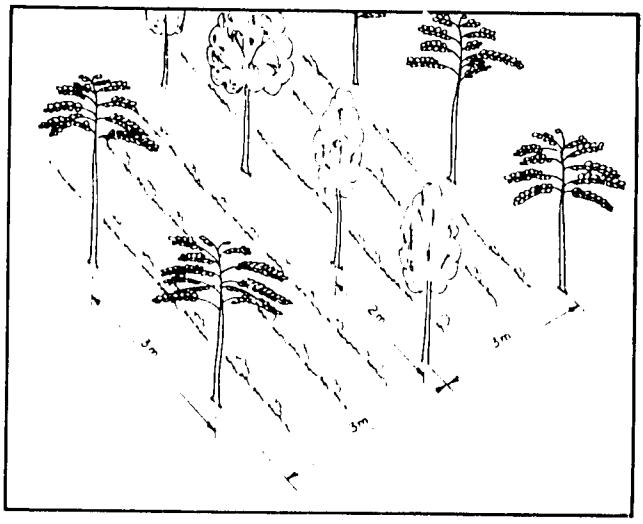


Fig. 27.1. (top) Schematic presentation of planting arrangement of Paraiso (*Melia azedarach* var. "gigante") with "yerba maté" (*Ilex paraguariensis*) and bananas: year 1. (bottom) Same combination as in Fig. 27.1 (top): year 7.

Years 4–14. Grass is planted and two head of cattle/ha are allowed to graze the woodlot. The leucaena is harvested as needed for forage, posts, firewood and poles. Harvest of paraiso for sawlogs can be started in year 12.

Year 15. Final harvest of paraiso for sawlogs. The primary component of the woodlot is now "timbó".

Figure 27.2 shows the schematic pattern of this combination in years 1 and 7.



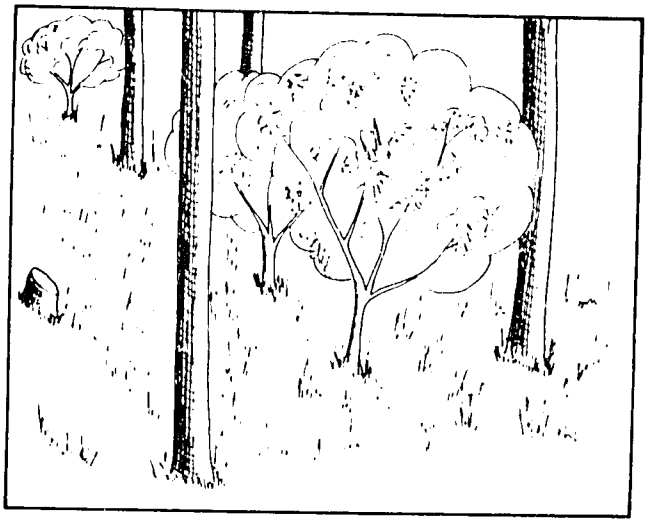


Fig. 27.2. (top) Schematic presentation of planting arrangement of paraiso (*Melia azedarach* var. "gigante") with leucaena (*Leucaena leucocephala*) and "timbó" (*Enterolobium contortisiliquum*): year 1. (bottom) Same combination as in Fig. 27.1 (top): year 7.

3.3. *Interaction of components*

The most readily observable interaction is competition for light between:

- *Trees and weeds.* Paraiso's growth is stunted when weed competition is intense. Growth is more than double when a crop is planted between the tree rows and the field is kept free of weeds.

Trees and crops. In the first year, a tall, fast-growing crop such as maize will shade the paraiso and slow its growth. Later, when the trees are taller, the opposite occurs and it becomes no longer possible to plant sun-loving crops.
Trees and trees. If allowed to become too dense, paraiso's growth is slowed. Likewise, without periodic thinnings of the paraiso overstorey, little light reaches the intermediate layer of leucaena and native hardwoods (if these components were included).

Thus, it is important to carefully plan spacings and thinnings to optimize the performance of the system's components. Another important interaction is the amelioration of the environment by the tree overstorey. Frosts, high winds and intense solar radiation are mitigated to some extent by the crowns:

The partially shaded bananas have a lower incidence of sigatoka (*Cercospora musae*) disease;
Under shade, "yerba maté" grows better than when in full sunlight;
Cattle grazing beneath the overstorey are less stressed by heat;
Crops (melon, tomato, pepper, etc.) interplanted with trees are protected from late frosts and can be planted earlier.

Other interactions include the production of foliage for cattle and of nectar for bees (if a bee component is included).

4. Functional aspects of the system

4.1. *Resource input and utilization*

Land

The size of the paraiso woodlots ranges between 0.25 and 2.0 hectares, with an average of about 1.0 ha. Thirty-seven families in the Guayaybi area have planted woodlots in a land area of about 35 hectares. These families have bought lands from the government and are full owners of their farms. The average population density is 0.7 persons/ha. This population density is currently increasing, due to immigration from older areas and a high birth rate (4.1%). In the future it is expected there will be a diminution of farm size from the current average of 12 ha/family to about 7 ha/family as land holdings are subdivided.

Capital

Only a small capital expenditure is required. Trees are sold at 10 guaranies (100 guaranies = US$ 0.30 in March 1984) a piece. All technical assistance provided by the project is free.

Labour

The largest investment is the labour required to establish and maintain the plantation. To plant one hectare, the following labour inputs (man-days) are required: ploughing – 2; tree planting – 2; sowing of crops – 1; weeding/hoeing (four times) – 16; pruning – 2 days the first year and 3 the second year.

4.2. *Seasonal pattern*

In Paraguay agroforestry activities are best undertaken during the cool months (May–September). During this period there is little work to be done in the fields. Also, during the winter, trees experience less stress after transplanting. From October to April the farmers are busy planting, tending and harvesting their cotton and tobacco crops.

Seeds are collected inside the country and are distributed free to the agroforestry extension nurseries. Trees from these nurseries are then sold at a low price to interested farmers. All traction power is supplied by oxen. Pesticides are sometimes used on vegetable crops intended for the market. Fertilizers are not used because of their high cost and limited availability.

4.3. *Production*

Though no accurate data are available on the yields of agricultural commodities from the paraiso woodlots, estimates indicate that a paraiso woodlot (4 × 3 m spacing), underplanted with bananas and "yerba maté", will have produced 110 m^3 ha^{-1} of posts, poles and firewood and 176 m^3 ha^{-1} of sawlogs by year 15. A woodlot of paraiso (3 × 6 m spacing) mixed with leucaena and native species will have produced, by year 15, 75 m^3 ha^{-1} of posts, poles and firewood from leucaena and the native trees and 176 m^3 ha^{-1}

Table 27.1. Early growth of paraiso and leucaena in the Guayaybi area.

Woodlot	Age (months)	Paraiso mean height (m)	Mean DBH (cm)	Leucaena mean height (m)	Mean DBH (cm)
Casere	9	3.34			
Acosta	6	2.98			
Soria	8	2.93		3.08	
Ronan	8	2.24		2.25	
Ortiz	12	3.76	3.32	3.22	2.50
Ortiz	19	7.00	5.75		

of paraiso sawlogs. Preliminary data on the growth of paraiso and leucaena in the Guayaybi area are given in Table 27.1. Photographs of the 6- and 12-month-old trees are given as Figs. 27.3a and 27.3 b.

Initially the primary output of the woodlots is food crops. As the trees grow taller the emphasis is shifted to shade-tolerant crops (banana, cassava) and wood products. The sawlogs are grown for the local market and/or export. The other outputs are intended for home consumption.

4.4. *Protective and service aspects of the system*

One of the primary goals of the woodlots is the improvement and productive utilization of degraded soils. Most farms more than 10 years old (after first forest clearing) have fields that are either producing very little or have been taken out of production altogether. The paraiso woodlots have the potential

Fig. 27.3a. Photograph of a six-month-old paraiso woodlot.

Fig. 27.3b. Photograph of one-year-old paraiso + leucaena (K. 67) stand.

to improve soil in the following ways:

- Organic matter is added to the soil through leaf drop and root decomposition;
- Nitrogen is added to the soil by nitrogen-fixing trees included in the woodlot;
- Aeration of the soil through the action of tree roots;
- Retrieval by deep tree roots of nutrients leached below the root zone of annual crops;
- Prevention of further soil erosion and subsequent fertility loss by the formation of a permanent protective vegetative covering. The paraiso woodlots are re-vegetating and utilizing formerly unproductive farmlands. The quantitative effect of the woodlots on soil quality is not yet known. However, qualitatively it can be observed that humus layers are being rebuilt and that soil structure is becoming less compact and more porous where woodlots have been planted.

4.5. *Socio-economic description*

In rural Paraguay, incomes ebb and flow with the tobacco and cotton harvest. Little income is realized from the sale of other crops. From October until January farmers spend large amounts of capital on seed and pesticides. By harvest time most families owe money to local merchants for food, clothing, tools and agricultural products. If the price for cotton and tobacco is good, the farmers earn enough profit (average harvest income from 2 ha of cotton = US$ 800) to pay off their debts and buy needed items. Often, though, the price of cotton is low and families have problems meeting their debt obligations. These are the times of greatest emigration out of the rural areas as the less-successful farmers sell their lands and seek work in urban centres.

The paraiso woodlots add a long-term dimension to the economic outlook of the rural farmer. The system has a real potential to provide large amounts of income 10–15 years after planting. The value of the harvested sawlogs has not been established on the Paraguayan market. However, in Argentina paraiso is replacing cedro (*Cedrela tubiflora*) – one of the highest priced native hardwoods – on the market, largely because the supplies of cedro are almost exhausted. Based on this, the value of a mature paraiso woodlot is estimated to be US$ 5,100–6,800 per hectare. The prospect of this long-term profit adds security to families' futures and encourages them to view agriculture as a long-term, sustainable enterprise.

4.6. *Overall performance assessment*

Paraiso has demonstrated its potential as a fast-growing reforestation species. When degraded land units with the woodlots are compared to similar land units without the trees, the advantages become obvious: formerly unproductive units of land are now supporting fast-growing trees and crops and are directly adding to the well-being of the families who work the land.

5. System dynamics

5.1. *Rate of growth*

The paraiso woodlots are a new land-use alternative and are expanding at an impressive rate. The demand for trees to plant woodlots is outstripping the production capabilities of the extension nurseries. According to an FAO study, Paraguay's wood products industry has 15 years of life left before it runs out of reserves of commercially valuable species. Paraguay's forests are

being destroyed at the rate of 3.3% each year, the fastest deforestation rate in the Western Hemisphere. At the same time, it is projected that the demand for Paraguayan wood products will be 14 times greater in the year 2000 than it was in 1970. On top of this, Paraguay has a high population growth rate and limited arable land. These factors add impetus to the push towards sustainable systems that produce both wood products and food, such as the paraiso woodlots.

5.2. *Degradation of the system*

The first two years of the woodlot are critical. The trees must be kept free of weed competition or their growth is stunted. This is the stage where the extensionist has a key role. Farmers who have been well supported by a forest extensionist have confidence in the woodlot and are willing to work hard to keep the trees free of weeds. Other farmers who have had weak support often develop doubts, concentrate their labour elsewhere and let the weeds grow, choking out the trees. It has been observed many times that when a woodlot failed, it happened because the farmer believed it would fail and did not invest the necessary labour.

5.3. *System sustainability*

Since the paraiso woodlots are new, no data are available at this time on their sustainability.

6. Evaluation

6.1. *Merits*

1. Paraiso grows rapidly, quickly establishing a vegetative cover and producing wood products in a short time (see Table 27.1).
2. The woodlots effectively combine food crops and trees to provide products for home consumption and the market on formerly unproductive lands.
3. The system shows promise as a means of rehabilitating degraded soils and protecting against erosion.
4. A prospect for long-term stability and security is gained by the farmers who plant the woodlots.

6.2. *Weaknesses*

Biological

In some plantations paraiso has been attacked by an unknown pest or disease. The attacked trees develop a horse-tail-shaped brooming of the growing tip. Apical dominance is lost and the trees cease active height growth. Up to 10% of the trees in some plantations have been attacked. Leaf-cutter ants are another major pest, sometimes causing complete defoliation.

Climatic

In the sapling stage paraiso is susceptible to frost damage.

Edaphic

When used as a component of a woodlot, leucaena has exhibited little tendency to nodulate on acid (pH $\leqslant$ 5.0) soils. Nevertheless, it grows rapidly.

Ecological

Paraiso does not compete well with weeds.

Technical support

Paraiso woodlots are a new land-use method that farmers are unfamiliar with. To be successful, the farmers need strong technical support from well-trained extensionists. Due to institutional constraints, this support is often difficult to provide.

6.3. *Constraints*

The lack of strong governmental support for an agroforestry programme is the primary constraint limiting the success of the paraiso woodlots. Without this support, it is difficult to provide the minimal level of technical assistance necessary to manage the woodlots. The spread of the woodlots in the field is outgrowing the institutional capabilities to support them.

Another constraint is the uncertain market for paraiso sawlogs. In Misiones, Argentina, a province along the southern border of Paraguay, paraiso is the second major reforestation species (after eucalyptus), and there is an ample market for the sawlogs produced. A similar market could be developed for paraiso in Paraguay, but does not exist as yet.

6.4. *Potential*

With greater institutional support and a firm market, paraiso woodlots could become a common type of land use in Paraguay. The woodlots could be made more productive by:

- Using improved strains of pasture grasses;
- Including an apicultural component if nectar-producing trees are planted in the woodlot;
- Including more shade-tolerant crops, such as coffee, papaya, etc.;
- Incorporating more nitrogen-fixing, soil-building leguminous trees other than leucaena;
- Collecting paraiso seed from superior trees and initiating a tree improvement programme.

6.5. *Extrapolatability*

In Paraguay and Argentina, paraiso is cultivated on acidic clay and sandy soils, in climates ranging from warm temperate to subtropical, with precipitation between 1,400 mm and 2,000 mm. While extrapolatable to areas with similar conditions, it is not known how the tree would grow in more tropical climates or at higher elevations.

6.6. *Research needs*

The paraiso woodlots and their management could be improved through research. Some research needs are:

- Growth predictions for different site conditions;
- Quantitative outputs of the crop component and how the tree component affects this yield;
- Effects of azedarachin, a compound contained in paraiso leaves, on crop pests;
- Growth rates of native species that could be used in the woodlots;
- Effects of the woodlots on soil fertility over time;
- Cost/benefit analysis of the woodlots;
- Timing of thinning;
- Pests and diseases of paraiso, focusing upon the horse-tail brooming and upon the relationship between root damage due to ploughing and root-rot proliferation.

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Data/information base

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28. Perennial crop-based agroforestry systems in northeast Brazil*

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Abstract. Land-use systems in the Northeast Region of Brazil are dominated by large holdings and extensive cultivation of perennial crops such as cashew, coconut, carnauba wax palm and babassu palm. The common feature which links these crops is the silvopastoral system of livestock (chiefly cattle, sheep and donkeys) grazing under them. Agrisilvicultural systems involving cultivation of annual subsistence crops, and in some instances other perennials, in the stands of these perennial crops are also common. This paper presents the available information on the management, production, rate of growth and economic importance of these agroforestry systems involving cashew, coconut and carnauba palm.

These systems are of considerable merit in the environmental, agricultural and socio-economic conditions of Northeast Brazil. However, practically no research, or even systematic data collection, has been done on these so that there is an almost total lack of information on them. In order to improve the systems, they should be studied in detail and research undertaken on various components (crops, trees and livestock) individually as well as on the system as a whole.

Selection of suitable species of grass and other herbaceous crops, appropriate management techniques for both overstorey and understorey species in relation to the age of the overstorey species, optimal stocking rates of animals, etc., have to be determined so as to enable plantation owners and operators to realize the full potential of these systems.

1. Introduction

Perennial cropping systems are found throughout the Northeast Region of Brazil under a wide range of rainfall conditions. Since the earliest period of Portuguese colonization, the Northeast has also been characterized by extensive livestock grazing, especially in the interior. In the present century, agriculture has become more intensive as a consequence of the burgeoning

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human population of the region and increasing opportunities for agricultural exports. This has resulted in a trend toward combining certain perennial crops and livestock grazing into definable silvopastoral and other forms of agroforestry systems. The major perennial crop components of these systems are cashew (*Anacardium occidentale*), coconut (*Cocos nucifera*), babassu (*Orbignya martiana*), cacao (*Theobroma cacao*), carnauba wax palm (*Copernicia prunifera*) and African oil palm (*Elaeis guineensis*).

To date, only a modest amount has been published about agroforestry systems involving these plantation crops. Of these, coconut-based systems have received the most attention. Coconut intercropping systems have been studied and reported from India (Nair 1979, 1983; Nelliat and Bhat 1979) and Sri Lanka (Liyanage *et al.* 1984), and cattle and grazing under coconuts from the Far East and the South Pacific (Plucknett 1979; Smith 1983; Smith and Whiteman 1983a, 1983b; Steel and Whiteman 1980). Warui gave a brief account of the crop combinations with cashew and other perennial crops on the Kenyan coast in East Africa (Warui 1980). Torres has mentioned the viability of the practice of cattle grazing under cashew and coconuts (Torres 1983). But none of the reports contains any information on the systems in Brazil.

The purpose of this paper is to describe some subtypes of the agroforestry (mainly silvopastoral) systems in the Northeast of Brazil. Babassu-based systems in Maranhão State and cacao-based systems in Bahia State are being studied in greater detail by researchers in the two respective research institutions and these systems are described in Chapters 29 and 30, respectively. Information on oil-palm-based systems is too fragmentary to be reported. Therefore, this paper concentrates on the systems based on cashew, coconut and carnauba wax palm.

2. General description of the area

The Northeast Region of Brazil has a land area of over 1.5 million km^2 and extends over tropical and equatorial latitudes from 18° S in the State of Bahia to 1° S in the State of Maranhão. Although representing only about 18% of the national territory, it contains approximately 30% of Brazil's 125 million people.

Precipitation is the key environmental factor of ecological significance for the region and can be characterized by three major zones trending north-east to south-west. First is a narrow humid coastal strip in the east which receives an average of 1,250 mm to over 2,000 mm of rainfall per annum. Second is a middle zone of moisture deficiency which accounts for the largest portion of the Northeast. Most of this zone receives less than 1,000 mm of annual rainfall, with an extreme low of less than 300 mm in one small area. The third

zone is one of high rainfall, over 2,000 mm per year, in western Maranhão. Reflecting this wide diversity of moisture conditions are natural vegetation patterns ranging from tropical rain forest to semi-arid thorn scrub.

Given such a large land area, only very broad generalizations can be made about soils. The FAO Soils Map of the World shows that the region is dominated by highly weathered, leached Luvisols, Ferralsols and Acrisols,

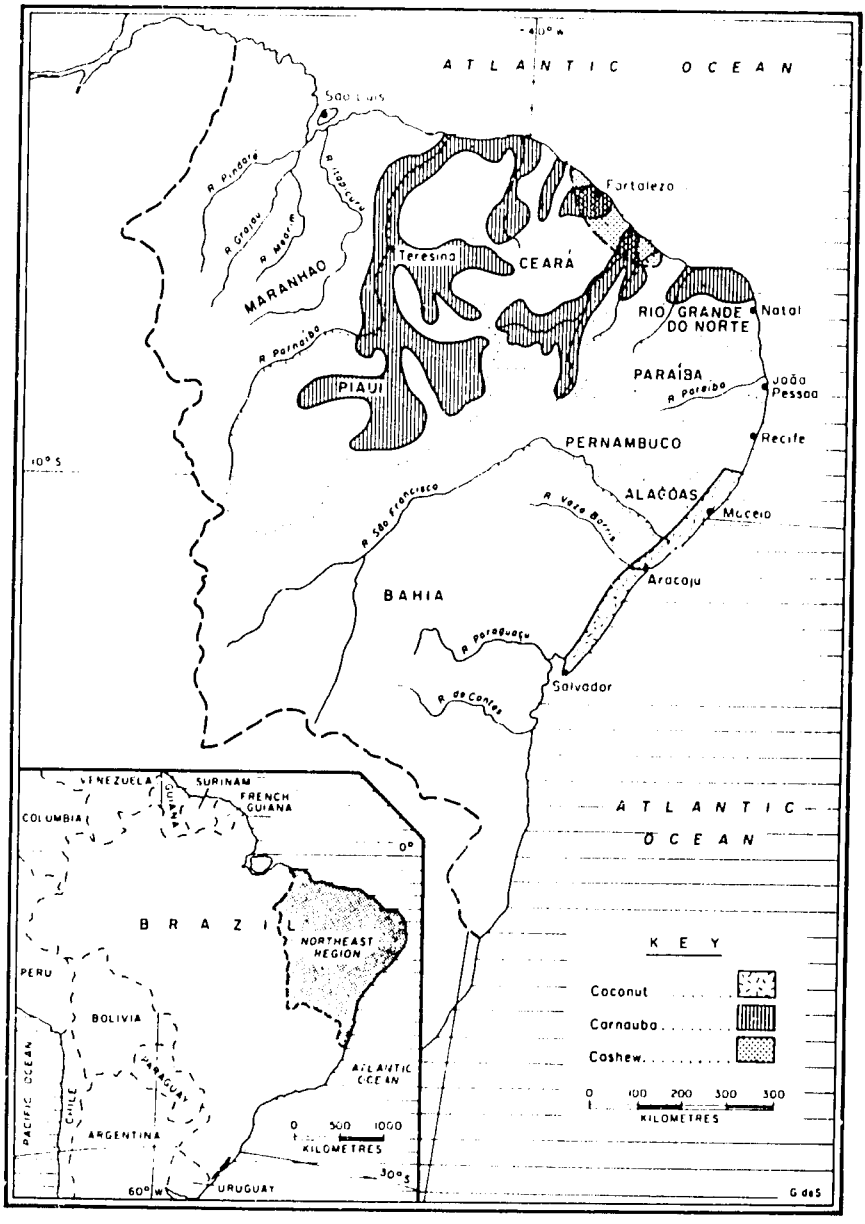

Fig. 28.1. Map of Northeast Brazil showing the major areas where agroforestry systems involving cashew, coconuts and carnauba wax palm exist.

with dry sandy Arenosols and Regosols common along the coast (FAO 1971). Topography in those locations where cashew, coconut or carnauba occur or are cultivated is nearly flat.

Land-use systems in the Northeast are dominated by large holdings, a pattern which has its origins in the early land grants by Portuguese colonists. In coastal areas, land was most often devoted to sugarcane monoculture, whereas in the interior large livestock ranches were the rule. Traditionally, beef cattle have been driven to the better-watered coast during the long dry season in the interior. Recently harvested sugarcane fields, as well as areas of cashew, coconut or carnauba have been used for such seasonal grazing. Even with the modernization of perennial-crop agriculture in the present century, these systems have been retained because of their benefit to both the land-owner and the cattleman. Increased raising of dairy cattle along the coast is also associated with plantation agriculture. Along with the improvement of the perennial crops themselves has come the improvement of cattle breeding stock and the cultivation of better grass species for planting beneath the tree crops. Figure 28.1 is a sketch map of Northeast Brazil showing the areas where the systems being described here can be found.

3. Structure of the system

The common feature which links cashew, coconut and carnauba is livestock grazing (silvopastoral system). Cultivation of annual subsistence crops, and in some instances other perennials, in the stands of these perennial crops (agrosilvopastoral system) is also common.

Both cashew and carnauba are native to Northeast Brazil and wild stands have a long history of exploitation. The Portuguese introduced the coconut to coastal Brazil during the sixteenth century where it quickly became naturalized. Thus, under conditions of sub-spontaneous growth, it is equivalent to the stands of the two native species. In addition to gathering the economic products of these three trees, the land areas they occupy are also traditionally used for other agricultural purposes. Locally raised livestock – chiefly cattle, goats and donkeys – are grazed on spontaneous grass and shrub growth beneath the trees and, as already mentioned, so are cattle brought in from the interior for seasonal grazing, and these tree stands provide much-needed shade for the livestock. Livestock are removed from the fields during the harvesting of cashew fruits and carnauba palm leaves. Figure 28.2 shows a coconut plantation with spontaneous grasses, typical of the type used for cattle grazing. Figure 28.3 is of a natural stand of carnauba palms with donkeys grazing. The crowns of the palms are sparse because of leaf harvest.

Fig. 28.2. A cultivated coconut plantation near Aracaju, Sergipe with spontaneous grasses, typical of the type used for cattle grazing. (Photo: D.V. Johnson.)

It is also a common practice to clear small plots within the stands of carnauba to plant subsistence crops during the annual rainy season. Typically, maize, beans and cassava are grown. Individual plots are fenced to keep the livestock out; however, once the crops have been harvested they are allowed to browse on the stubble.

Under formal plantation cultivation of cashew, coconut or carnauba, the components are slightly modified. Basically the change involves cultivation of subsistence catch crops between the rows of trees for the first few years of their growth. Once again, maize, beans and cassava are the rule. On very large holdings which are mechanized, industrial catch crops such as grain sorghum, peanuts, sesame (*Sasamum indicum*) or cotton are planted. This industrial catch cropping is most often found on cashew plantations. The choice of a

Fig. 28.3. A natural stand of carnauba wax palm near Fortaleza, Ceará, with grazing of donkeys. The palm crowns are sparse because of leaf harvest. (Photo: D.V. Johnson.)

particular crop depends upon environmental conditions and the presence of local demand for the commodity.

Once catch cropping is phased out as the trees increase in size, spontaneous grasses replace them or pasture grasses are planted as permanent ground cover. Native ginger grass (*Paspalum maritimum*) and African Guinea grass (*Panicum maximum*) have proved to be successful on cashew plantations (Johnson 1974). Thus, in contrast to what occurs with native stands, when these perennial crops are formally cultivated grazing replaces annual cropping after a few years rather than coexisting with it.

Occasional intercropping of cashew, coconut or carnauba with other perennial crops is also practised in the region. But this represents a variation of the system where the high planting densities of the main crop exclude livestock

Fig. 28.4. Agroforestry system of growing coffee under the shade of cashew on a farm near Garanhuns, Pernambuco. (Photo: D.V. Johnson.)

and annual cropping. For example, in southern Bahia, there is limited use of coconut to provide cacao with shade and protection from wind. In the elevated areas of Pernambuco, where coffee is grown, some older plantings are shaded with cashew trees (Fig. 28.4). In Ceará, cashew trees reportedly are utilized to provide support for pepper vines. On very small farms one can see coconut and cashew, cashew and citrus, and cashew, banana and coconut interplanted. Carnauba is not found in association with other perennial crops.

4. Functional aspects of the system

In Brazil, as in most other countries, agricultural statistics are given under the separate headings of annual crops, perennial crops and livestock. However, in

Brazil statistics are also published on the quantities of products gathered from wild plants. Cashew is included as both a perennial crop and a gathered product, coconut as a perennial crop only, and carnauba as exclusively a gathered product. Under such circumstances it is impossible to determine the area of the respective crop which is currently associated with livestock grazing, or the degree to which intercropping of annual crops exists. Nevertheless, the statistics available on perennial crops can be examined to gain a rough idea of the situation. The figures in the following discussion are from FIBGE (1981, 1982).

In 1980, an area of 184,151 ha was enumerated for cashew plantations in the Northeast. Also that year, 18,387 t of unshelled nuts were gathered from natural stands. Conservatively, a cashew tree in Brazil yields about 2 kg of nuts per year. Thus 9,193,500 trees can be estimated to have provided the total. Using the common plantation density equivalent of 100 trees per ha, this would represent 91,935 ha. Therefore 276,086 ha of cashew trees can be used as an approximate total. The coastal areas of Ceará and Rio Grande do Norte States account for more than 70% of this national total (Fig. 28.1). In addition to the cashew nuts which furnish high-value kernels and the industrially valuable cashew-nut shell liquid, the fleshy peduncle or apple of the fruit supports small local industries which produce juice and several types of preserves for the domestic market. Kernels and shell liquid are exported.

The area under coconut is less complicated to determine, and in 1980 totalled 164,779 ha for all of Brazil. Over 60% of Brazil's total production of coconuts is from the coastal strip, about 50 km wide, in the states of Alagoas, Sergipe and Bahia (northern parts) (Fig. 28.1). About 10% occurs outside the Northeast Region. On the average, a coconut palm yields 25–30 nuts per year in Brazil. Green coconuts are harvested for direct consumption of coconut water as a beverage. Mature nuts support an industry which produces coconut milk and grated coconut; copra is not made. Locally the palm leaves are utilized for thatching and fencing. Brazil does not export coconut products.

As far as the carnauba palm is concerned, no statistics on area are available, although the stands of native trees are estimated to number in the hundreds of millions. Major concentrations are to be found in the river valleys and coastal lowlands of Piauí, Ceará and Rio Grande do Norte (Fig. 28.1), which account for more than 90% of the carnauba wax produced in the country. An indeterminable number of palms have been planted, at densities of 800–1,200 per ha, but the practice apparently ended in the 1950s. The palm furnishes two economic products: wax from the leaf surface which has many industrial uses, especially in food industries because it is edible; and leaf fibre which is the raw material for a small, exclusively domestic, cottage industry making hats, baskets, etc. In 1980, wax production amounted to 18,857 t, all from the Northeast. At a wax yield of 5 g per leaf, and each tree providing 20 leaves per year, a single palm would produce 100 g (Johnson 1972). Thus 1980

production involved 188,750,000 palms. Wax has been a Brazilian export since the middle of the nineteenth century. Carnauba leaf fibre production in 1980 was reported to be 1,398 t. Although no statistics are collected, carnauba wood is widely used in the Northeast for construction purposes.

According to information obtained in the field, livestock raising is most often found in associations with cashew, coconut or carnauba on large land holdings. On cashew plantations, grazing is not practised all the year round; cattle tend to be found in coastal areas, goats in the interior. Typically, smallholders do not have the capital to invest in cattle, but may run a few head of goats or donkeys and an occasional hog or two. No information on stocking rates for plantation grazing is available. Plucknett states that the carrying capacity of one hectare of coconut plantation in Sri Lanka is 1.25–5 head of small Sinhala cattle (Plucknett 1979).

In socio-economic terms, these three perennial cropping systems are quite labour-intensive, but only on a seasonal basis. Harvesting of cashew nuts and apples, coconuts and carnauba leaves is all done by hand, as is a significant portion of the subsequent processing. Fortunately for these agro-industries, Northeast Brazil has a sizeable rural population which does seasonal harvest labour to supplement their income as subsistence-level farmers.

6. System dynamics

Over the past few decades, each of these three tree crops has experienced different rates of change. Area under cashew has increased considerably due to the establishment of large-scale plantations. Before the Brazilian government initiated a major programme to encourage cashew cultivation in the late 1960s, there were probably no more than a few thousand hectares under actual plantation conditions, and prior to that virtually all of the cashew nuts came from natural stands. The new programme proved to be a powerful stimulus to agri-business and led to the establishment of some 180,000 ha of modern cashew plantations, most of which were at a density of 100 trees per ha. Many of the new plantations are engaged in catch cropping of subsistence and industrial crops, and some have subsequently converted the areas to pasture for grazing.

Below-average rainfall during the period 1979–1983 led to some losses of cashew trees, particularly on plantations in areas of poorer soil. Not unexpectedly, insects and diseases affecting cashew have also become more serious. These factors have prompted a period of retrenchment with plantations placing greater emphasis on cattle raising. In order to make this more feasible, new plantings are at a density of 51 trees per ha to allow more open area for grass growth. On some plantations, the earlier more dense plantings have been thinned. It is difficult to generalize about the state of cashew cultivation today

because, on the one hand, some plantations are without livestock and, on the other, there are establishments which have livestock as a primary objective and cashew growing as a secondary activity.

Area under coconuts has also undergone a strong and steady expansion. From 73,583 ha in 1960, it increased to 117,193 ha in 1970 and to 164,770 ha in 1980. Currently the Brazilian Government has a major programme under way to encourage the establishment of new large-scale plantations of coconut, which, although focused on the Northeast, also includes the Amazon Region. Part of the programme is to make available improved coconut varieties, including dwarfs, for the new plantings as well as for the needed replacement of older plantings. Since this programme involves large holdings almost exclusively, there exists the potential to expand the practice of plantation grazing.

Quite a different pattern is found with regard to the carnauba palm. Wax production, which stood at 10,982 t in 1980, nearly doubled to 20,378 t in 1970, but declined in 1980 to 18,857 t. The major reason for this decrease is the substitution of artificial waxes for carnauba in many of its non-food uses. However, this decline in production does not reflect any decrease in the number of palms. When demand for wax is slack, the trees are simply not harvested. Some minor losses of palms do occur when land is cleared for other purposes, but since the carnauba's native habitat is poorly drained sites and floodplains there is minimal conflict of land use. Moreover the palms reproduce vigorously.

The performance of the perennial-crop-based system appears to be favourable in the case of cashew and coconuts, but marginal for carnauba because of economic factors. Even without much wax harvesting, however, the multiple utility of the carnauba and its compatibility with grazing and annual cropping assures a continuation of the sub-type. High demand for meat on domestic and foreign markets has made livestock more and more attractive to agri-business concerns. In fact, properly managed livestock raising on plantations should increase their sustainability and avoid over-reliance on a single commodity.

7. Evaluation

The system discussed in this paper has considerable merit in the context of the environmental, agricultural and socio-economic conditions in Northeast Brazil. From an environmental standpoint, in most areas establishment of new plantations of cashew or coconut represents an upgrading of the vegetative cover from what currently exists. There is a strong justification for protection of native stands of carnauba because of their multiple utility. Plantation grazing is an environmentally sound practice, and adheres to the general

recommendation that grazing is a preferred system for the dry savanna climates characterizing so much of the Northeast (Nair 1982).

Agriculturally, the diversity of this perennial-crop-based agroforestry system offers the advantage of making more efficient use of labour and equipment over the entire calendar year, thereby avoiding the peaks and slacks of activity associated with monoculture. Plantation grazing does, however, have a few disadvantages too. Careful management practices must be followed to prevent animals from physically damaging young trees. Moreover, when natural stands are utilized, such as with the carnauba, grazing may, over time, hinder natural replacement of trees due to browsing on young leaves and trampling of seedlings. Livestock grazed beneath cashew trees can eat unutilized cashew apples, but excessive quantities should not be allowed because of their high tannin content. Domestic animals also feed on the small carnauba fruits which fall to the ground. There is no general agreement among agronomists as to the advisability of grazing on plantations. Ohler (1979) recommends against it, though from a rather narrow monocultural viewpoint. Plucknett views grazing on coconut plantations as an acceptable practice, and one which especially benefits smallholders (Plucknett 1979). Similar results have been reported from studies in the Solomon Islands (Smith 1983; Smith and Whiteman 1983a, 1983b; Steel and Whiteman 1980). With respect to Northeast Brazil, the long tradition of a variety of successful grazing systems cannot, in any case, be ignored.

There are a number of socio-economic benefits from this system in the Northeast. The international market for cashew kernels is strong and elastic, and good potential exists for increased domestic utilization of the cashew apple. Coconut products enjoy high demand within the country, which is providing an incentive for expansion of the crop. The future of carnauba wax as a raw material is not very promising. Apparently international markets are undergoing an adjustment which will likely stabilize demand at a level below current production. Economically, livestock raising is profitable in the Northeast, and the combining of it with cashew or coconut should strengthen the economic base of the individual plantation. In social terms, the growth of agro-industry in the region creates new industrial employment. Given the large rural labour pool, there is not a strong incentive to mechanize plantation operations. In the rural areas, local inhabitants also benefit to a degree from having free or very inexpensive sources of thatch, wood, etc., from the plantations. Social reasons may, in fact, be the overriding justification for encouraging the expansion of perennial-crop-based systems.

8. Research needs

It is obvious from the above description that although the system is practised over extensive areas and it has a number of merits, there is an almost total

lack of information on its various management details. Practically no research, not even systematic survey and data collection, has been done on the system, so that no quantitative information is available on many, if not any, of the basic aspects. Therefore the first essential step in improving the system will obviously be to collect quantitative information on the functional and dynamic aspects. This should include current levels of production of various components, as well as the rate of change of production of components with time. It is important to note that not only will the production of grass or other understorey species vary depending upon the age (and consequent interaction effects) of the overstorey species, but also the pattern of production of components of the system at a given growth stage or age of the overstorey species will have changed over a span of a few years in a given region. Once these data are assembled, the logical next step will be to examine the reasons for the observed behaviour and see how the efficiency of production could be improved. This will involve research on a large number of management aspects of the individual components as well as of the system.

The role of livestock in this system needs to be studied in more detail. Research must be conducted to ascertain optimal stocking rate, which, in turn, will involve all the related aspects such as the species of grass, the type and breed of livestock, management of overstorey and grass species, and so on.

Plantation owners and operators need to have better general and crop/site-specific management techniques so that the full potential of this system can be realized.

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29. Babassu palm in the agroforestry systems in Brazil's Mid-North region*

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Abstract. Babassu palms (*Orbignya* spp.) cover nearly 200,000 km^2 in Brazil, providing cash income, fuel, fibre, edible oil and food to a large number of tenant farm households. Babassu is closely integrated within pastoral and shifting cultivation systems of Mid-North Brazil. In pastures, babassu provides shade for cattle, aids soil moisture retention, produces organic matter, generates supplementary farm income at little cost, and offers year-round employment. On the other hand, the persistence of juvenile palms reduces pasture grass productivity due to plant competition, and therefore there is a trend to eradicate babassu through clearcutting and understorey suppression. At moderate densities of less than 100 individuals per ha, mature babassu palms in crop land do not appear to harm crop productivity. In such cases, palms are thinned and leaves of the remaining ones are cut back, supplying fuelwood and soil nutrients. However, reduced fallow cycles due to pasture conversion threaten babassu as well as crop productivity.

1. Introduction

The babassu palm (*Orbignya phalerata* Mart.†) and related species occur widely in Brazil, Bolivia, Colombia, Mexico and other parts of Latin America. Kernels extracted manually from babassu's thick-shelled fruit are a source of lauric oil having both edible and industrial uses. Figure 29.1 shows the distribution of babassu in Brazil. Over 80% of babassu kernel marketed in Brazil comes from the north-east states of Maranhão and Piauí, known as the Mid-North region, which produces about 200,000 t of kernels annually (Table 29.1). A major industry that expresses oil from from these kernels is concentrated in the region. In 1980, over 30 oil factories operated in Maranhão alone

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† Also referred to in the scientific and popular literature as *Orbignya martiana*, *O. barbosiana*, *O.* sp. and other names.

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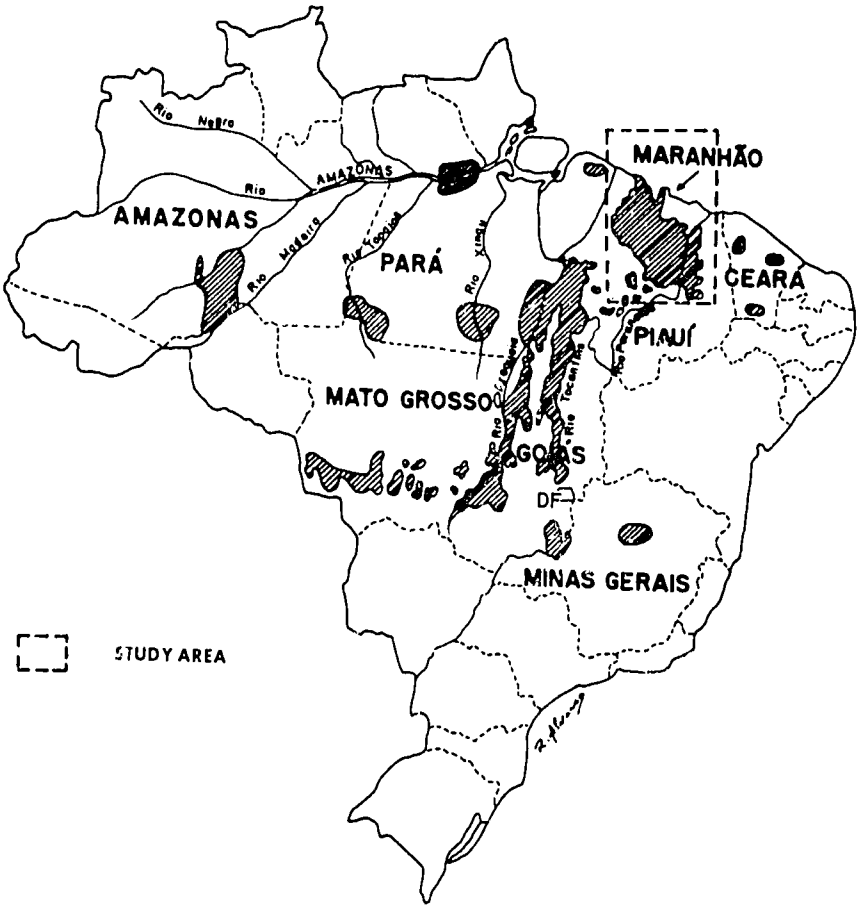

Fig. 29.1. Areas of occurrence of babassu palms in Brazil. States where babassu occurs are labelled. Heavy dotted line encloses the mid-north region. (Drawn by R. Alvares based on maps in Anderson and Anderson, 1983; MIC/STI 1982.)

Table 29.1. Area of babassu stands and their commercial exploitation in the Mid-North region of Brazil.

Region	Area of stand occurrence		Kernels marketed (1980)	
	km²	%	Metric tons	%
Maranhão	103,040	53	183,455	73
Piaui	19,780	10	20,214	8
Mid-North (subtotal)	122,820	63	213,669	81
Other areas	73,550	37	37,282	19
Brazil	196,370	100	250,951	100

Sources: IBGE (1983); MIC/STI (1982).

(Amaral Filho 1983). Kernels constitute less than 8% of the fruit by weight, although strains containing up to 17% kernel have been encountered. The remaining parts can be used industrially for production of charcoal, feedmeals and other by-products for which efforts have been initiated recently. These technological developments permit breaking babassu fruits mechanically and separation of their components for further processing.

Babassu kernels are third only to timber and rice in gross agricultural product value in Maranhão, where the economy relies on the primary sector for over 60% of its GDP. The palm also provides non-market goods and services to the rural population of the Mid-North region in the form of fuel, fibre and food.

Babassu palms are seldom planted, but are managed within regional agroforestry systems, performing a vital role in the local economy.

2. General description of the area

2.1. *Geographical location*

The babassu zone of Mid-North Brazil includes portions of Maranhão north of 6° S and east of 46° W, and of Piauí, west of 42° W bounded on the north by the Atlantic Ocean (Fig. 29.2). Although most of the babassu zone is under 200 m altitude, palms are found up to 1,000 m. Babassu stands occupy over 120,000 km^2 in this region, some on upland sites and others in galleries along valley bottoms.

2.2. *Historical evolution*

The indigenous tribes which originally inhabited the region identified their territorial rights with stands of fruit-bearing palms such as babassu which provided fuel and fibre as well as a reserve against famine (Steward 1963). After colonization by Europeans, the region became an important producer of sugarcane and later cotton on slave plantations. After slavery was abolished in 1888, the plantation economy collapsed and freed slaves and new immigrants established homesteads in unsettled areas where hunting, gathering and fishing complemented subsistence agriculture. The settlers relied on babassu palms for food, fuel and shelter. Since the 1920s, a steadily growing market for babassu kernels has contributed to inhabitants' cash incomes.

Most residents today are landless tenant farmers on properties controlled by a relatively small number of people (in Maranhão, 85% of the land is owned by 15% of the enterprises [IBGE 1980]). The landless pay in kind for the right to live on the property and use the land for shifting cultivation; they must sell the babassu kernels they extract to the landowner or his agent.

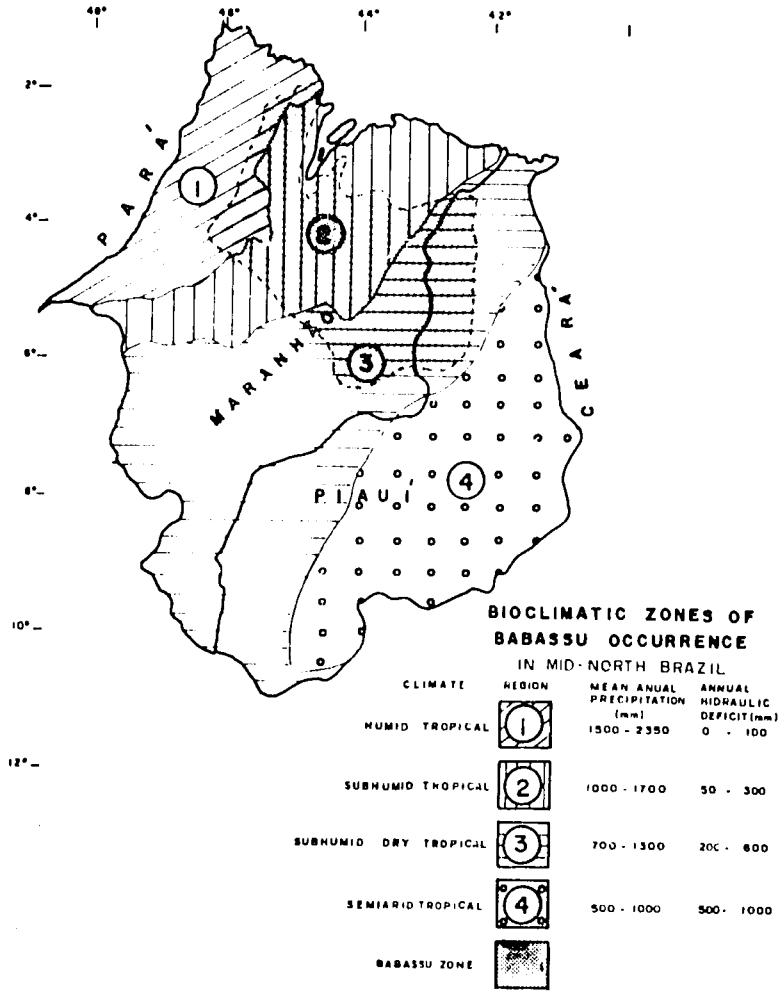

Fig. 29.2. Bioclimatic zones of babassu occurrence in Mid-North Brazil. (Drawn by R.M. Lima after map in Golfari and Caser 1977.)

2.3. *Biophysical environment*

The Mid-North babassu zone is one of bioclimatic transition between Amazonian humid overgreen forests, savannas and woodlands (*Cerrado*), and semi-arid thorn scrub (*Caatinga*) of the north-east. Annual mean temperatures range from 20 to 27 C. Seasonal rainfall varies within three pluviometric regimes (Fig. 29.2) from 700 to 2,100 mm annually (Golfari and Caser 1977), 90% of which falls unimodally from January to June.

Within the eastern dry *Cerrado* belt (700–1,300 mm) babassu occurs in galleries along river banks whose alluvial sandy clays retain water during a 6–8 month dry season. Soils of the upland *Cerrado* are deeply weathered sandy laterites. Babassu is sparse on these dry lands, whose vegetation consists

mainly of leguminous trees and scrub with carnauba (*Copernicia prunifera*) palms appearing on unimproved range.

A more humid sub-region (1,500–1,800 mm) lies to the west, where alluvial deposits from three major rivers create well-structured Alfisols with moderate P and N content, high cation-exchange capacity and base saturation. Over 80% of the land is covered with babassu palms in this *Cocais* (palm forest) sub-region.

The "Pre-Amazonic" zone (1,600–2,100 mm) lies on Maranhão's western frontier. Patches of tropical moist forest are interspersed with young secondary forest (*Capoeira*). Babassu is present in the former and dominant in the latter. As rapidly accelerating settlement encroaches on the Pre-Amazonic zone, dense babassu stands spread into the frontier.

2.4. *Land-use systems*

Agriculture

In the *Cerrado*, mixed-enterprise farms involve shifting cultivation within bottomland stands of babassu with beef cattle grazed on upland unenclosed range. In the *Cocais* and Pre-Amazonic regions, babassu and primary forests are being converted to improved pasture and some mechanized crop production. There are many dairy farms in the *Cocais*. Construction of paved highways in this region has strengthened rural-urban communications, yet most babassu-zone farm land remains inaccessible to vehicles during the rainy season.

Forestry

Hardwood timbers from native forests are extracted to defray the expenses of clearing new pasture and crop land at the frontier. National reforestation incentives have prompted landowners to plant eucalyptus (*Eucalyptus urophila*, *E. braciana*, and *E. elata*) on poor *Cerrado* soils. Bamboo (*Bambusa vulgaris*) and pine (*Pinus caribaea*) are being planted in lowland areas cleared of babassu. Cashew (*Anacardium occidentale*) and coconut (*Cocos nucifera*) are also being established. Total area reforested between 1978 and 1983 is over 35,000 ha in Maranhão alone (Table 29.2).

The government has supported reforestation efforts using babassu in several states with strongest impetus during a period in the late 1970s when babassu fruit mesocarp first began to be considered as a potential source of fuel ethanol. None of the attempts to establish babassu plantations have been of notable success. One reason for this is the lack of knowledge of appropriate agronomic techniques for nursery and field planting or management. Recent

Table 29.2. Area reforested per year by species: Maranhão (ha).

Year	Species					
	Cashew	Coconut	Eucalyptus	Pine	Bamboo	Total
1978	250	—	—	—	—	250
1979	1,100	250	—	—	—	1,350
1980	1,900	1,400	200	—	—	3,500
1981	1,710	930	2,800	1,600	1,500	8,540
1982	3,088	870	5,920	2,400	1,500	13,778
1983[a]	3,270	850	3,250	700	900	8,970
Totals	11,318	4,300	12,170	4,700	3,900	36,388

Source: Personal communication: Instituto Brasileiro de Desenvolvimento Florestal (IBDF), Delegacia Estadual do Maranhao.

[a] Figures for 1983 are based on areas proposed for reforestation under IBDF programmes, and not area actually reforested.

studies have found that babassu, like most palms, flourish best if first planted under nursery conditions in polythene bags which allow for the deep root growth characteristic of the species.

Trees are seldom planted for fuel or fencing. Secondary forest fallows provide for most polewood, and babassu husks are the major source of cooking fuel in rural areas. The majority of rural households use babassu charcoal as their principal fuel (Table 29.3).

Table 29.3. Proportion of rural families using babassu products in Maranhão municipios.

Municipio	Percent of families interviewed					
	Thatch	Basketry	Charcoal	Milk	Oil	Palmito
Bacabal (n = 104)	86	96	96	44	53	n.a.
Lima Campos (n = 64)	94	83	92	70	66	
Sao Bento (n = 57)	76	72	49	72	74	16
Chapadinha (n = 98)	86	90	96	89	91	42
Average	86	85	83	69	71	22

Source: Bacabal, Anderson and Anderson (1983); data for other areas P. May (unpublished).

N = sample size.

Agroforestry-type systems/practices

There are two general agroforestry practices involving babassu: (a) palm – pasture; and (b) palm – shifting cultivation. These systems are associated and together cover much of the region. The first involves pastures planted under native palm stands thinned of senescent and unproductive palms; babassu shades cattle and it protects and replenishes soils. The second involves shifting cultivation within native babassu stands where babassu leaves provide fuel-wood for cooking and mature palms are retained over crops to provide a range of subsistence and market products during the fallow cycle (Anderson and Anderson 1983; May *et al.* 1985).

3. Structure of the system

3.1. *Components of babassu agroforestry systems*

Crops

Shifting cultivation typically consists of intercropped rice (*Oryza sativa*), maize (*Zea mays*), cassava (*Manihot esculenta*) and several bean species under babassu palms. Rice is by far the region's most important crop and is used as a payment for land rental, a cash crop, and a principal source of sustenance. Over 125 regional upland varieties are in use (Fonseca *et al.* 1982). Maranhão is one of the major rice producing states of Brazil, even with traditional methods. Dried maize is used as feed for animals and rarely sold. Bitter cassava is used for making flour ("dry" or fermented "*farinha d'agua*"), which is a basic staple. Cowpeas (*Vigna sinensis*) and lima beans (*Phaseolus lunatus*) are also primarily for subsistence consumption. Among other cultivars planted are squashes (*Cucurbita* spp.), watermelon (*Citrulus lanatus*), West Indian gherkin (*Cucumis anguria*), locally known as "*machiche*", okra (*Hibiscus esculentus*), cucumber (*Cucumis sativa*), and banana (*Musa* spp.).

Trees and other woody perennials

Dominant species found in babassu-associated secondary forest and their principal uses are listed in Table 29.4. Regrowth cycles of secondary forest correspond with long fallow periods of shifting cultivation, after which useful tree species are harvested as polewood or timber during land preparation for cultivation. Other palms, such as carnauba, buriti (*Mauritia flexuosa*) and tucum (*Astrocaryum vulgare*) occur in varying abundance in association with babassu and furnish oils, food, waxes, fibre and construction materials for rural households.

Table 19.4. Uses of principal woody species found in babassu agroforestry systems.

Species	Local name	Uses
Spondias mombim	*Cajá*	Edible fruit
Inga spp.	*Ingã*	Edible fruit
Cecropia spp.	*Imbauba*	Leaves eaten by sloths (game meat)
Acacia spp.	*Unha de gado*	Construction, fence posts
Tabebuia spp.	*Pau d'arco*	Construction, fence posts
Cedrella odorata	*Cedro*	Construction, fence posts
Astrocaryum vulgare	*Tucum*	Oil, basketry
Mauritia flexousa	*Buriti*	Edible fruit, thatch, basketry
Copernicia prunifera	*Carnauba*	Wax, basketry, construction
Acrocomia sclerocarpa	*Macauba*	Oil, meal
Euterpe oleacea	*Juçara*	Palmito, edible fruit
Orbignya phalerata	*Babaçu*	Oil, charcoal, thatch
O. teixeirana		Feed, basketry, construction
O. eichleri	*Piaçava*	Basketry, brushes

By far the dominant woody species encountered in these systems is the babassu palm (66% dominance in 1 ha of secondary forest in the *Cocais* (Anderson 1983). Babassu dominates the landscape due to its cryptogeal mode of germination in which the growing point (apical meristem) initially grows underground remaining until the stem emerges several years later. This adaptation permits juvenile palms to survive the cutting and burning associated with shifting cultivation.

According to local farmers interviewed, babassu palms attain fruiting stage after 10–12 years under optimal conditions (although there have been no controlled trials to confirm this). Adult palms produce a single inflorescence with each new leaf. Panicles contain about 200 fruits averaging 190 g each (range: 80–450 g). Fruits are mostly collected from the ground and broken manually by women and children by hitting with a club and breaking the fruit against the upright blade of an axe. Most kernels extracted in this way are sold and the husks used to produce charcoal. The importance of babassu products in the subsistence economy of the region has recently been assessed (Anderson and Anderson 1983; May *et al.* 1985) (Table 29.3).

Animals

Landowners typically have more numerous and varied livestock than their tenants. Prosperous families raise guinea hens, turkeys, ducks and geese, along with pigs, goats and sheep (all consumed by the family and slaughtered during local festivals). Most families have a few chickens; some have mules, donkeys, horses and oxen as beasts of burden. There is very little use of animal traction for cultivation. Small farmers rarely own cattle; those that have a few head

frequently rent pasturage rights from landowners at monthly rates which averaged the equivalent of US$ 2.75 per head in early 1983 (Fundação Getulio Vargas 1984). Animals are fed babassu leaves from juvenile palms, kernel residues, palm heart and mesocarp meal, as well as cassava peelings, corn and crop residues.

Ranchers raise herds of cattle and some water buffalo. Ranchers have been investing gradually in improving their local "*pé duro*" mixed cattle breeds. The preferred cattle species are Zebu and "Nelore" breeds of Brahman stock and "Holandés" dairy cows. Cattle are generally range-fed on native and planted pastures and on young secondary forest regrowth in fallowed crop land. There is little use of silage or stored grains as feed. Pastures are managed at low stocking rates, seldom exceeding one animal unit per ha. More modernized operations involve pasture rotations. The most popular pasture grasses are *jaragua* (*Hyparrhenia rufa*), *colonião* (*Panicum maximum*), and one or more species of *Brachiaria*. Fodder grasses, particularly elephant grass (*Pennisetum purpureum*), are also planted in small areas, cut into forage and fed to cattle during the dry season, along with cassava chips and babassu oil press cake.

Game and fish

Small farmers rely to a considerable extent on hunting and fishing for animal protein. Several large rodent species such as *cotia* (*Dasyprocta punctata*) and paca (*Agouti paca*) abound in the palm forests, feeding on the mesocarp of fallen babassu fruit (Smith 1974). Game potential in babassu forests is enhanced by this feed source. Rodents' removal of the mesocarp also appears to stimulate germination in babassu (Anderson 1983) thus making the relationship somewhat symbiotic. Fishing is done in even the smallest freshwater streams. Game animals and fish are cooked in babassu-kernel milk and home-made oil.

Synthesis of traditional systems

Figure 29.3 schematically describes the composite structure of traditional babassu agroforestry systems following a format developed for descriptions of similarly integrated crop and animal production systems throughout the tropics (McDowell and Hildebrand 1980). This diagram, which is self-explanatory, shows interconnections between different enterprises of landowners and tenants, as well as the social relations of production through which these enterprises function.

3.2 *Arrangements/interaction of components*

In babassu-associated cropping systems, stands of senescent and unproductive palms are thinned to between 50 and 100 adult palms per ha. The leaf biomass

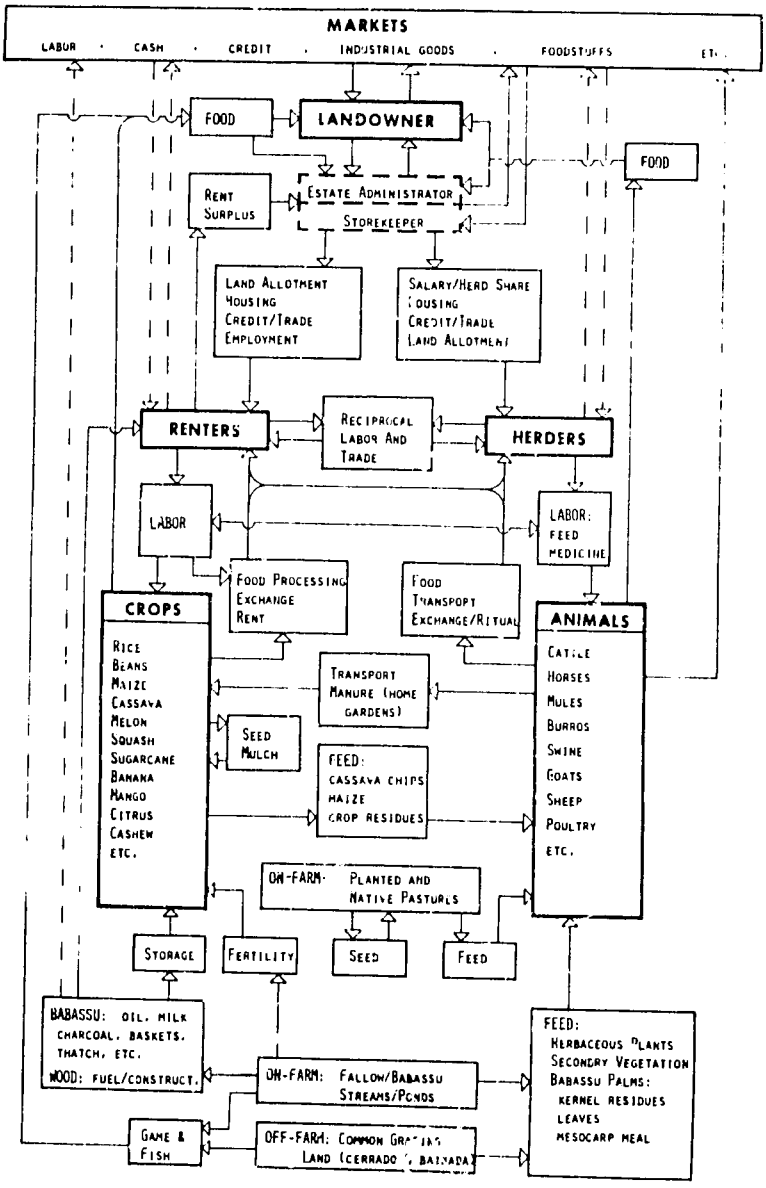

Fig. 29.3. Principal interactions in traditional babassu agroforestry systems in Mid-North Brazil. (Drawn by J. Barki based on a diagram by P. May.)

in babassu stands is exceptionally high. On a 1 ha site in the *Cocais* region the leaf biomass totalled 52.7 t dry weight (DW) and an annual leaf production of 16.8 t DW was recorded (Anderson 1983). A burned stand requires about four years to recover its full complement of leaves. After the annual burn in October, emergent (but still immature) panicles exposed to fire are worthless for kernel extraction as the liquid endosperm is destroyed by excessive heat. However, productive palms quickly regain productivity and recover

completely after 2–3 years, according to local farmers. This occurs because non-emergent inflorescences are protected from fire by heavy leaf sheaths. Cutting of leaves, which is also a common practice to meet the farmers' storage and shelter needs, also serves to increase light penetration during the subsequent growing season.

Harvesting of babassu fruit from fallow sites is a regular aspect of regional farming activities. Fruits commence to mature and drop from the panicle in August, continuing up to the beginning of the rainy season in January when planting of annual crops commences. People continue gathering babassu fruit from the ground during the rest of the crop cycle as a secondary activity which is limited by labour requirements in weeding and harvesting annual crops, as well as reduced accessibility of stands due to flooding.

In the crop field, farmers plant rice densely in holes about 20 cm apart and maize in hills in rows up to 2 m apart among the rice. Cassava is also planted, sometimes between these maize rows. Beans are either planted around maize stalks and babassu trunks, drilled in rows in a separate destumped plot, or scattered in a previously cropped site. Earlier in the season, farmers randomly plant the other crops (e.g., watermelon, okra, squash, etc.) within the annual crop field.

Harvesting of annual crops begins in late March after two manual weedings. Farmers first harvest early rice varieties, green corn and beans for household consumption. Most of the harvest period is devoted to rice cutting after completion of an average 120-day cycle. Farmers store rice on the sheaf in shelters covered with babassu leaves. After breaking stalks during the rice

Fig. 29.4. Bananas growing under babassu palms in Lime Campos, Maranhao. (Photo: P. May.)

harvest, maize dries in the field until August–October, when it is harvested and stored as grain. Farmers usually plant additional cassava at the end of the rice harvest, which extends the life of the crop field. Cassava varieties in use typically require up to 18 months to mature, after which household members harvest the tubers as needed for flour production, which peaks in the slack period before new land clearing. Once they harvest the cassava, they abandon the plot to secondary forest fallow dominated by babassu. Banana planted under babassu also extends the life of the cropping system (Fig. 29.4).

In most planted pastures, palms are retained at 50–120 stems ha^{-1}. Ranchers also tend to thin unproductive palms. This appears to promote the growth of pasture grasses and increase palm yields. Total fruit productivity of palms per unit area inventoried within 136 blocks in a uniform-aged stand on a yellow latosol in the *Cocais* increased linearly with stand density to about 120 stems ha^{-1}, beyond which yield tended to drop off with increased stand density (Frazão and May, unpublished data). Palm stands with pastures underneath, as compared with secondary forest, facilitate safer collection of fruits because of reduced undergrowth and the ease of sighting snakes. Ranchers interviewed asserted that pastures under palms retained moisture better and had higher productivity in comparison to open conditions. On the other hand, juvenile palms must be frequently cut back to avert competition with pasture grasses, representing a major cost to the rancher (averaging the equivalent of US$ 15 ha^{-1} yr^{-1} for manual cutting). For this reason, some ranchers consider babassu a serious weed problem that they attempt to permanently eradicate with herbicides or soil grading. Suppression of juvenile palms, however, will result in stand degradation of babassu after about 50 years due to senescence of the remaining palms.

4. Functional aspects of the system

4.1. *Resource input and utilization*

Land

According to the 1980 census (IBGE 1980), fallows and forest account for 66.5% of agricultural lands in the *Cerrado*. In the *Cocais*, pastures dominate (47.9%), with proportionally smaller areas in fallow and forest. The landowner allocates land annually to tenants for shifting cultivation at his discretion. Unwritten tenancy contracts involve a fixed rent which represents up to 30% of average rice yields in traditional intercropping systems for each land unit cultivated by the tenant farmer. The area of annual shifting cultivation plots averaged 1.0 ha in the *Cerrado* and 2.3 ha in the *Cocais* in the period 1982–1984; this may be lower than normal due to drought (May,

unpublished data). Area under crops per household is more for landowners than for tenants, but usually involves similarly rudimentary technology.

Labour

Households average four persons, but show a considerable range in size and are not stable in composition. This is because active males migrate to mining and urban areas either seasonally or year-round, so there are usually more women, children and older people in permanent residence within landless households. Land preparation (clearing, burning, fencing) is done by adult males. Given labour shortages, the household may employ daily workers (50% of families surveyed used this tactic), or engage in labour exchanges ("*troca de dias*") with other households to reduce labour costs and assure timely completion of essential tasks. Daily wages averaged US$ 1.50 in 1983–1984. Women and children are occupied in babassu fruit collection and breaking during the entire land-preparation period (August–December). Agricultural operations in February and March (weeding) and May–June (harvesting) may require more family members to be involved so that the quantity of babassu fruit harvested declines during this period.

This pattern of labour allocation ensures the availability of a steady labour force throughout the year. Landowners employ their tenants and, at peak periods, hire non-resident labourers whose wages will be paid in cash or kind (usually a fixed amount of the crop harvested, but also in meat; labourers customarily receive a meal as part of their wage). Although no labour obligations to the landowner are built into the tenancy contracts, the estate residents are generally regarded as a reserve labour force that can be called upon when needed. Tenants are also employed in herding landowners' livestock, for which they receive a share of the calves – typically one in every four calved.

Capital

Small farmers accomplish most tasks with the help of little more than an axe, a hoe, sickle and machete. Sales of babassu kernel finance the household's cash requirements up to the next harvest (Table 29.5).

Most frequently landowners use the cash from sale of babassu products and other revenues to invest in the expansion of the cattle herd or pasture rather than in mechanization. Nevertheless, there has been considerable growth over recent years in tractor utilization for pasture establishment and management, as well as some mechanization of rice production. These projects have largely been financed by banks and Federal Government subsidies rather than capitalized from revenues of current production.

Table 29.5. Per capita weekly income by source: average of 75 households in three Maranhao municipios, October–December 1983.

Source	Cash		Non-cash		Total	
	Cr$[a]	%	Cr$	%	Cr$	%
Babassu	597	39.7	217	26.0	814	34.8
Non-babassu	906	60.3	617	74.0	1,523	65.2
Totals	1,503	64.3	834	35.7	2,337	100.0

Source: May *et al.* (1985).

[a] Exchange rates averaged Cr$ 1,000 per US$ during this period.

Inputs

Chemical fertilizers are rarely used in crop production, though most producers use manures and decomposed babassu stems as a planting medium for kitchen gardens. Pesticides are in more frequent though sparing use. Many rely on spells and prayer to ward off crop failure, though these are of little help in combating the drought cycles which have begun to affect the region from the neighbouring semi-arid zone. Most seed is retained from the previous harvest by farmers who prefer to perform their own seed selection rather than rely on government sources. Large landowners have easier access to bank credit than do their tenants, using either land or anticipated production as collateral. The national bank has special credit schemes at low interest rates to help cover small farmers' production costs. Nevertheless, most farmers complain of problems in securing or obtaining timely release of production loans.

4.2. *Production*

Outputs vary widely among farmers, agro-ecological regions, and over time; average figures are given in Table 29.6. They may be slightly biased by output from non-intercropped or mechanized production, which represents a small proportion of overall crop output. Cassava and bananas are successional species in annual crop fields. Babassu output is for normal fallow cycle production of 2 t ha^{-1} in average regional stands (fruit yields range from less than 1 to over 6 t ha^{-1}).

Pé duro cattle breeds raised on the *Cerrado* seldom achieve marketable beef weight over 100 kg in 3–5 years at extremely low stocking rates; this output is somewhat lower than the Brazilian average of about 125 kg, most raised on comparably extensive range. Superior breeds raised on improved pastures in the *Cocais* yield considerably more meat in a shorter period at higher stocking rates, which helps to explain why much of this region is giving way to pasture.

Table 29.6. Production and value of principal crops and babassu per unit area.

Crop	Average output/ha	Gross value/ha (US$)[a]
Rice (unhulled)	1.63 t	150.40
Maize (grain)	0.47 t	45.37
Beans	0.31 t	184.63
Cassava (roots)	6.40 t	128.83
Banana	1,102 bunches	517.94
Babassu kernel	10.14 t	74.31
Babassu charcoal	10.45 t	26.87

Sources: CEPA-MA (1984); IBGE (1980); McDowell and Hilderbrand (1980); and P.H. May (unpublished data).

[a] In April June 1984 average market prices. Net revenues would be somewhat lower.

The Mid-North region rarely experiences drought. Abnormally dry rainy seasons between 1980 and 1983 resulted in significant crop land and herd adjustment. Small farmers were unable to save sufficient quantities of seed for planting; to avert risk they planted considerably less area than normal. Sale of babassu kernel and off-farm income were crucial to maintain household income.

4.3. *Protective and service aspects*

Besides a number of important subsistence products such as thatch and basketry, babassu leaves contribute to the sustainability of shifting-cultivation systems. Given a long enough fallow period, babassu leaf biomass provides sufficient fuel and nutrients so that mature palms may be retained when clearing secondary forest for crop production. High leaf productivity enables shifting cultivators to return to the same site within four or five years. In addition, microclimate conditions under palms may promote moisture retention in soils. On hillsides, palms appear to prevent soil erosion, both through crown protection against exposure to erosivity caused by direct rainfall and root binding of soils. Utilization of babassu fruit husks for charcoal reduces deforestation pressure on other woody species that would otherwise be used as fuel sources.

4.4. *Socio-economic description*

Small farmers incur mounting indebtedness during the period between harvests. Capital peaks at the termination of the rice production cycle in July. Cash flow from babassu kernel sale is fairly constant from September to January, providing an important supplement to stored grain. When goods stored from the harvest and babassu income become insufficient, goods are purchased on credit from landowners and local shopkeepers. This debt is sometimes not

fully defrayed at harvest time. This creates strong dependency relationships which go beyond purely economic ties to the landowner or other source of credit. Formal organization among small tenant farmers is minimal, probably due to their fragmentation and dependency on their landlords. Rural workers' unions have been formed, attempting to assure job security for wage workers and to mediate land-title disputes between smallholders and speculators. Such disputes are particularly severe in the Pre-Amazonic region where squatters are losing battles to secure legal title.

5. System dynamics

5.1. *Rate of growth – expansion/degradation*

The historical growth in babassu kernel production is directly related to population increase and frontier expansion in the region. Migration from drought-stricken and mechanizing areas of Northeast Brazil swelled Maranhão's population by 430,000 between 1950 and 1970. Land-use change and rural employment shifts have affected areas of the babassu zone at different times. During the 1960s, the *Cocais* was the area of most rapid population growth; during the 1970s, the highest growth rates were observed in the Pre-Amazonic region. Conversion to pasture in the *Cocais* forced many small farmers to migrate to the west where there were then relatively more free lands. Accompanying this migration has been a gradual expansion of babassu stands into the Pre-Amazonic region as primary forests are cleared for shifting cultivation.

The amount of land available for shifting cultivation has been reduced by widespread conversion to pasture, resulting in a decline in productivity of crops, as well as of babassu palms, in remaining areas available for cultivation. With degradation of shifting cultivation sites, the rural poor are becoming increasingly dependent on pasture stands of babassu as a source of income and subsistence products. Despite babassu's beneficial attributes, ranchers often treat it as marginal to their overall enterprises. People who gather babassu fruits are perceived as interfering with pasture management, being blamed for starting wild fires, cutting fences and leaving behind fragments of fruit husks that can cause injury to the hooves of cattle. To rid themselves of such incursions ranchers are increasingly clear-cutting the palm forests.

Ranchers who receive government subsidies for pasture establishment are encouraged to remove native forest, which in practice represents a further incentive to clear babassu. From 1967 to 1980, 72 such projects were approved for financing in Maranhão alone on an area totalling over 1 million ha (Amaral Filho 1983). Babassu stands are also being felled to make way for mechanized rice operations as well as plantations of sugarcane and bamboo.

These projects correspond with national efforts to stimulate agricultural exports to service international debt or substitute for imported fuels. Babassu, an indigenous plant resource of considerable local economic significance, is being substituted by export crops from the region. Though state laws prohibit clear-cutting of babassu in an attempt to preserve moderate densities of palms in pasture systems, these laws are unenforceable. We suspect that the rate of deforestation is increasing exponentially in more humid and fertile areas due to the combined pressures of pasture conversion, breakdown of shifting cultivation and establishment of permanent agricultural systems.

5.2. *System sustainability*

The future role of babassu in regional farming systems largely depends on the attitudes of the people who own and manage land. In regions where land uses are intensifying, such as the *Cocais* and Parnaiba Valley, the palm is often considered marginal due to its low yields and slow growth. In these relatively fertile areas, babassu's continued dominance of the landscape appears to be seriously threatened. Yet the palm has shown a remarkable capacity to recover and eventually dominate landscapes where intensive forms of land use were practised in the past.

In drier, less fertile areas, such as the *Cerrado* region in Maranhão and most of the babassu zone of Piauí, the palm is still an integral part of traditional land-use systems and will probably remain so.

6. Evaluation

6.1. *Merits*

The productive and service functions of babassu in traditional systems are ranked as follows:

1. Babassu is an important source of vegetable oil and feed cake and has considerable unrealized potential to supply fuels as well as other industrial products such as starch and tar.
2. Cash income from sale of babassu products (principally kernels and charcoal), constitutes a significant share of small farmers' income obtained during the period between harvests of annual crops. This income, which is generated principally by women and children whose labour is not critical to agricultural activities in the land-preparation phase, strongly complements that derived from other activities and provides a risk cushion in the event of crop failure.

3. A wide variety of subsistence products, consisting chiefly of charcoal, thatch, basketry, edible oil and food products, feed and fodder is obtained from the palm by small farm families.
4. High biomass production provides farmers with sufficient material for fuel in shifting-cultivation systems without requiring drastic thinning of the stands.
5. Land coverage by babassu palms appears to promote soil-moisture retention and improve pasture productivity, as well as providing shade for cattle.

6.2. *Weaknesses/constraints*

1. Low current fruit productivity in wild stands of babassu leads to their replacement with open pastures, mechanized crop production and even other trees.
2. Pasture encroachment diminishes the land available for shifting cultivation and reduces the duration of fallow cycles, which compel shifting cultivators to drastically thin or clear-cut the very palm stands on which they depend for a sizeable part of their incomes.
3. Ranchers consider juvenile palms noxious weeds that compete with pasture grasses due to their capacity to survive cutting and burning.
4. Stands maintained over pastures are subject to gradual deterioration as new growth is suppressed.
5. Utilization of existing stands for kernels accounts for only about 30% of total fruit production, due to low value of product, inaccessibility, and prohibition against collection.
6. Efforts to develop technology for processing whole babassu fruit and marketing them threaten to reduce employment and subsistence benefits from the existing cottage industry.
7. Inequitable land distribution constrains the prospects for developing babassu-based agroforestry systems.

6.3. *Potential*

1. Babassu's attributes as provider of a wide range of products, its ease of establishment and maintenance, and its current close integration with extensive production systems on marginal lands could be enhanced by a breeding programme to upgrade productivity of apparent natural hybrids of babassu with palms such as *inajá* (*Maximiliana maripa*) and *piassava* (*Orbignya eichleri*) to select strains more tolerant of dry and nutrient-poor soils.

2. Babassu palms could be retained on hillsides in fertile regions as a means of preventing soil erosion; increased market demand for whole babassu fruits will make this attractive to landowners.
3. There is a potential for stand and yield improvement through dissemination of seed from prolific stands encountered in the wild, or genetically improved strains. For example, there are reports of babassu fruits containing up to 17% kernel, in contrast to the average of 7%; exploitation of such strains for oil would prove advantageous. Corresponding variations have been noted in fruit size, endocarp weight and hardness, all of which affect industrial viability. From the farm production perspective, recent fieldwork in Pirapora, Minas Gerais has identified babassu palms demonstrating yields 500% higher than average yields in the Mid-North region (M. Balick, J. Frazão, J. Costa, J. Veira, unpublished data). Occurring in a palm-pasture combination, this population of a distinct species (*Orbignya oleifera*) was estimated to produce about 10,000 kg fruit ha^{-1} yr^{-1}.
4. Available technology for mechanical processing of whole babassu fruits can be scaled down to the level of the producer; fruit components can be more completely utilized within the farm system for feed, fuel and fibre, with kernels and charcoal still being supplied to regional industries. With such a technology, part of the estimated 70% of fruit output that is currently underutilized could become economically harvestable.

6.4. *Extrapolatability*

Babassu-related agroforestry practices with present productivity levels show greatest promise in areas having marginal soils and sparse population, where the palm's multiple products can contribute to diversified shifting cultivation and pastoral farming systems. With crop improvement efforts already under way, the palms are also promising as fuel-, food- and fibre-generating components of more intensive production systems in a wide range of tropical environments.

6.5. *Research needs*

1. Highest in priority should be a focus on the potential of apparent natural hybrids of babassu with *inajá* and *piassava* for reforestation of marginal areas. This would involve selection of seed from promising native stands or individual trees, development of seed propagation techniques, and testing of growth performance on representative soils.
2. Development of technology for processing babassu fruit at the farm level would involve engineering studies to scale down available peeling-separating-breaking equipment and adapting locally available charcoal kilns

to facilitate recuperation of tar. Such developments should go hand in hand with market research to identify potential users of non-traditional babassu products, and study of alternative organizational and financial arrangements for fruit collection and processing.

3. Continuing research is needed on management of native stands and studies of the most efficient crop and pasture species combination in a farming systems context. Trials examining the palm's productivity response under varying levels of soil fertility and water availability are also needed to serve as the basis for recommendations regarding environmental conditions to speed growth to maturity, improve the ratio of female to male inflorescences, as well as the number of palms bearing fruit and the number of panicles per tree.
4. Since many factors affecting productivity appear to be genetically determined in babassu, research is needed to distinguish between environmental and genetic conditions affecting characteristics important to industry such as kernel content. To do so, seed specimens from prolific populations such as that of *Orbignya oleifera* in Pirapora, Minas Gerais, described above, must be secured before the palms are cut for crop and pasture development, a real threat in the Pirapora case where the present population appears to be geographically restricted and endangered, and perhaps comprised of only a few thousand individual trees.

6.6. *Data/information base*

The Brazilian National Corporation for Research on Agriculture and Livestock Husbandry (EMBRAPA), through its National Center for Genetic Resources (CENARGEN) and state-level activities in both Maranhão and Piauí, has begun a broad-based programme of research and development with babassu and associated palms. A National Babassu Research Programme (PNP-Babau) has been established with staff based in EMBRAPA's Special Unit for State-Level Research (UEPAE) in Teresina, Piauí, responsible for overseeing nine local projects under way in 1984 on palm phenology, taxonomy, germination and seedling production, and forage combinations, among other concerns (EMBRAPA 1984), and for disseminating results in its publication series. A bibliography on babassu literature has been published (EMBRAPA 1983) as well as a collection of current and historical literature.

CENARGEN, with local resources as well as a USAID grant to the New York Botanical Garden (NYBG), has established an active Babassu Germ Plasm Bank in the Mid-North region in collaboration with EMBRAPA staff and state agencies in Maranhão and Piauí. Specimens collected from other parts of Brazil and Latin America have been planted as a base for genetic improvement. Voucher specimens for seed are also retained in CENARGEN headquarters in Brasília, at the Museu Goeldi in Bélem, and at the NYBG.

Data on babassu phenology, taxonomy, ecology and utilization were obtained recently by Anderson (1983) and Anderson and Anderson (1983).

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30. Combination of cacao with other plantation crops: an agroforestry system in southeast Bahia, Brazil*

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Abstract. Brazil's production of cocoa accounts for about 20% of world production, and about 95% of the cocoa produced in Brazil is from the south-eastern part of Bahia State. Traditionally, cacao is grown in monoculture (though under the shade of various other species). But various crop combinations involving cacao have recently been undertaken by the farmers with encouragement from the Brazilian Government.

As a part of the crop diversification programme in the traditional cacao growing areas and their surroundings, extensive areas are being planted to other plantation crops, mainly cloves and rubber and, to some extent, coconut. Crop combinations have been adopted in some of these new plantings and cacao is an important component of most such combinations. Whereas several other crops are combined with clove trees, cacao is usually the only species grown with mature rubber trees. Young rubber trees are, however, interplanted with a number of other species. Productive coconut areas are found mostly in sandy soils along the coast so that there is little intercropping. However, scattered farms are found where coconuts are underplanted with guarana, black pepper, cacao, cashew, etc., as is done commonly in other parts of northeast Brazil.

This paper presents some data on the performance of some of the combinations involving cacao and other plantation crops based on a field survey, and discusses the potentials and constraints of extending the system to more areas in the region.

1. Introduction

Bahia State, situated in the south-eastern part of the Northeast Region of Brazil, has an area of about 570,000 sq km and a population of 10.28 million (1980). The major economic activity in the State is cacao production, which extends over 650,000 ha and involves about 2 million inhabitants in south-east Bahia. The total annual production is 350,000 tonnes of dry cocoa, which

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contributes an estimated US$ 700 million annually to the national economy. Brazil produces nearly 20% of the world production of cocoa and about 95% of the cacao produced in Brazil is from south-east Bahia. Cacao is now being extended to other parts of Brazil also, especially Amazonia (see Fig. 30.1).

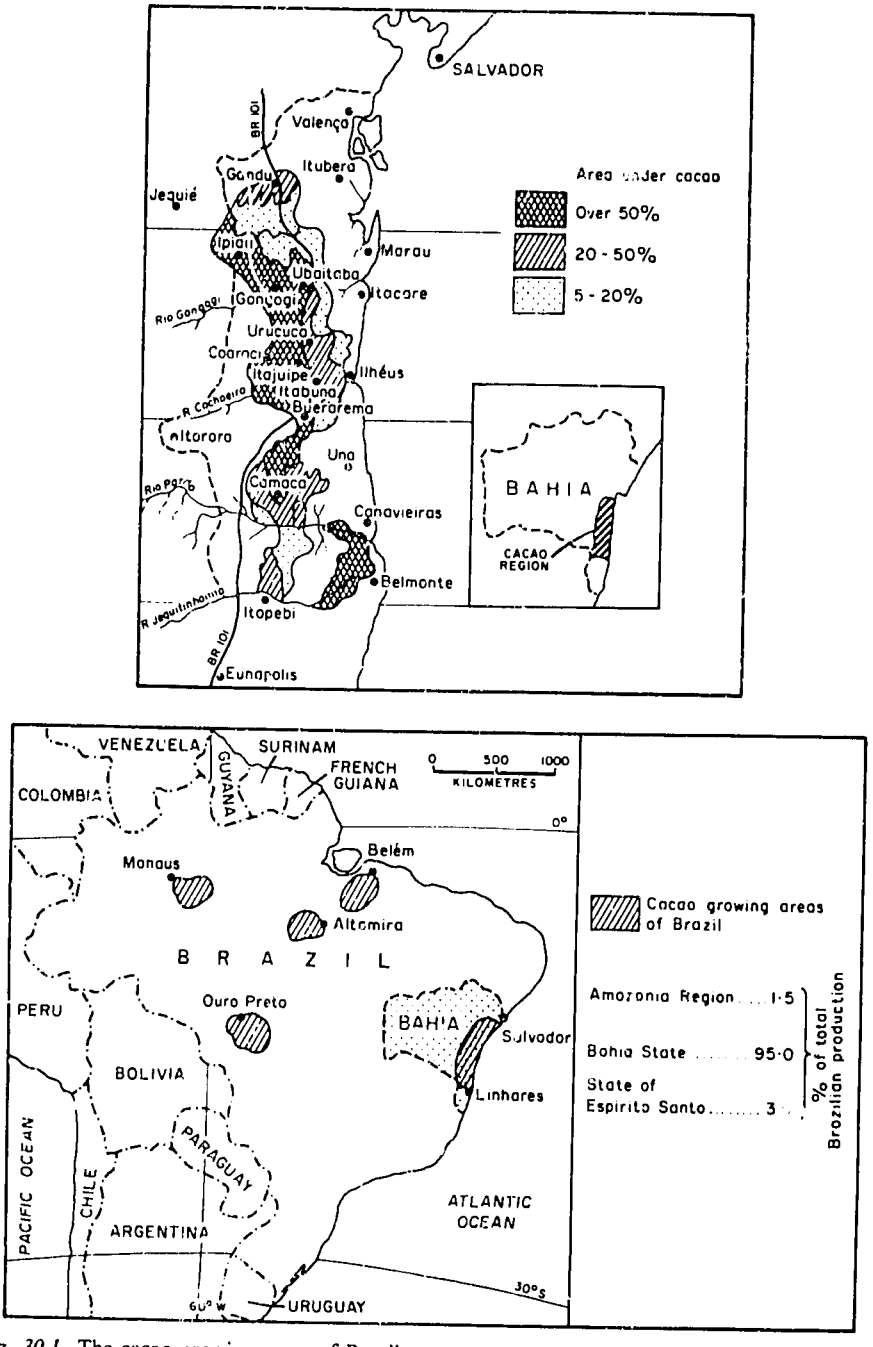

Fig. 30.1. The cacao growing areas of Brazil.

Traditionally cultivation of cacao presents a good example of the agroforestry approach. Being a shade-tolerant plant, cacao is grown in association with other species, either in selectively cleared secondary forest or, more commonly, along with food crops that provide early shade until the shade trees planted along with the cacao take over as the overstorey (shade) species. Thus, the eventual combination of cacao with shade/forest species provides an excellent illustration of compatibility and complementarity of various species with one another and of the sustainability of such multistoreyed production systems. This paper describes some such crop-combination systems existing in south-east Bahia. Owing to the long tradition of cacao cultivation in the region, cacao is an important component in all cropping systems, and it will inevitably be suggested as a component of any potential (new) system.

2. General description of the area

The area, located between 13° S and 18° S, and longitudes 39° W and 40° W, has a humid tropical climate. Total annual rainfall ranges from 1,200 mm to 2,200 mm with a dry season (when evapotranspiration exceeds precipitation) not exceeding three months a year. The annual temperature varies from 23°C to 24°C, with a difference of 8–10°C between the average maximum and minimum temperatures. The soils of the main cacao growing area are deep, reddish-brown to red, well-structured Alfisols (ferric Luvisols and eutric Nitosols). They are acidic but only moderately to strongly leached with a base saturation of over 50%, are well structured and permeable and fairly fertile. Although they possess good aggregation, and particularly so the Nitosols, there is a fairly high erosion hazard owing to the heavy rainfall and moderate slopes. However, the major soil type of the area, where other plantation crops such as rubber and clove are planted, is leached and weathered Oxisol. Cacao is also planted as a mixed crop in these areas.

In most parts of the region, cacao is grown in monoculture (but under the shade of various timber species). However, the year-round production potential offered by the favourable climatic conditions of the region has encouraged the local farmers and the Brazilian Government to adopt crop diversification in order to counterbalance the socio-economic and ecological risk of cacao monocropping. The traditional crops chosen to expand regional agriculture over the past 20–30 years include rubber, oil palm, coconut, piacava or Bahia piassava palm (*Attalea funifera*), black pepper (*Piper nigrum*), clove (*Syzygium aromaticum*), and more recently, coffee and guarana (*Paullinia cupana*). In some places, small areas have also been planted with papaya (*Carica papaya*), vanilla (*Vanilla planifolia*), cardamom (*Elettaria cardamomum*), nutmeg (*Myristica fragrans*), patchouli (*Pogostemon cablin*), passion fruit (*Passiflora edulis*), peach palm (*Bactris gasipaes*), allspice (*Pimenta dioica*) and mangosteen (*Garcinia mangostana*). Although most of the areas planted with major

plantation crops such as rubber, oil palm and coconuts are in monoculture, crop combinations have been adopted in some instances. The factors that favour such crop combinations are:

- Ecological requirements of some species like clove, cardamom, vanilla and nutmeg which necessitate provision of shade at least during their early stages of growth; and
- The advantages of crop combinations and multiple land use are clear to the local farmers from the experience of cacao cultivation (under shade).

Combinations of these different crops, with cacao as one of the components in most, if not all, of them, present a multilayer pattern of canopy admixture, and it is often difficult to distinguish them according to their species composition. However, based on the predominant cash-crop component involved, three different sub-systems can be identified, namely, multiple cropping systems with clove, rubber and coconut as the major components.

3. Multiple cropping with clove

The clove tree (*Syzygium aromaticum*) is being established on a large scale in the region; over 5,000 ha have already been planted with clove in the past 25 years, 50% of which are already bearing. Clove is usually established under the shade of food crops, most commonly cassava or in combination with black pepper (*Piper nigrum*).

3.1. *Clove with black pepper*

Clove is planted at 8 × 8 m or 10 × 10 m spacing in an already established stand of black pepper at 2 × 2 m or 2.5 × 2.5 m. The pepper vines, trailed on to wooden posts, provide lateral shade to young clove trees and protect them against wind. The pepper plant is usually affected by a disease supposedly caused by nematodes and fungi, so that they die in 4-6 years after planting. However, within this short period, it yields heavily providing cash benefits to the farmers when cloves are still not yielding. The cloves benefit by the heavy fertilization given to the pepper, and they start bearing from the sixth year so that continuity of cash income is maintained after the decline of the pepper.

Three main problems are encountered in this crop combination:

- Under the usual management given to pepper, which involves frequent weeding, the soil is seriously exposed to erosion;

- The large number of wooden (dead) posts required to support pepper makes pepper cultivation very expensive;
- Following the removal of the dead pepper and posts, weeding of inter-row spaces becomes necessary, which exposes the soil under cloves.

Leguminous live posts have been tried as support for pepper so as to offer better soil protection, improve soil fertility and reduce establishment and weeding costs. *Erythrina fusca*, *Gliricidia sepium* and *Leucaena leucocephala* have been found very successful. These woody species are lopped periodically to provide more light to the pepper and the loppings are applied as mulch to the pepper. Experiments are in progress in which herbaceous crops such as cowpea and pineapple are also being tried in between rows of these leguminous live posts (Fig. 30.2). So far the results have been successful.

3.2. *Cacao after pepper in clove stands*

Some farmers plant cacao after the removal of pepper in order to avoid erosion-prone bare interspaces between cloves. But this would necessitate frequent pruning of cacao branches so as to minimize overlapping of cacao and clove canopies (that can lead to inflorescence deformation in cloves).

Fig. 30.2. Experimental plot showing crop diversification and mixed cropping in south-east Bahia. The picture shows a combination of *Leucaena leucocephala* and Pejibaye palm as the woody components with various agricultural species. (Photo: P.K.R. Nair.)

Another possible component in this scheme would be cinnamon (*Cinnamomum zeylanicum*), the stems of which need to be periodically removed to obtain the bark, which is its main economic product.

3.3. *Some production data from farmers' plots*

In "Sitio Jurema", located near Ubaitaba, clove was planted 8 m apart in a 5 ha plot in 1973, initially under the shade of cassava. After two years, cassava was replaced by oranges, and when the cloves started giving too much shade for the oranges, they were removed and cacao was established irregularly in the clove inter-rows. Figure 30.3 is a 1983 photograph of the farm. Only cacao plants are fertilized in this combination. In 1982, the nine-year-old clove plants yielded an average of 3 kg dry cloves per plant. By 1984, the average yield went up to 5 kg/plant, and cacao, which was then seven years old, produced 600 kg (dry beans) per hectare. The market price (1984) was the equivalent of US$ 4/kg of cloves and US$ 1.6/kg of cacao beans (these being the prices paid to the farmer).

In some other farms in the region, nine-year-old cloves are interplanted with coffee and chillies (*Capsicum* spp.). There are also mixed plantings of clove and coconut. Since coconuts cast little shade when they are over 30 years old (Nair 1979), this kind of permanent mixed cropping will possibly result in realizing the full yield potential of both the species. "Fazenda Boa Esperanca" in Valenca and "Fazenda Auxiliadora" near Taperoa are two of the most organized and apparently remunerative examples of multiple systems

Fig. 30.3. Crop combination involving mainly clove (ten years old) and cacao (six years old) in a private farm near Ubaitaba, south-east Bahia. Other crops such as black pepper, coffee and papaya, as well as the leaves of a coconut palm on the border, can also be seen in the picture. (Photo: P.K.R. Nair.)

with clove. In the former, cloves planted at 7.5 × 7.5 m spacing are interplanted with passion fruit, papaya and coffee. Data on the yield and other growth parameters are, however, not available as the owner is too reserved to divulge such information to outsiders. "Fazenda Auxiliadora" consists of a 4-ha plot of clove in multistoreyed combination with Pejibaye or peach palm (*Bactris gasipaes*), papaya, coffee, patchouli, cardamom and vanilla. Figure 30.4 is the schematic arrangement of different crops, and Fig. 30.5 is a photograph of a section of the farm showing patchouli, vanilla, pejibaye, cardamom and coffee with clove trees.

The cloves were planted 8 m apart in 1974. Vanilla cuttings are trailed on to dead wooden posts as well as pruned coffee plants. Shade-tolerant species like patchouli and cardamom form the lower storey of this crop mix. As a consequence of this intimate plant association, weed growth is almost totally suppressed. Vegetables and other food crops are grown in an adjacent area along with coffee, cardamom, patchouli and vanilla. Pigs reared in a separate site and fed with crop wastes provide organic manure that is added to the soil. Chemical fertilizers are given only to coffee, patchouli and papaya, but the quantities given were not disclosed by the farmer. Patchouli, harvested once every three months, yielded about 3 kg of commercial product (fresh leaves and stem) per metre row length; yield of clove was 937 kg/ha of the mixed garden. Yield data for cardamom and vanilla were not disclosed by the farmer. Patchouli was sold at the equivalent of US$ 0.5 per kg of fresh produce, vanilla $ 80/kg and cardamom $ 20/kg.

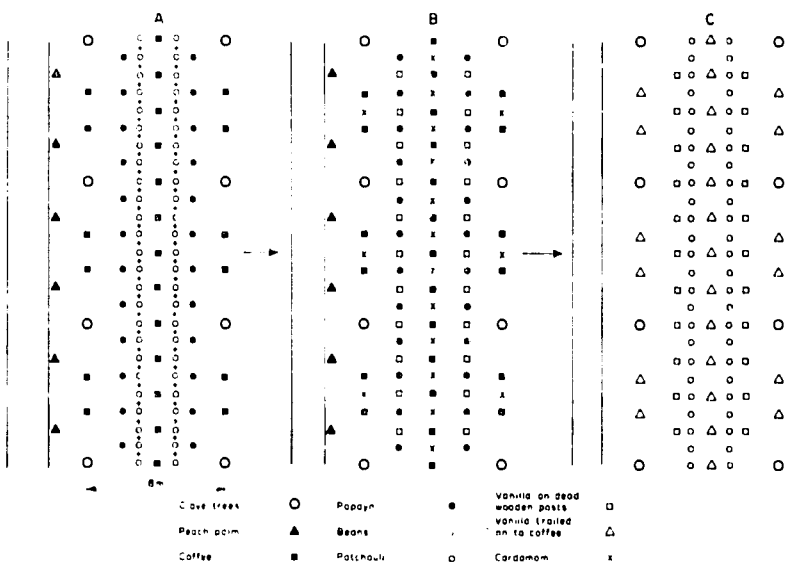

Fig. 30.4. Schematic arrangements of the various components of crop combinations with clove at the "Fazenda Auxiliadora" in Taperoa, south-east Bahia. (A) with peach palm, coffee, papaya, beans and patchouli; (B) with peach palm, coffee, papaya, cardamom and vanilla on wooden posts; (C) with patchouli and vanilla on wooden posts and on coffee.

Fig. 30.5. Photograph of one of the crop combinations mentioned in Fig. 30.4 showing patchouli, vanilla, pepper and coffee with clove trees. (Photo: P.K.R. Nair.)

4. Multiple cropping with rubber

South-east Bahia has about 30,000 ha under rubber, most of which is in pure (sole crop) stands. But in about 2,000 ha cacao is interplanted at the rate of 1–2 rows between every two rows of rubber (Fig. 30.6). Both rubber and cacao are spaced 3 m along the rows, and rows of rubber are 7 m apart. Thus, there will be 476 rubber trees per ha and 476 or 952 cacao plants – depending on whether there are one or two rows of cacao between two rows of rubber. The most successful arrangement so far seems to be two rows of cacao in every inter-row space of rubber trees.

Research data and other systematically collected information are not available on the yield figures of the two components of this combination because, on the one hand, research-station trials are in their early stages, and, on the other, farmers who adopt the practice are not very co-operative in providing actual yield figures. Some field observations were made on a number of farms of south-east Bahia with representative areas of cacao of different age groups (4–10 years). In all cases cacao seedlings had been introduced after the rubber trees had attained maturity. The findings of the survey are summarized in Table 30.1. These figures indicate that the performance of cacao grown in combination with rubber is comparable to that of the average crop in the locality, but lower than that of cacao in sole stands and under improved

Fig. 30.6. Interplanting of cacao in mature (20-year-old) stands of rubber trees. (Photo: R. Alvim.)

management. The yield of rubber trees in the mixture is also comparable to, if not better than, that of trees in pure stands. The rubber trees in the mixture benefit from reduced weed competition as well as from the fertilizer application and other aspects of cacao management.

Because of the dense canopy of rubber trees and the convenience of management, commercial rubber plantations always consist of sole-crop stands (except for the legume cover crops). Until recently, crop combinations with rubber were even considered not feasible (Hardy 1961). However, intercropping with rubber is a usual practice in smallholdings, and research efforts are now under way in Malaysia and other rubber-growing countries to improve this practice (Pushparajah and Weng 1970; Wan Embong 1976). Crop combinations with rubber seem particularly suitable in Bahia conditions where rubber trees are usually severely defoliated (in addition to their natural leaf shedding) by fungal diseases and insect damage. Improved clones of rubber having a synchronous leaf-fall pattern will be more suitable for this crop combination.

New rubber plantations are now being established in the flat lands ("*Tabuleiros*") of south-east Bahia as a consequence of the subsidy and credit schemes implemented by the Brazilian Government. In these areas, especially near market outlets, the farmers interplant a variety of food crops and vegetables with young rubber trees, and most of the field operations are

Table 30.1. Average yields of cacao and rubber in south-east Bahia.

	Cacao kg dry beans/ha	Rubber kg dry rubber/ha
1. *Pure stands*		
(a) General level (conventional farming practices; unregulated shade for cacao)	650	600
(b) Improved management (cacao under moderate shade, usually *Erythrina* trees 18 m apart)	1,000	1,200
(c) Experiment station yields	2,500	2,000
2. *Mixed stand of rubber and cacao* cacao 4–10 years old (average of data from several farms)	645 (range 195–1,155)	588 (range 488–671)

mechanized. However, the choice of intercrops with rubber is rather limited in the hilly areas nearer the traditional cacao producing areas which have few possibilities for mechanization. Local practices by some farmers indicate the suitability of some intercrops for these areas. For example, on relatively poor soils in Una, açai palms (*Euterpe oleracea*), planted at 3.5 m × 1 m spacing under old rubber trees, yielded commercially valuable hearts of palms (2.5 cm in diameter and weighing 400 g per plant) four years after planting, even without addition of any fertilizers. Moreover, the palms suppressed weed growth after they were about 30 months old. Another potentially promising crop mixture in the region is a combination of black pepper and patchouli between the rows of young rubber trees. However, this combination needs considerably higher levels of inputs and management attention than in the case of açai palms. Old rubber stands are also being interplanted with guarana (*Paullinia cupana*), but yields are considerably lower than in pure (unshaded) stands. Passion fruit (*Passiflora* spp.) is another cash crop that is being popularized thanks to the establishment of passion-fruit juice industries. Sometimes rubber and mangosteen (*Garcinia mangostana*) are planted between rows of passion-fruit vines.

5. Multiple cropping with coconuts

There is very little to report on mixed or multiple cropping with coconuts in Bahia, mainly because productive coconut areas in the region are found almost entirely in marginal sandy soils along the coast. Recent plantings on

better soils are still too young for the introduction of shade-tolerant species like cacao under the palms. Scattered farms, however, are found where coconuts have been underplanted with guarana, black pepper and, on a small farm on the coast, with cashew, similar to the practices in areas further north in the Northeast Region (Johnson and Nair 1985; Chapter 28).

Mixed coconut and guarana is an interesting combination in view of the yields obtained from both crops and the reduced costs of weeding. Some small farmers are underplanting single or double rows of guarana spaced 4 or 5 m in the row when the coconuts are 3–5 years old.

6. Evaluation and research needs

The crop combination systems described here have several advantages in the agricultural and socio-economic context of south-east Bahia. As discussed by Nair (1979, 1984), crop diversification systems can make more efficient use of labour and equipment over a calendar year or other relevant time span, reduce the cost of weeding that would be required in sole-crop stands, make complementary (and thus more efficient) use of soil-fertility resources, reduce erosion hazards and increase the land's total productivity on a sustained basis. Socio-economic advantages lie not only in increasing the overall productivity but also in avoiding over-reliance on a single commodity and the other risks of monocultural cropping. Some of the additional crops that are being tried or are potentially feasible (e.g. various species and medicinal plants) have a strong international market, whereas the various fruits and vegetables enjoy high demand within the country. Environmentally also, crop mixtures are preferred over monocultures (Nair 1982).

The feasibility of expanding crop combinations with various tree crops is evident from the success attained by the few farmers who adopt these practices, as already cited. Among the three tree crops examined here, crop combinations are most popular with clove and least with coconuts. However, this is possibly a reflection of the soil conditions under which these crops grow and the managerial skill of the farmers involved rather than the suitability or amenability of the particular tree crops for intercropping. Morphologically, among these three crops, rubber, which has a dense canopy that easily closes, is the least suitable for intercropping and coconut the most. Because of the high proportion of light reaching the plantation floor during the early and late stages of coconut's growth, intercropping with coconuts is particularly feasible during these periods (Nair 1979). Weed competition in monoculture stands of coconuts is a serious problem, but it can be overcome to some extent through intercropping. Livestock, such as sheep feeding on food-crop wastes or grazing on interplanted cover crops, could also keep the growth of weeds in check. Such crop-diversification practices and animal integration with coconut

palms are popular in several other countries (Nair 1983; Liyanage *et al.* 1984), and even in the northern parts of Northeast Brazil (Johnson and Nair 1985). Failure to expand these promising practices to the desirable extent in southeast Bahia can be ascribed to the lack of sufficient technical and scientific know-how on the subject.

Obviously a great deal of research and development effort needs to be devoted to the realization of the full potential of these systems. As already mentioned, there are quite a few examples of very promising crop mixtures with cloves. But the practitioners of these systems would not divulge information on the agronomic management and production particulars of their farms. With some tactful persuasion, however, these details can be gathered and could form the basis for further studies on improvement of the already existing systems on the one hand, and for extension of the method to other potential areas on the other. In the case of intercropping with coconuts, a great deal of research information is already available from elsewhere (Nair 1979, 1983, 1984), which could be tried extensively in the region. The main tasks in popularizing these practices would be the choice of appropriate intercrops, deciding their agronomic requirements, training the traditional monoculturist farmers in the management and processing of several crops, and ensuring the marketability of the various products.

In addition to the three main crops listed here, a large number of other crops can also be combined with cacao. An excellent illustration of this possibility is the complex system of agroforestry combination being practised very successfully by farmers of Japanese origin in Tomé Açu near Belem in Para State of Brazil. An inventory of the commonly cultivated plants in these mixed systems lists 32 species ranging from the tall Brazil nut tree (*Bertholletia excelsa*) to herbaceous crops like rice and soyabean in various types of intimate plant association (EMBRAPA 1982). Several Brazilian agencies such as EMBRAPA (the Brazilian National Council for Agricultural Research), CEPLAC (Executive Commission for the Development of Cacao) and others are now undertaking such perennial-crop combination experiments in various parts of the country.

These crop-combination systems are, understandably, more demanding than monocultures not only in terms of labour and capital but also technical and managerial skills. Care and management of a large number of crops where one or two grew before involves considerable amounts of technical knowledge and competence. Processing the various products and their marketing can also pose serious problems. Lack of possibilities for mechanization of various farm operations is another issue that is often cited as a disincentive to crop-combination schemes, so that the feasibility of such practices is seen as being confined to small-scale farmers who usually undertake most of their farm operations manually. Nevertheless, the agronomic, socio-economic and environmental advantages of the systems are so vivid and appealing that they

are potentially very suitable for the traditional smallholder cacao-production areas of south-east Bahia (and possibly other such areas). Researchers and development experts need to be encouraged to give more attention to surmounting the technical and operational constraints in popularizing these systems.

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31. Promising agroforestry systems in Venezuela*

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Abstract. The main agroforestry systems in Venezuela are the multispecies plant associations in the integrated coffee production system and the silvopastoral system. This paper describes the functional and structural aspects of these systems. The multi-layered coffee production systems are practised mainly in the moist pre-montane forest of the Andes region, but are also found in other areas of the country. Various tree species are used for shade and as fences in big coffee plantations, whereas in small units with a traditional production pattern, coffee is planted along with many other species, often constituting a 3-4 layer canopy. Available data are presented on the production as well as some socio-economic aspects.

The silvopastoral systems are found in the tropical dry forest (savannas) and in the very dry tropical forest of the semi-arid zones of the country. A large number of trees and shrubs are found in these pastoral areas where they play both productive (fodder and feed) and service (shelter) roles.

Although both these systems are practised over large areas of the country, practically no research has been done to improve them. In order to strengthen national capability to undertake such research, international support in the form of cash as well as technical advice is needed.

1. Introduction

The Republic of Venezuela is located between 0°40′ and 12°28′N and 60° and 73°30′ W. It is bounded by the Caribbean Sea and the Atlantic Ocean to the north, Guyana to the east, Brazil to the south and Colombia to the south-west and west. The physical relief varies from the level topography of the plains to the peaks of the Andes. About 20% of the area falls within the Amazon basin. Three broad geographical regions can be discerned:

- The coastal mountain region reaching a height of 5,030 m a.s.l.;
- The plains up to 300 m a.s.l.; and
- The "forest" region up to 2,500 m a.s.l.

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The coastal mountain range that represents only 3% of the national territory contains the greatest concentration of people. The plains occupy approximately a third of the country's territory, extending about 1,300 km from the mouth of the Orinoco River to the foothills of the Andes and varying in width from 100 km in the east to 400 km in the west. About half of Venezuela is covered with forests of various kinds. A little less than half of the area is under the "Llanos" (savanna) with wild grass, though much of this is used for occasional grazing. Only about 6% of the area, mostly in the valleys of the Andes and of the coastal ranges, is under permanent cultivation.

Venezuela has a tropical climate with seasons marked more by differences in rainfall than in temperature. There is an enormous variation in rainfall, ranging from 125 mm to over 4,000 mm per annum depending on location, altitude and aspect. Average annual temperatures vary from 28 C at sea level to 18 C at 1,600 m a.s.l. (10.3 at Mucuchies in the Andes at 2,980 m a.s.l.).

In Venezuela agroforestry systems exist in many ecological regions of the country. In the semi-arid environments, trees have a special role as fodder. In the tropical moist forest of the humid environments, timber trees are very important where they are used as shade in the coffee/cacao plantations. In the highlands, trees are used in pastures; a typical example being "aliso" (*Alnus jorullensis*) which is very important in supplying shade, fodder and fuelwood to the small farmer and his animals. A map of Venezuela showing the major ecozones and the spread of major agroforestry systems is given as Fig. 31.1.

Most of these agroforestry systems have developed empirically within the limitations of the natural environment, and they need to be improved to make them more efficient. As a basis for initiating such improvements, this paper aims at describing and evaluating the two most prominent agroforestry systems in Venezuela, namely, trees in perennial cash-crop systems and silvopastoral systems.

2. Trees in perennial cash-crop systems

Perennial cash crops such as coffee and cacao have been very important in the Venezuelan economy for a long time. In the last few centuries, large-scale coffee plantations were established under traditional farming techniques, mainly in the Andes region. Today, it is the largest coffee producing area representing 57% of the total coffee production in the country.

2.1. *General description of the area*

The area is located in the Andes mountains of Venezuela, made up mainly of the States of Tachira, Merida and Trujillo, and the northern parts of Barinas

State. The total area under cultivation in this region is about 120,000 ha, which represents 43% of the national total under coffee production (Fig. 31.1). Lara, Portuguesa, Auzoategui and Sucre are the other important coffee producing States.

The coffee production system is mainly located in the area classified as "Premontane moist forest" according to Holdridge's classification (Ewel *et al.* 1976). The average annual rainfall (RF) ranges from 1,000 to 2,000 mm and the average annual temperature is 18–24 C, with potential evapotranspiration (PET) of 1,100–12,000 mm per year and PET/RF ratios of 0.5 to 1.0. There is a dry season of 2–5 months duration from January to April, and the rainy season lasts for 7–9 months from May to December. Other climatic characteristics of the area are: mean wind velocity – 8 km/h; average relative humidity – 76–84%.

The soils of the area are mainly light in texture, shallow and stony (sometimes rocky) with slightly acidic to slightly alkaline reaction. Erosion is light to moderate; the topography is variable, slopes range from 5 to 20%, but there are also places with steeper slopes of 40–60%. Slope is the main limiting factor for using the land for agricultural systems other than coffee production.

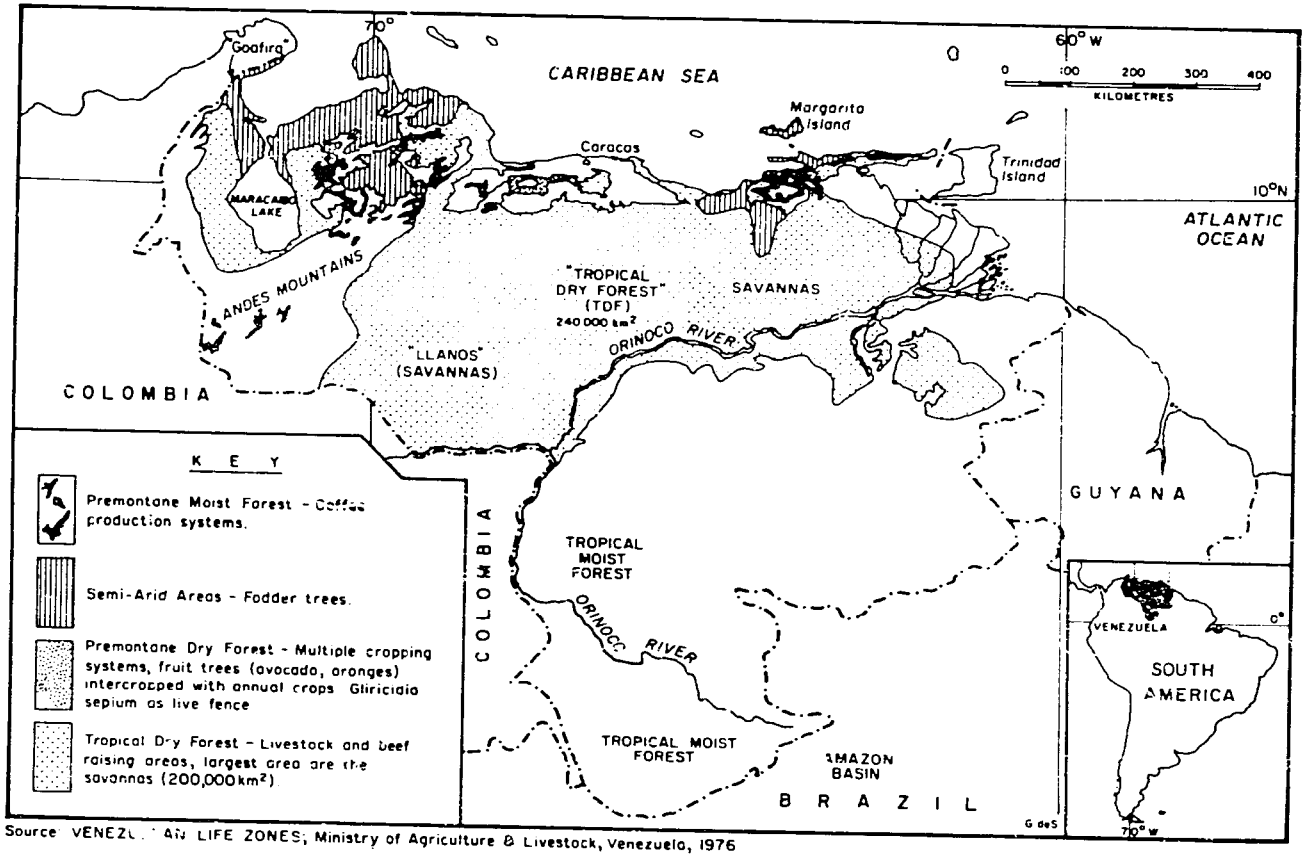
The other main agricultural systems of the area include:

- Pasture/cattle grazing – small farms in which grass productivity is low; with increasing erosion problems in areas with steep slopes;
- Shifting cultivation – smallholdings of 2–3 ha area are deforested to establish monocrops of subsistence crops such as maize, beans or cassava, but the yields decrease over time.

In steep areas in the State of Trujillo, there are some primary forests which have a three-to-four-layer canopy stratification. Frequently the highest layers reach 40–50 m in height. Some of the main species are "ceiba" – *Ceiba pentandra* (Bombacaceae), "muco" – *Couroupita guianensis* (Lecythidaceae), "sarrapia" – *Coumarouma punctata* (Papilionoideae), and "carapa" – *Carapa guianensis* (Meliaceae). Secondary forest consists of two layers, with dominance of leguminous trees; among them are "roble" – *Platymiscium polystachum* and "drago" – *Pterocarpus podocarpus*, and "saman" – *Samanea saman*. The non-leguminous tree species include "vera" – *Bulnesia arborea* (Zygophyllaceae), "mijao" – *Anacardium excelsum* (Anacardiaceae) and "Indio desnudo" – *Bursera simaruba* (Burseraceae).

2.2. *Structure of the system*

Coffee (*Coffea* spp.) is usually grown under trees that provide shade and fuelwood. Most of the big farmers use *Inga* spp. and *Erythrina* spp. as shade



Source: VENEZUELAN LIFE ZONES; Ministry of Agriculture & Livestock, Venezuela, 1976

Fig. 31.1. Map of Venezuela showing the major ecozones and the extent of major agroforestry systems.

trees. A large percentage of the farmers also use living trees as fences around coffee farms; the most common species so used are *Inga* spp., *Erythrina glauca*, *Erythrina poeppigiana* and *Syzygium malaccense* (Myrtaceae). Figures 31.2 and 31.3 show some of the typical coffee production units under the shade of various tree species.

Fig. 31.2. Coffee under the shade of "Bucare" (*Erythrina poeppigiana*).

Fig. 31.3. "Bucare" (*Erythrina poeppigiana*) and "Guamo" (*Inga* spp.) play an important role as live fences and shade in coffee production systems of the Venezuelan Andes.

The old, traditional plantations use the coffee variety "Tipica". The new, improved plantations use the varieties "Bourbon", "Caturra", "Mundo nuevo", and "Semper flores".

In the traditional smallholdings, coffee is intercropped with a diverse mixture of fruit species and timber trees. Over coffee, a 5–10 m high layer is formed by fruit species such as oranges and bananas. Other fruit trees and shade species form a third layer, 10–20 m high. The species include "aguacate" (avocado) (*Persea americana*), "guamo" (*Inga* spp.), and "bucare" (*Erythrina* spp.). The highest layer (20–30 m high) is composed of special timber species of exceptional value such as "cedro" (*Cedrela* spp.), "pardillo" (*Cordia alliodora*), "bucare remoso" (*Erythrina glauca*), "mijao" (*Anacardium excelsum*), and *Terminalia* spp.

Seeds and seedlings of coffee are obtained from agricultural agencies, however, most of the medium and small farmers raise the seedlings in their own nursery. Plant density is very variable; in old plantations, the range is from 4,000 to 12,000 plants per hectare, distributed sometimes in irregular patterns. In the new plantations, many of which receive technical advice, plant density is between 3,300 and 6,000 per hectare, with 1 m between plants on the row and 2–3 m between rows.

In the old plantations, shade trees are randomly distributed, and are usually not pruned. But in many new plantations that use *Inga* spp. and *Erythrina* spp. these shade trees are planted 8–10 m apart at a density of 100–150 trees/ha. Weed control is manual, with or without a machete. Only 20% of the farmers use chemical fertilizers.

The average yields of coffee in the four main coffee producing states are:

Tachira – 320–965 kg/ha
Marida – 140–370 kg/ha
Trujillo – 215–310 kg/ha, and
Barinas – 140 kg/ha.

In some exceptional areas or farms, yields of 1,500–2,000 kg/ha are obtained.

The average size of the management unit is 3–5 ha. In most of the production areas the range is from 0.5 ha to 100 ha; however, 90% of the production units are less than 10 ha.

An estimated 55,000 people are directly involved in and supported by the system. Most farms (over 70%) are owner cultivated. Other socio-economic features include a population growth rate of 2.8% per annum, an unemployment rate of 7–10%, and an estimated migration rate of 1.2% of the population leaving the region every year.

Marketing facilities are poor to fair; the small farmers who represent a large percentage of the producers have to sell their produce to intermediaries for lower prices. The remoteness of the area of production and the lack of good roads are the major bottlenecks.

Since 1936 there has been a programme to improve the traditional coffee farms by which farmers were given credit facilities and other forms of help. In the last 15 years, 20% of the area under coffee has been renewed or improved. The farms so improved have an average size of 4.6 ha. In general, it can be said that the programme is successful.

2.3. *System dynamics and evaluation*

The coffee production system was the mainstay of the Venezuelan economy until the beginning of the twentieth century. Since the oil economy started to grow, agricultural activities in Venezuela have declined and coffee has been no exception; big farms have disappeared and many became old plantations with low productivity. However, the system is still efficient and profitable in some places where technical advice is available and better technology adopted.

In the traditional diversified production system of the smallholdings, the farmers also get various other products such as fruits (bananas, avocados, oranges, inga fruits), timber, fuelwood, etc., which are used for home consumption and/or sale. Quantitative information on the production of these subsidiary products is not available.

This integrated production system enables the small farmer to meet many necessities of daily life from his own farm and to obtain cash income.

Ecologically, also, the system is a sound one. It has good potential in Venezuela. The country has 50,210 km^2 of premontane moist forest, representing 5.52% of the national area (Ewel *et al.* 1976). Shifting cultivation is the major land-use system in most of these areas. With proper planning and sound technical assistance it will be possible to bring thousands of hectares of these premontane forest lands under coffee production according to the agroforestry approach. This will provide thousands of small farmers with a sound and adoptable alternative to resource-depleting and under-productive shifting cultivation.

Concerted efforts are needed on the research side to improve the system. Some experimental stations such as "El Laurel" (Central University of Venezuela) and "Bramon" (National Fund of Agricultural and Livestock Research), and a few others, are currently undertaking research in coffee production systems. But most of this research is on coffee varietal production with very little on shade trees or other associated species. Future efforts should concentrate on all aspects of the interrelationships among the different components in order to improve the overall productivity of the system.

3. Silvopastoral systems

The main livestock-raising areas of the country are located in the savannas ("Llanos"), a region classified as "tropical dry forest" according to Holdridge's classification. The tropical dry forest, with a total area of 342,660 km^2 is the most extensive life zone of the country. This includes about 90% of the savannas, which represents around 20 million hectares. Other important regions of animal production are located at the southern parts of the Maracaibo Lake (Zulia State), and many fertile valleys and small plains in different zones of the country. In all these pasture lands several species of trees play an important role providing the animals with not only shade and shelter but also feed (foliage and fruits). At times the fruit are even more valuable than foliage due to their high protein content.

3.1. *General description of the area*

General climatic conditions of the area are as follows: altitude: 0–1,000 m above sea level; average annual rainfall: 1,000–1,800 mm; average annual temperature: 22–29 C; the rainfall is almost always lower than the annual potential evapotranspiration with PET/RF ratios ranging from 1.0 to 2.0; there are four to six months of severe drought (Ewel *et al.* 1976).

This zone consists mainly of the big plains of the savannas. The soil types vary greatly: they are mostly acid laterites, but there are also very recent alluvial soils, for example in some valleys of the northern rivers.

Vegetation

Floristically the tropical dry forest is an extensive formation with three distinct vegetation forms: primary forest or climax vegetation, secondary forest and savanna. The climax vegetation produces high-value timber and is found on the alluvial soils in the north of Barinas State and the central parts of Portuguesa State. The climax forest has three layers, up to 35 m in height; most of the species are deciduous, with a high vertical density. In alluvial soils some trees have a breast-height diameter (DBH) of 150 cm and a basal area of more than 100 m^2 per ha (Ewel *et al.* 1976). The dominant species of trees include "caoba", *Swietenia macrophylla* (Meliaceae); "cedro amargo", *Cedrela odorata* (Meliaceae); "apamate", *Tabebuia pentaphylla* (Bignoniaceae); "geteado", *Astronium graveolens* (Anacardiaceae); "betun", *Calicophyllum candidissimum* (Rubiaceae); "trompillo", *Guarea trichiliodes* (Meliaceae) and "palo de mora", *Chlorophora tinctoria* (Moraceae).

The secondary forests are more common than the climax forest; they are the result of forest exploitation or fires, but more frequently are the consequence of intensive agricultural activity, which is why the soils have eroded and lost fertility. Depending on the age of development, these forests can have one, two or three layers; some trees reach 30 m in height. Most of the species are deciduous. Trees with a wide canopy are typical in this formation, such as "saman", *Samanea saman*; "capaiba", *Copaifera officinalis*; and "caro", *Enterolobium cyclocarpum*, which are all legumes. Saman is widely used as shade, shelter or for the pods which have a crude protein content of about 15% (Armas and Chicco 1978; French and Chaparro 1963). It is generally found in places with good alluvial soils, high fertility and good drainage; it is very common in the savannas and valleys of Aragua, Carabobo, Yaracuy, Miranda and Anzoategui States, and in the south-eastern part of the Maracaibo Lake. Figure 31.4 shows saman trees over pastures in Aragua valley.

Other common tree species in the secondary forest are "yagrumo", *Cecropia peltata* (Moraceae); "jobo", *Spondia mombin* (Anacardiaceae); "ceiba", *Ceiba pentandra* (Bombacaceae); "camoruco", *Sterculia apetala* (Sterculiaceae); "guacimo", *Guazuma ulmifolia* (Sterculiaceae); "roble", *Platymiscium polystachum* (Leguminosae); "indio desnudo", *Bursera simaruba* (Burseraceae); and "habillo", *Hura crepitans* (Euphorbiaceae).

The third type of vegetation common in tropical dry forest is the savannas. There are three types of savanna, one dominated by *Trachypogon* spp., the second by *Paspalum fascilatum*, and the third has a mixture of numerous graminaceous species. The first two are characterized by the floristic composition and the third by topography and drainage. The savannas are usually burned each year and only a few species of trees survive the fire, such as the "curata", *Curatella americana*, "alcornogue", *Bowdichia virgiloides*, "chaparro", *Byrsonima crassifolia* and "carne asada" *Roupala complicata*.

Fig. 31.4. "Saman" (*Samanea saman*) in pastures in the tropical dry forest zone, Aragua valley.

Crude protein values of the fruits of some species of trees and shrubs found in the cattle growing areas of Venezuela are given in Table 31.1.

3.2. *The major types of system*

In the semi-arid parts of Venezuela, there are three life zones where fodder trees are very important as components of silvopastoral systems. These are the shrub desert, the thorny mount and the very dry forest.

The shrub desert is the driest zone of the country spread over 270 km^2 in the Margarita island of the Nueva Esparta State and in the "Goajira" in the northern part of Zulia State. The altitude of the region is 0–100 m above sea level. It receives an average annual precipitation of 125–250 mm, and has an average annual temperature range of 26–28 C. The potential evapotranspiration is 8–16 times greater than precipitation. The landscape is rocky although the topography is generally flat. Primary vegetation does not exist because in many parts it has been exposed to great overgrazing. Its main flora are "cuji" species such as *Prosopis juliflora* and *Popona* sp. and "yabo", *Cercidium praecox*. The only economic activity of the zone is goat grazing (Ewel *et al.* 1976).

The thorny mount is located mainly on the western coast of the country in Falcon State and also on the islands of Margarita of the Nueva Esparta State. It covers 9,333 km^2 at an altitude of 0–200 m a.s.l. The mean annual precipitation is 250–500 mm and the mean annual temperature 24–26 C.

Table 31.1. Crude protein values of fruits and seeds of some trees and shrubs of the cattle region of Venezuela.

Common (local) name	Scientific name	CP (%)
Caro	*Enterolobium cyclocarpum*	19.50
Jabillo	*Hura crepitans*	19.12
Cuji blanco	*Prosopis juliflora*	19.10–15.18
Tiamo	*Acacia glomerosa*	14.40
Saman, Lara	*Samanea saman*	13.54
Cuji negro	*Propanax flexuosa*	13.30
Higuera	*Ficus carica*	13.20
Guatacaro	*Beureria cumanensis*	12.20
Palo blanco	*Casearia decandra*	11.63
Canafistola	*Cassia moschata*	9.99
Guacimo	*Guazuma ulmifolia*	6.69–8.84
Algarrobo	*Hymenaea courbaril*	8.8
Tamarindo	*Tamarindus indica*	7.26
Merey	*Anacardium occidentale*	6.85
Corozo	*Acrocomia sclerocarpa*	4.32

Source: French and Chaparro (1963).

Potential evapotranspiration is 1,800 mm, which is 4–8 times greater than precipitation, with nine very dry months per year. The soils belong to the large group of Aridisols, and are highly eroded. However, the soils of the Tocuyo and Baragua valleys in Lara State are alluvial and more suitable for agricultural activity. The most common species are trees that belong to the *Cercidium*, *Prosopis*, *Pithecolobium* and *Capparis* genera. Some species seem to have been eliminated by goat overgrazing which is the main land use of the zone. The most representative species of the vegetation are "yabo", *Cercidium praecox* (Leguminosae), "yacure", *Pithecolobium unguiscati* (Leguminosae), "guasabara", *Opuntia caribaea* (Cactaceae), and "olivo", *Capparis odoratissima* (Capparidaceae). The average number of trees is 28 per ha with more than 20 cm DBH and an average height of 4.9 m. The inhabitants of the zone use some species as fuelwood and for the production of charcoal and tannin. Some cactaceous fruits, such as the fruits of "cardon de dato", *Lemairecereus griseus*, are eaten by people and goats (Ewel *et al.* 1976).

The very dry forest zone covers 26,630 km^2, mostly in the northern part of the country in the Falcon, Zulia and Anzoategui States. Its main climatic characteristics are an altitudinal range of 0–600 m above sea level; average rainfall 500–1,000 mm; average annual temperature 24–29°C, and potential evapotranspiration 1,600 mm. Because of the relatively high intensity of precipitation, soil erosion is a common problem. There are only five months of effective moisture, from July to November. The soil belongs to the large soil groups "red chestnut" and "desertic". In some places the climax vegetation has two layers 8–18 m high, the most representative trees being "gatillo",

Capparis linearis (Capparidacea), "vera", *Bulnesia arborea* (Zygophyllaceae), and others of the genera *Platymiscium*, *Pithecolobium* and *Tabebuia*. The secondary vegetation in this zone takes a long time to develop a closed canopy because of four factors, namely fire, goat grazing, erosion and the selective exploitation of some species for fuelwood and posts. The erosion problem is closely related to fire and goat overgrazing. The main land use of the area is silvopastoralism for goats, sheep and beef cattle. Forestry products are also obtained: the main timber species include "vera", *Bulnesia arborea*; "granadillo", *Caesalpinia granadillo*; and "roble", *Platymiscium pinnatum*; whereas "cuji", *Prosopis juliflora*, *Poponax* sp., "Curari", *Tabebuia billbergii* and *Tabebuia serratiflora* are the preferred fuelwood species. From the research carried out in the semi-arid zones of Lara and Falcon States (Garcia *et al.* 1981; Garcia and Bravo 1981), it has been reported that there exist a good number of species with a high nutritional value (see Tables 31.2 and 31.3). However, the main problem is their availability because 91% of the species are arboreal so that the animals must wait until the fruits, leaves and flowers fall. It has also been observed that some species are fast approaching extinction as a consequence of goat grazing. In course of time the dominant, if not the surviving, species will be the thorny and less palatable ones (e.g., "tuna de cabra" *Opuntia schumannii*, which is very thorny, and "carcanapire" *Croton rhamnifolius*, which is highly toxic to animals).

3.3. *Evaluation*

The principal merit of the presence of trees and shrubs in the savannas and semi-arid zones is that the animals can feed on their leaves, fruit and flowers

Table 31.2. Crude and digestible protein values of different parts of some species consumed by goats in the semi-arid zones of Falcon State.

Common (local) name	Scientific name	Part of plant	CP %	DP%
Yabo	*Cercidium praecox*	Flowers	27.6	23.06
Olivo	*Capparis odoratissima*	Leaves	16.3	11.74
Vera	*Bulnesia arborea*	Leaves	8.8	4.24
Dividive	*Caesalpinia coriaria*	Leaves	12.5	7.94
Cuajaro	*Cor dentata*	Leaves	15.1	10.04
Curari	*Tabebuia billbergii*	Leaves	18.1	13.54
Caudero	*Mimosa tenuiflora*	Pods	15.8	11.24
Cardon de dato	*Lemairecereus griseus*	Bark	7.7	—
Yacure	*Pithecolobium unguiscati*	Leaves	17.4	12.84
Jebe	*Lonchocarpus atropurpureus*	Leaves	21.0	16.44
Cuji	*Prosopis juliflora*	Pods	10.8	6.24

Source: Garcia *et al.* (1981).

Table 31.3. Crude protein content of plant parts of some species consumed by goats in the semi-arid zones of Lara State.

Common (Local) name	Scientific name	Part of plant	CP %
Vera	*Bulnesia arborea*	Leaves	15.6
		Fruits	22.2
Platanico	*Cassia fruticosa*	Leaves	17.9
Yabo	*Cercidium praecox*	Flowers	30.0
Curari	*Tabebuia billbergii*	Fruits	17.1
		Flowers	24.5
		Leaves	15.0
Caudero	*Mimosa tenuiflora*	Pods	22.3
Olivo	*Capparis odoratissima*	Leaves	24.5
Yacure	*Pithecolobium unguiscati*	Leaves	17.2

Source: Garcia and Bravo (1981).

in times of scarcity of pasture or forage. In arid and semi-arid zones, forage trees and shrubs practically sustain the few cattle in the area in the virtual absence of pasture or forage. Another important aspect is the availability of shade or shelter provided by these trees, which is important in the extreme heat in the savannas or in the desert environments. Fortunately, many producers and cattle raisers know the advantages provided by these trees and shrubs and try to keep them in the pasture areas. However, the practice lacks technical knowledge. For example, it has frequently been observed that small trees are eliminated in the process of pasture maintenance. When bush control is carried out with a rotary plough or roller, the small trees are cut or broken at the base, thus impeding good natural regeneration. Thus, when the large trees die or are cut and removed, the density of vegetation diminishes. Moreover, in many regions, the introduction of artificial pastures substituting the natural ones has caused the elimination of many trees on the grounds that their presence is an obstacle to pasture maintenance.

Obviously a great deal of research needs to be undertaken on all these aspects. The highest priority is to undertake a general survey in the entire country and for each life zone to identify the most important and promising species. Following this, more specific work could be started on particular species that are good for food and wood supply. Some species such as *Samanea saman*, *Gliricidia sepium* and *Cordia alliodora* are already known to be valuable in this respect and their usefulness demonstrated in the cattle-grazing zones of the country. Support of international aid agencies and technical organizations is needed to strengthen the national capability in this regard.

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Part 6

Productive and protective role of agroforestry

32. Food-producing trees in agroforestry systems

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Most of the agroforestry practices listed in Chapters 5 and 6 and the systems described in Parts 3, 4 and 5 are currently being adopted in "agricultural lands", or in transitional zones between farmlands and forests; but some are also in forest lands. The primary function of most of these practices and systems is food production, either directly (producing edible products) or indirectly (facilitating enhanced and/or sustained food production). The role and extent of contribution by trees to food production through major agroforestry systems and practices will be examined here.

1. Homegardens

The word "homegarden" has been used rather loosely to denote diverse practices from growing vegetables behind houses to complex multistoreyed systems. Numerous terms have been used by various authors to denote these practices. These include, for example, mixed-garden horticulture (Terra 1954), mixed garden or house garden (Stoler 1975), home-garden (Ramsay and Wiersum 1976), Javanese homegarden (Soemarwoto *et al.* 1976), compound farm (Lagemann 1977; Okafor and Fernandes 1987), kitchen garden (Brierley 1985), household garden (Vasey 1985), homestead agroforestry (Nair and Sreedharan 1986; Leuschner and Khalique 1987), and so on. Various forms of Javanese homegardens dominate in most of the writings on the topic so that the Javanese words "pekarangan" and "talun-kebun" are often used interchangeably with the word homegarden. In an analysis of the structure and function of some tropical homegardens, Fernandes and Nair (1986) defined homegardens as "land-use practices involving deliberate management of multipurpose trees and shrubs in intimate association with annual and perennial agricultural crops and invariably livestock within the compounds of individual houses, the whole crop-tree-animal unit being intensively managed by family labour".

The Javanese homegardens are usually cited as an excellent example to show the diversity and complexity of the structure and function of tropical homegardens. However, it is important to point out that there are also several other types of homegardens in other geographical locations, each with its own characteristic features. In fact, homegardens can be found in almost all tropical and sub-tropical ecozones where subsistence land-use systems

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predominate. The structural compositions of some homegardens have been presented schematically elsewhere in this book (e.g., Figs. 16.6, 16.7, 20.3 and 25.4).

Homegardens display many agroforestry concepts: the intimate mix of diversified agricultural crops and multipurpose trees fulfils most of the fundamental needs of the local populations, and their multistoreyed configuration and high species diversity avoid the environmental deterioration commonly associated with monocultural production systems. Moreover, they have been producing sustained yields for centuries in a most resource-efficient way. Thus homegardens are economically efficient, ecologically sound and biologically sustainable agroforestry systems. According to the classification of agroforestry systems based on the nature and type of components (Nair 1985; Chapter 4), most homegardens are agrosilvopastoral systems consisting of herbaceous crops, woody perennials and animals; some are agrisilvicultural systems consisting of the first two groups of these components only.

As said earlier, homegardens are found in most ecological regions of the tropics and sub-tropics, but a majority of them are in the lowland humid tropics. Similarly, except in some cases (e.g., the Ka/Fuyo gardens of semi-arid Burkina Fasso and the homegardens in the Pacific Islands), the population density is generally high in most homegarden areas, and the average size of a homegarden management unit is less than one hectare (thus indicating the subsistence nature of the practice).

Although the choice of species is determined to a large extent by environmental and socio-economic factors, as well as dietary habits and market demands of the locality, there is a remarkable similarity with respect to species composition among different homegardens in various places.

A conspicuous character of the woody components of the homegardens is the predominance of fruit trees and other food-producing trees. Apart from providing a steady supply of various types of edible products, these fruit-and-food trees also combine well – biologically and environmentally – with other components of the system (Nair 1984). While the fruit trees such as guava, rambutan, mango and mangosteen, along with other food-producing trees such as *Moringa* sp. and *Sesbania grandiflora*, dominate the Asian homegardens, indigenous trees that produce leafy vegetables (*Pterocarpus* spp.), fruit for cooking (*Dacroydes edulis*), condiment (*Pentaclethra macrophylla*), and so on, dominate the West African compound farms. A schematic presentation of the interactions among the different components of homegardens in Kerala was proposed by Nair and Sreedharan (1986) (Chapter 10, Fig. 10.2).

The various food crops from the homegardens may provide a substantial proportion of the calorific and nutritive requirement of the local diet. For example, Terra (1954) and Stoler (1975) reported that the Javanese

homegardens provided more than 40% of the total calorific requirement of the local farming communities.

It has also been recognized that homegardens are an important source of nutrients. Covich and Nickerson (1966) reported that consumption of 100 g each of *Minilkara sapotilla*, *Persea americana*, *Manihot esculenta* and *Guilielma utilis* grown in Choco Indian dwelling clearings in Darien, Panama, was equivalent to approximately 10, 12, 150, 15.5, 31, 25 and 113% of the minimum daily requirement of protein, calcium, carotene, thiamine, riboflavin, niacin and ascorbic acid, respectively. Homegardens in villages in Lawang, East Java, produced a daily average of 398.4 calories, 22.8 g protein, 16.4 g fat, 185 g carbohydrate, 818.4 mg calcium, 555 mg phosphorus, 14 mg iron, 8,362 IU vitamin A, 1,181.2 mg vitamin B and 305 mg vitamin C (Haryadi 1975). Soemarwoto and co-workers have found that rice fields gave higher yields of protein and calories than homegardens, but more calcium, vitamin A and vitamin C were obtained from homegardens than from rice fields (Soemarwoto 1987).

Similarly, from a survey of 40 households of the Philippines homegardens, Sommers (1978) found that nearly all the households could meet the recommended daily requirement for Vitamin A, Vitamin C, iron and calcium; over half could obtain a sizeable contribution towards their thiamine, riboflavin and niacin requirements; and one in four households could meet their protein and energy requirements with the outputs and resources from the homegardens. Okafor (1981) reported from an analysis of the edible parts (fruits, seeds, nuts) of some trees in the compound farms in south-eastern Nigeria that most of them contained substantial quantities of fat and protein. He found that seeds of *Irvingia gabonensis*, nuts of *Tetracarpidium conophorum* and fruit pulp of *Dacroydes edulis* are rich in fat (44–72%), whereas nuts of *T. conophorum* and *Pentaclethra macrophylla* contain large quantities of protein (15–47%).

Food production is, thus, the primary function and role of most if not all of the homegardens and a large proportion of the production from homegardens is consumed by the gardeners themselves. The Chagga homegardens, where arabica coffee is the dominant crop, are perhaps the only exception. Even in that case, the system evolved as a subsistence food production system and it remained so until coffee was introduced as a commercial component by the European settlers around the year 1890. However, the system has not lost its food-production objective because the farmers maintain a careful balance between coffee and food crops (banana, vegetables and tubers) and switch over from one to the other depending upon the market price of coffee and demand for food.

Another aspect of the role of food production in homegardens is the maintenance of almost continuous production throughout the year. The combination of crops with different production cycles and rhythms is such

that an uninterrupted supply of food products is maintained. Depending upon the climate and other environmental factors, there may be some peak and slack seasons for harvesting the various products, but in general there is something to harvest daily from most homegardens. Most of this production is for home consumption, but any marketable surplus can provide a safeguard against crop failure as well as a security for the interval between the harvests of other agricultural crops of the homegardens (rice in Java and Sri Lanka, coffee and maize in Tanzania, coconut and rice in S.W. India, and so on). All these harvesting and other upkeep operations require only a relatively small amount of working time from the members of the family.

2. Multistorey tree gardens

These are mixed tree plantations consisting of forest species and commercial tree crops, forming a forest-like system. As opposed to homegardens, which surround individual houses, these tree gardens are usually away from houses, and are mostly on communally owned lands surrounding villages which consist of a dense cluster of houses, as in Indonesia (Java and Sumatra). Depending upon the characteristics and conditions of the places where the systems are practised, various forms of tree garden systems can be found. Most important among these are:

- tree gardens (*kebun* or *talun*) of Java (Wiersum 1982) and agroforest garden system of Sumatra (Michon *et al.* 1986; Chapter 16);
- compound farms (gardens) of south-eastern Nigeria (Okafor and Fernandes 1987; Chapter 25);
- Kandyan forest gardens of Sri Lanka (Jacob and Alles 1987; Chapter 12);
- crop combinations with cacao and other plantation crops in south-east Bahia, Brazil (Alvim and Nair 1986; Chapter 30).

Many characteristics and functions of all these tree-gardening systems are often similar, although their relative importance may change from one system to another. Wiersum (1982) lists the following common characteristics of tree gardens:

1. The tree gardens are characterized by a large variety of mostly multipurpose plants in various vegetation layers (and sometimes animals, e.g., chickens, etc.), which provide for a good utilization of environmental factors like water, nutrients and sunlight. This variety ensures a varied production of different materials throughout the year.
2. Most of the systems are dominated by perennial rather than annual crops, resulting in a relatively high ratio of nutrients stored in the vegetation to

those stored in the soil. This ensures an effective nutrient cycle and relatively small leaching and erosion hazard. An effective nutrient status is further maintained by the uptake of minerals through deeply rooted perennials from deeper soil layers and effective catchment of mineral inputs by rain and by nitrogen fixation of leguminous species.

3. The tree gardens are only part-systems: mostly they form a part of a whole farm system, which also comprises annually cultivated fields. Normally, the latter are used to produce staple, high calorific food stuffs (rice, maize, cassava), while the tree gardens are used to produce supplementary products with high nutritive value (proteins, vitamins, minerals), medicinal plants and spices, firewood, and sometimes also forage crops and construction wood.
4. Normally, the tree gardens are used to produce a small, continuous flow of these supplementary products for subsistence and a possible small surplus for sale to local markets. In time of sudden necessity (unfavourable climatic conditions or social necessities) higher production and marketing levels may be attained.
5. Although the general cultivation practices are somewhat standardized, important regional and individual variations in tree gardens occur. These variations occur in response to various factors like climate and soil, as well as socio-economic conditions.

The role of these tree gardens in food production will depend upon their species composition. In general, it is not as significant as that of homegardens. However, in most tree gardens, fruit trees are important components and are exploited for their fruits. Table 16.2 gives a list of common fruit trees in the "agroforest tree gardens" of western Sumatra (Michon *et al.* 1986; Chapter 16) and Table 25.1 gives the food-producing woody species in the compound gardens of south-eastern Nigeria (Okafor and Fernandes 1987; Chapter 25).

In most cases, the important value of the tree gardens is their contribution to the general cash economy of the farmers through the sale of various (mostly non-edible) commercial products. Table 16.3, based on the study of Michon *et al.* (1986) lists the value of agroforest tree gardens in two villages in Maninjau in West Sumatra.

The tree gardens have potential utility as efficient buffer zones around protected forests. It is possible to develop interesting practices and strategies for integration of forest resources into the tree-garden structure through incorporation of forest species and protection of natural components. Similarly, growing cash crops under the canopies of useful trees, similar to the system in south-east Bahia, Brazil (Alvim and Nair 1986; Chapter 30) has good extrapolatability to many areas, subject to climatic and socio-economic limitations. The most significant contribution of tree gardens to food production will, however, be derived from the exploitation of the vast variety of fruit trees.

3. Fruit trees

Various fruit- and nut-producing trees and shrubs are important components of many agroforestry systems and they make substantial contributions to the dietary needs of large numbers of people. Examining the biological and socio-economic attributes of fruit trees and their role in agroforestry systems, Nair (1984) noted that while some of these fruit trees are widely distributed in different geographical regions (e.g., mango, papaya), some others are highly localized and found only in certain specific geographic regions (e.g., rambutan – *Nephelium lappaceum* – in south-east Asia; pejibaye palm – *Bactris gassipaes* – in Central and South America). Lists of such localized fruit trees that occur in tree-garden systems in Sumatra (Indonesia) and Nigeria have been given in Chapters 16 and 25 (Tables 16.2 and 25.1, respectively).

Although most of these fruit trees are also eminent multipurpose species, they are seldom harvested for non-edible vegetative parts such as fuelwood, fodder and green manure (unlike most other woody components of agroforestry systems). However, fruit trees have a distinct advantage over other woody species in that they can be harvested periodically and/or in a staggered manner, and thus be a source of cash income (in addition to food) to the farmer. Because of the location specificity of these socio-economic values and benefits and their strong links with the prevailing social habits of the locality, these values cannot be precisely assessed and expressed in quantitative terms.

4. Other indigenous food- and fruit-producing trees

Food- and fruit-producing trees that are commonly found in "managed" agroforestry systems, most of which are included in Table 32.2, have received some – in some cases substantial – attention. But in many developing countries, rural populations derive a significant part of their food and energy requirements from various indigenous trees and shrubs which are seldom "cultivated". Many such species occur naturally in forest environments which are under pressure to yield land for agriculture. Therefore, the variety and value of food and food products that are derived from such trees are not often appreciated, nor are any efforts made towards "domestication", improvement through breeding and better exploitation of the potential of the species.

Evaluating this situation in Africa, von Maydell (1987) stated that the contribution of agroforestry to food production is generally not statistically recorded for a variety of reasons. For example, the significance of the phrase "food from trees, shrubs and palms" is not fully understood. These sources are important in quantity as well as in quality in being in seasonal

complementarity with agricultural crops and animal products and as emergency supplies in times of drought, as well as part of the regular diet. The latter becomes evident from what is offered at local markets, although this is only a small fraction of what is consumed overall. Moreover, most of these foodstuffs are obtained from "no-man's land", i.e., public lands, free of charge and usually require only a small labour input, mainly by women and children. This social aspect of tree food must not be overlooked.

Potential food production from trees and shrubs in northern Senegal (Ferlo) and northern Kenya (Turkana, Samburu) has been analysed by Becker (1984). Her results can be summarized as follows: the annual harvestable production of leaves and fruits amounts to about 150 kg per ha in the Saharo-Sahel, 300 kg per ha in the typical Sahel and 600 kg per ha in the Sudano-Sahel. This corresponds with the rule of thumb, derived from various observations in the West African Sahel, that in "normal" ecosystems the annual increment of non-woody biomass from trees, shrubs and palms in kilograms per hectare roughly equals the average rainfall in millimetres. Results from East and West Africa indicate that about 15% of that biomass can be classified as edible. Thus, in the above three ecological zones 23, 45 and 90 kg, respectively, of edible material would be available per hectare annually. Correlating these figures with an average population density of 1 per sq km, and assuming a ratio of 4:1 for leaves and fruits, 450–1,800 kg of edible tree/shrub fruit could be utilized per caput, which corresponds to 1.25–5.0 kg fruit per adult human being daily.

In the Ferlo, Senegal, an inventory of baobab (*Adansonia digitata*) was made in a typical area in a German-Senegalese rural development project. The results showed 6,611 baobab trees and 1,200 people lived on 20 sq km, i.e., 5.5 trees per caput. The leaves of these trees are intensively used as a green vegetable and dried as a powder and have a remarkable nutrient content: 100 g of fresh leaves contain 23 g dry matter, 3.8 g crude protein, 700 mg calcium and 50 mg ascorbic acid. They provide 69 calories. Even more valuable is the fruit pulp which is rich in vitamin B_1 and C, and the flour produced from the seeds contains up to 48% protein and 2% vitamin B_1 on a dry-weight basis.

This is only one example demonstrating the potential food production of woody perennials growing on agricultural and/or pastoral lands in the Sahel. From the many species available, merely a fraction are used for food, and, in normal times, people tend to be very selective about species, varieties and parts consumed. Plants used by one group of people in one region may not be accepted by other groups in the same region or the same ethnic group in a different region. Moreover, there are pronounced differences in the quality of food, depending on varieties or provenances. *Adansonia digitata* may again be cited as an example. There are trees with soft and tasty leaves and others with fibrous and bitter leaves. As no cultivation has been practised with these local species, selection and breeding have not yet started but may offer a hitherto

unknown potential for improvement. This should be tried with at least 30 food-tree species in the various parts of dry Africa.

Recent publications from FAO (FAO/SIDA 1982; FAO 1983a, b, 1984, 1986a, b) have brought out information on various food and fruit-bearing "forest" species in different parts of the tropics. Some of these are relatively better known "fruit trees" described in Table 32.2. But the majority of these species are quite restricted in their distribution and are virtually unknown outside their usual habitat. Since the above-mentioned FAO publications cover them in detail, a listing of these species is not attempted here.

Another recent FAO study on "Forest as a Source of Food: India, Malaysia and Thailand" (FAO 1983a) reports that a large number of species of plants and animals are utilized by forest-dwelling communities as a sole means of sustenance. For example, the Jarawas, Sentinelese and the Onges of the Andaman Islands and the Kurumbas of Kerala in India still depend entirely on wild animals and plants for their food as they have practically no contact with the outside world. Depending on the season, they gather tubers, berries, leaves and shoots of a large number of higher plants, mushrooms, mammals, reptiles, fish, birds and honey for their food.

Additionally there are also several "emergency food plants" that are not usually eaten, but are consumed as food at times of natural calamities which result in failure of common food crops. These include:

(i) rhizomes, tubers and roots;
(ii) leaves, flower stalks, flowers;
(iii) fruits and seeds of trees and shrubs;
(iv) grains of grasses, bamboos and reeds;
(v) barks and starchy pith of stems; and
(vi) resinous and gummy exudates.

About 150 species, representing nearly one-fifth of the number of species consumed as food, have been identified as sources of emergency food at times of natural calamities which result in failure of food crops. The kernels of *Aesculus indica* and *Shorea robusta*, and bark of *Acacia arabica*, *A. leucocephala*, *Bombax ceiba*, *Ehretia laevis* and *Prema mucronata* are actually ground into fine flour to make traditional *chapati* (normally made out of wheat or rice flour). The tubers and other underground parts of plants like *Arisaema concinnum*, *Dioscorea* spp. easily take the place of potatoes and other tuberous crops. The grains of several species of grasses, particularly bamboos, contribute to the bulk of the food in such periods of scarcity. The earlier-mentioned FAO study (FAO 1983a) lists about 700 such species that are used as "emergency food services". Whitmore (1975), from his studies in India, Malaysia and Thailand, recognized that these species with food value fall into the following categories in these three countries:

1. Species which are entirely wild and are gathered for local consumption or trade:

   - *Knema attenuata* (India)
   - *Syzygium cuminii* (India)
   - *Elateriospermum tapos* (Malaysia)
   - *Minusops elangi* (Thailand)

2. Species which occur in the wild and also in cultivation, but without improvement:

   - *Emblica officinalis* (India)
   - *Parkia* spp. (Malaysia)
   - *Morinda citrifolia* (Thailand)

3. Species cultivated in improved varieties but whose wild relatives are still popular and are gathered:

   - *Artocarpus heterophyllus* (India, Malaysia and Thailand)
   - *Mangifera* spp. (India, Malaysia and Thailand)

4. Species mostly known in cultivation but whose wild relatives also exist in particular localities:

   - *Areca catechu* (India)
   - *Garcinia mangostana* (India, Malaysia and Thailand).

An important and sustained contribution to human food is made by the first two categories. The contribution of the last two categories is limited and often restricted to "tribal" communities within the forest as others have easy access to produce from cultivated sources.

It may be pointed out here that these lesser-known (if not unknown) species of food plants do not form components of any agroforestry systems. For example, ICRAF"s agroforestry systems inventory does not record "systems" that contain such species because they are not components of any definable systems or practices, nor are data available on their production, availability, gathering and marketing. Yet these are species on which some isolated communities depend wholly or partly for their sustenance, and food scientists and forestry/agroforestry experts ought to take due note of them.

The exploitation of these food-producing indigenous tree species, no matter whether they are domesticated, semi-wild or wild has wide implications not only for the nutritional status of the local population, but also in conservation of natural gene resources as well as their adaptation to present and future human needs.

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33. Tree-fodder and silvopastoral systems*

F. TORRES

Various fodder trees play an important role in human food security through their function as animal-feed sources, especially as drought reserves. Agroforestry systems consisting of such trees and animals and/or pasture are called silvopastoral systems (Nair 1985; Chapter 4). Extensive silvopastoral systems consist of browsing or grazing systems, and the discussion here is restricted to the former where the trees play a more direct role.

1. Browsing systems

Browse has been defined as the "shoots or sprouts, especially tender twigs and stems of woody plants with their leaves, which are cropped to a varying extent by domestic and wild animals" (Torres 1983). However, the term can be broadened to include fruits or pods, which can be more valuable than foliage, particularly if the woody component happens to be a deciduous one.

Gray (1970) highlighted the role of browse plants as drought reserves and their feeding value as sources of protein-rich fodder. The use of fodder trees mainly as drought reserves has been emphasized by Moore (1972). A comprehensive discussion on the role of browse in the management of natural grazing lands, including the importance of fodder "trubs" (trees and shrubs) in different ecological zones and the potential of some components (*Opuntia* sp., *Atriplex* sp., etc.) has been presented by Le Houérou (1980), who postulated that technologies based on permanent feed supply from fodder trubs could transform pastoral production systems into settled agropastoral ones. An extensive review by Ibrahim (1981) presents one of the most comprehensive listing of references (175) on factors affecting dry-matter yield, palatability, nutritive value and utilization of fodder trubs, including recommendations for further research and development on fodder trees and shrubs. The role of woody components in animal production has also been discussed by Felker (1980), and McKell and Malechek (1980). Robinson (1985) reviewed the role of trees as fodder crops and highlighted the problems involved as well as research needs for developing successful systems to integrate fodder trees on farmlands and rangelands. The importance of indigenous shrubs and trees in the silvopastoral systems of Africa was evaluated, and the problems involved in managing them for sustained production discussed by Le Houérou (1987).

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* Adapted from Torres, F. (1983). The role of woody perennials in animal agroforestry. *Agroforestry Systems* 2: 131–163.

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The review of Torres (1983) on the role of trubs in animal agroforestry outlines the various issues of relevance to the context here, and the salient aspects of that review are reproduced here.

2. Trub species

Probably as a reflection of their importance in rangeland management, African fodder trubs have been described in several papers. Touzeau (1973) described 42 species belonging to 15 families for the Sahelian zone. That description included not only botanical and ecological characteristics but also distribution and utilization. Kadambi (1963) made a selection of 10 fodder trees for the different ecological zones of Ghana, based on their agronomic and forage characteristics. Predominant browse plants in the East African highlands are described by Dougall and Bogdan (1958) with emphasis on their use, including chemical composition. A list of the main browse plants in the Sudanian zone of West Africa is given by Toutain (1980).

For the southern part of Africa, Jurriaanse (1973) described six species useful to humid and arid areas, but concluded that they had not reached a development stage making them worth propagating for economic fodder production. For the more arid areas (100–500 mm rainfall), however, Kock (1967) suggested that *Opuntia* sp. and *Atriplex nummularia* could play an important role in limiting fodder shortages during droughts.

A pioneer work on fodder trees and shrubs of Australia is the one by Everist (1969), including more than 100 species. Seventeen important fodder trub species for the arid grazing country in western New South Wales were described by Stannard and Condon (1968), who visualized their contribution essentially as drought reserves and to prevent soil erosion caused by wind. Carob, mesquite and honey locust were proposed by Eardley (1945) for south Australia. The agronomic characteristics and uses of the widely distributed genus *Leucaena* is described by Brewbaker (1987).

From the Americas the most relevant genus seems to be *Prosopis*, whose potential has been reviewed by Felker (1979). He concluded that pod yield could go up to 10,000 kg ha^{-1} and that selection could be developed for various ecological niches and uses.

In spite of the widespread use of fodder trubs in the Indian subcontinent, the literature describing useful species is not that abundant. Sharma (1977) briefly characterized more than 30 winter and summer fodder trees of Hichachal Pradesh according to their palatability. A thesis by Panday (1975) presented a systematic list of fodder trubs in the Sindhupalchok District of Nepal, as well as observations and comments on their occurrences and propagation, production and utilization practices. After concluding that trub leaves made up the bulk of the green fodder available during the dry season,

he proposed a selection criterion on the basis of chemical composition and farmers' observations. Mann (1981) has described the salient features of *Prosopis cineraria*, the "wonder" tree of arid N.W. India, used by the local population as a source of fuelwood and fodder and to improve soil fertility.

A comprehensive list of leguminous browse species for the tropics can be found in the book by Skerman (1977), and it is complemented by the paper by Felker and Bandurski (1979).

3. Trub productivity

Should the more ample definition of browse be accepted, i.e., including pod utilization, it would be convenient to deal separately with leaf-twig and pod production. The difficulty involved in estimating "useful" production of leaf-twig (that accessible to the browsing animal) and the "substitution" approach (of woody by herbaceous components) that has prevailed in range improvement may have precluded research on trub dry-matter production. A valuable review on production of browse in the savanna regions is that by Trollope (1981). Using data from other authors, he mentioned that the mean total biomass of such savannas is approximately 20,000 kg ha^{-1} yr^{-1}, of which 1,500 kg are twigs and leaves, 600 kg stems and branches, and 1,000 kg come from growth of the herbaceous layers. Applying available data, the same author estimated that only 33% 76% of those browsable leaves and twigs would be within reach of the animals, amounting to 500–1,150 kg ha^{-1} yr^{-1}. As a result of this and other available information, Trollope (1981) concluded that "... data emphasizes an important principle in savanna ecology, viz. that the herbaceous grass layer is potentially able to produce more edible plant material for domestic livestock than the browse layer. However, the grass sward can be extremely variable in its production, mainly in response to seasonal fluctuations in rainfall. Conversely, it would appear that the production of browse by the woody component is much less variable and less influenced by short-term fluctuations in rainfall, presumably because the woody plants possess deeper root systems".

Another interesting paper on primary production of fodder trubs in the African tropics is that by Bille (1980), who showed a relationship between stem circumference and foliage and fruit biomass for several browse species in the Sudano-Sahelian zone, within a rainfall range of 250–600 mm. The relationship, log biomass = a × log diameter + c, has a mean value of 2 for a and 1 for c. It means that for trub stem diameter of 5, 10 and 15 cm, biomass production will be 0.25, 2.2 and 6.2 kg respectively. An average tree in the Sahel would then produce a kilogram of leaves plus 0.25 kg of fruits and 4–5 kg of branches; or about 1,000 kg ha^{-1} of foliage. This productivity is affected by the browsing regime.

For the Sahel, Penning de Vries and Djiteje (1982) have estimated that the mean annual production of leaves of woody species ranges from around 50 kg ha^{-1} for the 500 mm rainfall zone (where soil cover of these species was of the order of 5%) to 1,000 kg ha^{-1} in the 1,000 mm zone (with a soil cover of 100%).

In the Mediterranean zone Le Houérou *et al.* (1982) also found a relationship between biomass and canopy diameter using data from 622 shrubs of four species. The average production of leaves/phyllodes per shrub for 16 species in those arid zones was 1.365 kg, ranging from 3.243 kg (*Acacia cyclops*) to 0.136 kg (*Periploca loevigata*), *Atriplex* sp. being nearer the average. This value does not differ substantially from the 2.33 kg that was measured by Jones *et al.* (1970) for *Atriplex nummularia* at 500 days from germination.

Studies on the productivity of around 20 shrub/brush species in the native grasslands of North America indicate that annual production ranges from 20 to 6,000 g/plant, and is affected by intensity and frequency of defoliation (Williard and McKell 1978; Lay 1965; and Garrison 1953).

The marked interest in *Leucaena* has led to several experiments on its productivity (Brewbaker *et al.* 1972; Hill 1971; Alferez 1977; Ferraris 1979). In humid Hawaii, Guevara *et al.* (1978) studied the productivity of shrubby and arboreal types of *Leucaena leucocephala* under different plant populations and heights of cutting. A population density of 133,000 plants (15 × 50 cm) and a cutting height of 105 cm produced higher forage yields with both types, being higher for the shrubby type (12.9 t ha^{-1} yr^{-1}) than the arboreal type (11.5 t ha^{-1} yr^{-1}), or 95 and 85 g plant^{-1} respectively. At Los Baños, Philippines, Mendoza *et al.* (1976) experimented with frequency and intensity of cutting on a cv. Peru planted at 3.0 x 0.05 m (66,000 pl ha^{-1}). Cutting height significantly affected total dry-matter yield, which was 10.7, 15.8 and 23.6 t ha^{-1} for 0.15, 1.5 and 3.0 m, respectively, which correspond to 162, 239 and 358 g plant^{-1} yr^{-1}. Under the sub-humid conditions of Queensland, Australia, Hutton and Beattie (1976) reported a total production of 5 t ha^{-1} (only 1.9 t of edible DM) for a fertilized Peruvian type at a density of 10,000 plants ha^{-1} cut 15 cm high three times a year, or 500 g plant^{-1}. In the semi-arid region of India (Jhansi), Pathak *et al.* (1980) studied the effect of population density and frequency and intensity of cutting. On a three-year average, density was the most important factor affecting total yield, which ranged from 5.4 t ha^{-1} for 4 plants m^{-2} to 1.9 t for 1.5 plants m^{-2} (135 and 127 g plant^{-1} yr^{-1}, respectively).

For an *Acacia aneura* community in Queensland, Beale (1973) reported that foliage weight per tree varied from 3 to 5 kg depending on density (640 to 40 trees ha^{-1}), leading to a production of 1,900–2,000 kg ha^{-1}.

Thus the literature appears to be consistent in showing relatively less scope for shrubs as components that can substantially increase production of edible

foliage matter, particularly in the arid and semi-arid zones. However, the important point to remember here is that the fodder that is available from the trubs in dry zones is usually obtained at critical times when there is little or no fodder from herbaceous species. Moreover, the trub fodder usually has better nutritive value than the herbaceous fodder (see the following section).

Information available on pod production is even scarcer. Data compiled by Felker and Bandurski (1979) indicate that species such as *Prosopis* sp., *Gleditsia triacanthos* and *Acacia albida* could produce of the order of 3–10 t ha^{-1} in different ecological zones. In the case of *Prosopis tamarugo* in the arid north of Chile, production per tree ranges from 20 to 70 kg for 14 to 22-year old plants at a density of 100 trees ha^{-1} (Elgueta and Calderon 1971).

4. Trub nutritive value

The nutritive value of any particular fodder depends not only on its nutrient content but also on the amount consumed and assimilated by the animal. Although there is a considerable wealth of information on chemical composition of fodder trubs, few of them have been evaluated in terms of animal response. A review on browse in nutrition of grazing animal was carried out by Wilson (1977), who concluded then that fodder trubs did not make a major contribution to the nutrition of domestic or most game animals and that further studies of browse-grass comparisons were needed.

The role of browsing appears to be particularly relevant for animal production systems based upon the utilization of rangelands in arid and semi-arid zones. Under these conditions protein content in the diet has been shown to be the most limiting factor affecting liveweight gains based on extensive studies in Botswana (Pratchett *et al.* 1977). Linear, quadratic and multiple regressions all indicated that liveweight change was influenced primarily by the crude protein content of the herbage selected, which accounted for 54% of the variation, while digestibility of the same samples accounted for 32%. They concluded that research efforts must be directed towards increasing the crude protein content of the diet available to beef cattle. In a study carried out with steers in the mixed tree savanna of the Transvaal, South Africa, Zimmerman (1980) estimated that the intake of digestible crude protein accounted for 79% of the variation in daily liveweight change of the cattle. Less conclusive but still supportive evidence comes from the work by McKay and Frandsen (1969) in the semi-arid upland areas of Kenya, and that of Ward (1975) for the rangelands in Arizona, particularly during summer periods.

An increase in the availability of crude protein to the grazing/browsing ruminant could be achieved through the introduction of fodder trubs, which are known for their high protein content (Rees 1973). Although the high standard error of this estimate by Rees (1973) in Zambia precludes any firm

conclusions, it appears that the fodder selected by four fistulated steers from 10 trubs contained 12–17% protein, while that of the grass was only 3%. A compilation of some of the available information on chemical composition of trub leaves and pods (Gohl 1981) would indicate their potential as a protein supplement to the fodder available in the tropical and subtropical rangelands (see Tables 33.1 and 33.2). An analysis of similar work done by Le Houérou (1980) on browse species of West Africa shows that the average protein content of 55 non-legume species is 14.1%, while that of 36 legumes is 18.8%. Carew *et al.* (1981) found that in the humid zone of Nigeria the mean crude protein content of browse, i.e., trees, shrubs and herbs (18.3, 19.7 and 19.4, respectively) was higher than that for grasses (11.1%).

This potential becomes particularly evident when protein content of browse species is compared with that of grasses from the same piece of land and harvested at the same time. Such a comparison was reported by Rose Innes (1965) for monthly recordings between May and December in the coastal and interior savanna of Ghana, including data from four browse species and unidentified native grass. The average protein content in eight observations in the coastal savanna was 18.1 and 5.8% for browse and grasses respectively.

Table 33.1. Crude protein content of trub leaves and twigs.

Species	Region	CP (%)
Acacia aneura	Queensland, Australia	13.1
Acacia arabica	Pakistan	12.8
Acacia arabica	Pakistan	20.0
Albizia lebbeck	Pakistan	22.0
Albizia lebbeck (whole)	Virgin Islands	16.2
Alchornea cordifolia	Nigeria	23.0
Azadirachta indica	Pakistan	13.4
Baphia bequaertii	Zambia	22.38
Baphia pubescens	Nigeria	24.3
Bauhinia variegata	India	15.6
Bauhinia variegata	Pakistan	18.5
Cajanus cajan	Nigeria	29.8
Combretum nigricans	Sahel	13.2
Commiphora africana	Sahel	14.2
Ficus religiosa	Pakistan	10.8
Gleditsia triacanthos	Pakistan	11.8
Glifforia simplicifolia	Ghana	15.7
Gliricidia sepium	Virgin Islands	17.4
Grewia sp.	Kenya	19.76
Gueira senegalensis	Sahel	13.9
Julbernardia paniculata	Zambia	12.28
Leucaena leucocephala	Virgin Islands	16.0
Prosopis spicigera	India	15.4
Zizyphus mauritania	Pakistan	11.3
Zizyphus mistol	Argentina	25.9

Table 33.2. Crude protein content of trub pods and seeds.

Species	Region	Pods	Seeds
Acacia albida	Tanzania	13.5	26.6
Acacia albida	Uganda	10.0	28.4
Acacia albida	Zambia	11.5	22.2
Acacia aroma	Argentina	14.0	
Acacia cavenia	Argentina	11.1	
Acacia nilotica	Kenya	12.4	20.8
Acacia sieberiana	Uganda	11.7	18.9
Acacia cynophylla	Cyprus		30.7
Acacia litakuensis	Rhodesia	17.3	37.8
Acacia nilotica	Siwalik	16.1	
Acacia nilotica	Uganda	10.0	
Acacia nubica	Kenya	15.2	
Acacia polyacantha	Zambia	10.4	27.4
Acacia senegal	Uganda	19.6	
Acacia sieberiana	Zambia	10.3	18.5
Acacia tortilis	Kenya	14.1	
Albizia versicolor	Zambia	12.6	
Bauhinia carronii	Australia	10.8	
Ceratonia siliqua	Australia	9.3	
Ceratonia siliqua	Brasil(s)	7.5	13.1
Cesalpinia paraguariensis	Argentina	4.6	
Dalbergia sissoo	Agra	11.9	
Dichrostachys cinerea	Rhodesia	11.4	
Geoffrea decorticans	Argentina	6.4	
Gleditsia triacanthos	Australia	14.3	
Phithecolobium saman	Venezuela	14.6	
Piliostigma thonningii	Rhodesia	6.4	
Prosopis alba	Argentina	8.9	
Prosopis juliflora	India	10.1	
Prosopis nigra	Argentina	8.2	
Zizyphus mistol	Argentina	5.4	

Corresponding values for the interior savanna were 15.1 and 4.8%. Moreover, it should be mentioned that grass protein content was always lower than 50% of that in browse (and as low as 8%), with the exception of that for the coastal savanna in May, when it reached 61% of the browse content.

As expected, protein content will change with season (Momin and Ray 1943; Rose Innes and Mabey 1964; McLeod 1973), but probably not nearly as much as that in grasses (Majumdar *et al.* 1967). Leigh *et al.* (1968) have shown that seasonal variation played a minor part in determining the browse quality of four Australian fodder trubs. Pal *et al.* (1979) processing the information on chemical composition of 26 species of fodder trees from Himachal Pradesh, India, found that average crude protein content was significantly higher in April (16.7%) than in August and December (14.7 and 14.3%, respectively).

Table 33.3. Protein digestibility of fodder trubs.

Trub species	Animal	1 Crude Protein CP (%)	2* Estimated CPD (%)	3 Measured CPD (%)	3/2 (%)
Acacia aneura	Sheep	14.9	66.5	63.1	94.9
Acacia pendula	Sheep	16.9	69.4	63.2	91.0
	Goat	16.9	69.4	68.8	99.1
Ailanthus excelsa	Sheep	16.2	68.5	80.2	117.1
Albizia lebbeck	Cattle	20.1	72.9	64.5	88.5
Albizia lebbeck	Sheep	16.8	69.3	65.0	93.4
Antiaris africana	Cattle	12.1	60.8	77.0	127.4
Atriplex nummularia	Sheep	20.6	73.3	82.0	111.8
Atriplex nummularia	Sheep	21.7	74.2	78.0	105.1
Atriplex nummularia	Sheep	17.0	69.6	83.0	119.3
Atriplex vesicaria	Sheep	12.5	61.8	71.4	115.5
Atriplex vesicaria	Sheep	18.4	71.2	74.0	103.9
Atriplex vesicaria	Sheep	11.1	58.1	71.0	122.2
Bambusa arundinaceae	Sheep	18.6	71.4	72.4	101.4
Baphia nitida	Cattle	23.1	75.3	72.3	96.1
Bassia diacantha	Sheep	12.5	61.8	49.3	79.8
Bauhinia variegata	Sheep	13.8	64.5	36.0	55.8
Brachychiton populneum	Sheep	14.6	66.0	75.8	114.8
Casuarina cristata	Sheep	9.4	52.1	22.1	42.4
	Goat	9.4	52.1	32.3	62.0
Ficus bengalensis	Cattle	9.6	52.9	20.0	37.8
	Goat	9.6	52.9	42.5	80.3
Ficus glomerata	Goat	11.2	58.4	59.7	102.2
Ficus infectoria	Cattle	9.6	52.9	56.0	105.8
Ficus religiosa	Cattle	14.0	64.9	56.6	87.2
	Goat	14.0	74.9	54.3	83.7
Ficus religiosa	Cattle	11.9	60.3	8.35	97.0
Grewia carpinifolia	Cattle	15.8	67.9	77.8	114.5
Grewia elastica	Goat	19.9	72.7	71.2	97.9
Griffonia simplicifolia	Cattle	18.6	71.4	81.4	114.0
Kochia pyramidata	Sheep	15.1	66.8	57.0	85.3
Mayreana pyramidata	Sheep	13.1	63.1	5.15	87.3
Mellotus philippensis	Sheep	14.5	65.8	53.2	80.8
Morus indica	Cattle	11.5	59.2	68.6	115.8
Prosopis cineraria	Sheep	14.2	65.3	22.0	33.7
	Goat	14.2	65.3	38.9	59.6
Sesbania aegyptiaca	Goat	19.5	72.3	80.8	111.7
Zizyphus jujuba	Cattle	8.6	48.5	35.5	73.2
Zizyphus nummularia		14.1	65.1	53.5	82.5
Zizyphus nummularia	Sheep	10.5	56.2	33.1	58.9
	Goat	10.5	56.2	36.2	64.4

* Calculated as digestible crude protein (CPD)/crude protein (CP), DCP being estimated as: % DCP (CPD) = (%CP X 0.9115)-3.67

Laboratory analyses may be of limited value in assessing fodder nutritive value. As is well known, the Weende system may not reflect the availability of cell-wall constituents, which may be hindered by a high lignin or silica content (Van Soest 1969). A high protein content may not, therefore, necessarily represent a potential protein supplement. Nevertheless, data compiled in Table 33.3 would indicate that actual protein digestibility of fodder trubs does not differ considerably from that estimated by a widely accepted regression equation for digestible crude protein on crude protein (McDonald *et al.* 1973). On the average, for the 38 sources measured, digestible crude protein would be only 90% of that estimated, but the range of values (34-127%) would suggest large variations between trub species.

But even digestibility may not be a good indicator of nutritive value. Experimenting with dried leaves of four shrub and four tree species, Wilson (1977) found that those of higher digestibility were eaten sparingly, there being no correspondence between digestibility and organic matter intake, probably as a consequence of unpalatability factors. In a recent review on the nutritive value of Australian browse plants, Wilson and Harrington (1980) went even further, stating that "there are no browse species of both high quality and high palatability and perhaps we should not expect them to be (because they will succumb to over-browsing)". Ibrahim (1981) discussed different plant and animal factors affecting palatability.

Information on pod digestibility seems to be rather scarce. The one paper available on *Prosopis juliflora* (Kargaard and van der Merwe 1976) shows that when used as the only source of feed, dry-matter digestibility (DMD) was 65%, while that for crude protein was 67.2%. It should be mentioned that pods were hammer-milled, otherwise seeds may pass undigested through the digestive tract. For *Ceratonia siliqua*, Charalambous (1966) reported a DMD of 82.6% and CPD of 80.1% from sheep digestibility trials carried out by others. Toxicity may be another factor limiting the nutritive value of fodder trubs. The toxic effect of mimosine contained in *Leucaena leucocephala* has been known for years (Brewbaker and Hylin 1965). The alkaloid could significantly affect animal response (Holmes 1981), which may be alleviated through mineral supplementation (Jones *et al.* 1978) or, better still, by breeding low mimosine cultivars (Winter and Jones 1980).

Trials assessing the potential of fodder trubs in terms of animal production are scarce. The use of *Leucaena* sp. as protein supplement is probably the best documented. A recent review by Jones (1979) indicates that, for beef fattening, effects are comparable with those derived from concentrated protein sources, when limited amounts are offered. Under grazing conditions the wide range in daily gains recorded (0.29-0.93 kg) was attributed by the same author to environmental factors influencing leucaena growth and mimosine content, as well as to the intake of leucaena and the corresponding alkaloid level. In the same review leucaena was found to improve milk production, but also tainted

the milk produced; this can be reduced by preventing cows from browsing leucaena for several hours before milking. When leucaena was substituted for a commercial ration for growing pigs, Malynicz (1974) found that weight gain and feed conversion ratio were adversely affected at levels higher than 20%.

Experiments using *Gliricidia moculata* as a supplement to *Brachiaria brizantha* in the diet of milking cows indicate that incorporating the tree foliage in proportions of 50 and 100% of the diet produces liveweight gains of 14 and 10 kg cow^{-1} in a month and yields of 6.6 and 7.6 l milk cow^{-1} day^{-1} respectively, as compared to a loss of 12 kg and a production of 5.8 l when cows were given grass alone (Chadhokar and Leeamwasam 1982). Reservations on the experimental methodology throw some doubts on the conclusiveness of these findings, but nevertheless point to the high fodder potential of *Gliricidia*. More reliable evidence of this potential was provided by Chadhokar and Kantharaju (1980) when *Gliricidia* was used as a supplement to *Brachiaria miliiformis* in the diet of pregnant ewes. Proportions of 25, 50 and 75% of *Gliricidia* in the diet increased lamb survival from 33 (no *Gliricidia*) to 75, 71 and 100%, and lamb weight at 15 weeks from 5.4 and 9.9, 10.0 and 11.0 kg, respectively. Using *Gliricidia sepium*, Carew (1980) found that sheep and goats fed for four months made a liveweight gain of only 30 and 14 g day^{-1}, respectively, despite a DMD of 66%, a CP content of 26.1% and a dry matter intake of 3.2 and 3.1 as percent of metabolic body weight. Although a closer analysis shows an adaptation period of 9 weeks, after which liveweight gains were of the order of 64 and 25 g day^{-1} for sheep and goats, respectively, the above-reported slow rates would suggest a mineral deficiency.

Available information would indicate, therefore, that of the major nutritive components in a ruminant diet, foliage from fodder trubs should be mainly considered as a source of protein. Fruits, particularly pods from legume trubs, could be used as both energy and protein supplements, provided that seed protein is made digestible through mechanical treatment.

In summary, the literature reviewed on the role of fodder trees and shrubs in animal production under rangeland conditions would suggest that:

- several species have been identified for different ecological zones, which are potential sources of fodder;
- although dry-matter productivity from the foliage of trubs seems to be rather small, its reliability in bad years and its presence during dry seasons makes it particularly valuable; while pod-producing trubs may become a very useful source of energy and protein concentrate;
- protein supply appears to be the main nutritive role of trubs, which could be limited by low intakes;
- there is a need to undertake studies evaluating the animal production potential of fodder trubs *vis-à-vis* alternative sources.

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34. The role of trees in soil productivity and protection

P.K.R. NAIR

In the process of conceptualization and principle formulation of agroforestry, a number of hypotheses and attributes have been advanced in the recent past. One of the most significant and oft-repeated among these is the suggested potential of agroforestry as a major practical land management alternative for maintenance of soil fertility and productivity in a variety of situations in the tropics. As stated by Sanchez (1987), the following hypothesis is strongly implied in the agroforestry literature: "appropriate agroforestry systems improve soil physical properties, maintain soil organic matter, and promote nutrient cycling". Most aspects of this hypothesis have not been tested and proven by research. However, past experience and accrued knowledge on the behaviour and management of tropical soils suggest that some of the agroforestry options can overcome at least a few of the drawbacks of monocultural (crop) production systems.

An account of soil productivity and management considerations under agroforestry has been given by Nair (1984). Wiersum (1984) and Lundgren and Nair (1985) discussed the role of agroforestry in soil conservation, taken in its broader sense to mean conservation of fertility as well as prevention of erosion. This was followed by a detailed ICRAF review which elaborated the potential of agroforestry as a practical means of sustaining soil fertility, and discussed the research needs in this direction (Young 1987). The role of agroforestry in the context of "land clearing and development in the tropics" was discussed by Nair (1987c) as a part of IBSRAM (International Board of Soil Research and Management) activities. Research on soil fertility aspects of alley cropping is being undertaken vigorously by IITA (International Institute of Tropical Agriculture), Nigeria and other research groups (Kang and Wilson 1987).

Thus, there is now a substantial volume of scientific activity related to soil fertility and productivity aspects of agroforestry, including field experiments in various phases of implementation at different places. As a consequence, the principles and concepts of agroforestry so far as soil fertility, productivity and protection are concerned, are gradually being translated into management technologies.

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1. Suggested mechanisms of soil improvements in agroforestry

1.1. *Evidence from existing land-use systems*

Based on the evidence collated from other existing and relatively well-researched land-use systems that are related to agroforestry, Nair (1984, 1987a) postulated the following hypotheses about the expected soil changes under agroforestry. In doing this, the emphasis was on those systems where trees and other woody perennials did not form a significant component of the existing land use, but where such species could be integrated without unduly modifying the production patterns of the main existing enterprises.

1. The inclusion of compatible and desirable species of woody perennials on farmland can result in a marked improvement in soil fertility. There are several possible mechanisms for this, which include:

   - an increase in the organic-matter content of the soil through addition of leaf litter and other plant parts;
   - more efficient nutrient cycling within the system, and consequently more efficient utilization of nutrients that are either inherently present in the soil or externally applied;
   - biological di-nitrogen fixation or solubilization of relatively unavailable nutrients, for example, phosphate, through the activity of mycorrhizae and phosphate-solubilizing bacteria;
   - an increase in the plant-cycling fraction of nutrients beyond the nutrient-absorbing zone of the soil;
   - complementary interactions between the component species of the system, resulting in a more efficient sharing of nutrient resources among the components;
   - an enhanced nutrient economy because of different nutrient-absorbing zones of the root systems of the component species;
   - a moderating effect of additional soil organic matter on extreme soil reactions and, consequently, improved nutrient release/availability patterns.

2. The improvement in the organic-matter status of the soil can result in increased activity of the favourable micro-organisms in the root zone. In addition to the nutrient relations mentioned earlier, such micro-organisms may also produce growth-promoting substances through desirable interaction and cause commensalistic effects on the growth of plant species.

3. The inclusion of trees and woody perennials on farmlands can, in the long run, result in marked improvements in the physical conditions of the soil – in permeability, water-holding capacity, aggregate stability, and soil temperature regimes. Although these improvements may be slow, their net effect is a better soil medium for plant growth.
4. The role of trees in soil conservation and erosion control is one of the most widely acclaimed and compelling reasons for including trees on farmlands that are prone to erosion hazards. The beneficial effects of trees in this regard extend beyond protecting the immediate farmland under consideration, to imparting stability to the ecosystem and reducing the rate of siltation of down-stream aquatic ecosystems, dams and reservoirs.
5. The influence of trees on hydrological characteristics can extend from the micro-site to the farm and regional levels. Although the effect of water use by a tree component on water availability to crop plants in different climatic conditions is not yet fully understood, there is evidence that the hydrological characteristics of catchment areas are favourably influenced by the presence of trees.

1.2. *Effect of trees on soils*

Sanchez *et al.* (1985) examined the role of trees as tropical soil improvers primarily from the point of view of plantation forestry. They surmised that some of the beneficial effects of trees on soils after the trees close canopy are unexpected, particularly the influence on chemical properties, such as calcium accumulation by *Gmelina arborea*, and that the main deleterious effects of tree crops on soil properties occur during their establishment phase. Discussing this topic, Young (1986) identified several positive and a few negative aspects of trees on soil, some well proven and others reasonable suppositions. These, as well as the above-mentioned hypotheses of Nair (1984) that are summarized in Table 34.1, indicate the mechanisms by which the generally favourable effects of trees upon soils may be achieved under appropriate conditions (Nair 1987). Kang *et al.* (1986) depicted these beneficial effects schematically under an alley cropping situation, as shown in Fig. 34.1.

Table 34.1 should not be interpreted to mean that trees have only favourable effects on soils. Some adverse effects have also been reported, notable among which are:

- Fast growing species (of trees) may place a heavy demand on soil moisture, and unless properly managed, this can lead to adverse effects, especially in drier environments;
- Nutrient losses from whole-tree harvesting may be excessive, especially in plantation forestry;

Table 34.1. Summary of the potential beneficial effects of trees on soils.

Nature of processes	Processes	Main effect on soil	Scientific evidence
Input processes (augment additions to the soil)	Biomass production	Addition of carbon and its transformations	Available
	Nitrogen fixation	N-enrichment	Available
	Rainfall	Effect on rainfall (quantity and distribution) and therefore nutrient addition through rain	Not adequately demonstrated
Output process (reduce losses from the soil)	Protection against water and wind erosion	Reduce loss of soil as well as nutrients	Available
Turn-over processes	Nutrient retrieval/ cycling/release	Uptake from deeper layers and "deposition" on surface via litter	Not adequately demonstrated
		Withholding nutrients that can be lost by leaching	Not demonstrated
		Timing of nutrient release: this can be regulated by management interventions	Available
"Catalytic" processes (indirect influences)	Physical processes	Improvement of physical properties (water-holding capacity, permeability, drainage, etc.) at the microsite as well as at watershed (macrosite)	Available
	Root growth and proliferation (enhanced)	Addition of (more) root biomass; growth-promoting substances; microbial associations	Partially demonstrated
	Litter quality and dynamics	Improvement of litter quality through diversity of plant species; better timing of quantity, and method of application of litter possible	Now being increasingly studied alley cropping and other intercropping experiments
	Microclimatic processes	Creation of more favourable microclimate; shelterbelt and windbreak effects	Available
	(Bio) chemical/biological processes (net effects of various processes)	Moderating effect on extreme conditions of soil acidity alkalinity, etc.	Partially demonstrated

Source: Nair (1987a).

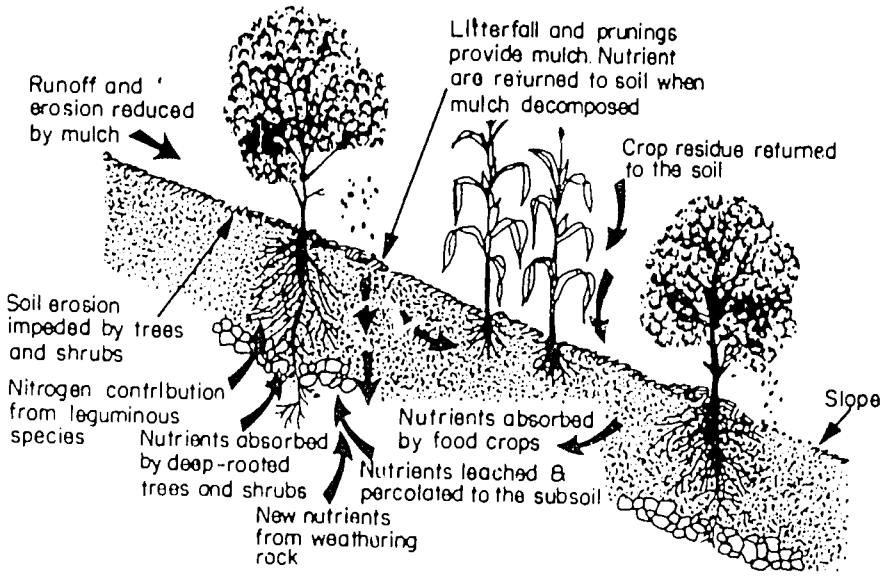

Fig. 34.1. A schematic representation to show the benefits of nutrient cycling and erosion control in an alley-cropping system. *Source*: Kang *et al.* (1986).

- Nutrient depletion may temporarily deprive adjacent, less competitive species of nutrients (although litter fall, root biomass, etc., may compensate for this to some extent in the long run);
- A badly managed tree stand, as with any vegetation, can cause accelerated erosion;
- Adverse chemical/biological effects may result from certain tree species, leading to acidification, allelopathy, accumulation of toxic exudates, the provision of alternate hosts of pests and pathogens, etc.; and
- Shading and changes in spectral quality of light on the growth of other species in close proximity (though not a direct effect on the soil, this can have considerable significance in agroforestry).

Most of these attributes (both beneficial and adverse) are either inferred from land-use systems related to agroforestry, or are still only untested hypotheses. The magnitude of benefit or adverse effect that could be experienced will depend upon a number of site-specific factors. Moreover, many of the attributes of trees, as compared to annual crops, can be realized only over relatively long periods of time. One of the main issues to be considered here is the soil-fertility improvement in agroforestry through addition of plant biomass *vis-à-vis* other uses for the biomass (fodder, fuelwood, food, etc.). Similarly, the proportion of space occupied by tree components in an agroforestry combination, in order to derive the suggested benefits to any tangible extent, will depend upon several factors such as soil type, plant (tree) species, tree-crop arrangement, etc. All these factors need to be taken into account while suggesting plant and soil management technologies in agroforestry.

Table 34.2. Perennial legumes commonly used in Asian farming systems.

Species	Ecological adaptation	Growth form and characteristics	Major uses/functions (see footnote for explanation of notations)	N_2-fixations (nodulation) capability	Other remarks
Acacia albida	Dry zone drought tolerant	Tree to 20 m; thorny	F, GM, A, SF, WLR	(+)	Leafless in rainy season; very common in African farming systems
Acacia auriculiformis	Lowland humid tropics	Tree to 20 m	PW, Or, SC, FW, ST	(+)	Pulpwood species
Acacia mangium	Lowland humid to sub-humid	Tree to 20 m	FW, SC, T, PW, SB	(+)	Plantation species; fast growing
Acacia nilotica	Dry zones drought tolerant	Tree to 10 m; very thorny; deciduous	SC, FW, T, A, DS, WLR	(+)	Widespread in dry regions
Acacia polycantha (*A. catechu*)	Lowlands; low drought tolerance	Tree to 25 m; coppices well	A, FW, G	(+)	Good fodder
Acacia saligna (*A. cyanophylla*)	Dry zones; low- and midlands; tolerant to salt, drought	Tree to 10 m fast growing; shrubby	FW, T, DS, WLR	(+)	
Acacia senegal	Dry zones; low- and midlands	Tree to 10 m; thorny; deciduous shrubby	FW, WLR, DS, G	(+)	Gum-arabic tree
Acacia seyal	Dry zones	Slender tree to 12m; long thorns	A, G, T, WLR	(+)	Important animal feed
Acacia tortilis	Dry (arid) zones; tolerant to alkalinity, drought	Flat-topped tree to 15 m; thorny	FW, A, WLR	(+)	More popular in Africa
Acacia xenthophloea	Dry to sub-humid tropics	Tree to 20 m; spiny	O, Or, FW	(+)	Lopped fodder

Albizia chinensis	Up to 1,500 m, dry to sub-humid sub-tropics	Tree to 15 m; deciduous; fast growing	T, A, ST	(+)	Rapid growth
Albizia falcataria	Humid to sub-humid lowlands	Tree to 30 m	SF, PW, Or	(+)	Common in SE Asia as plantation species
Albizia lebbek	Wide adaptability; dry-humid tropics	Tree to 25 m	FW, A, CT, Or	(+)	Rapid growth
Albizia odoratissima	Tropical highlands	Tree to 25 m	A, Or	(+)	Severely lopped for fodder
Cajanus cajan	Wide adaptability	Annual to perennial	F, GM, FW, SC, A	(+)	Widely used for a variety of purposes
Calliandra calothyrsus	Humid tropical midlands	Shrub to 8 m; fast growing; acid tolerant	FW, SC, BF, GM, A, Or, T	(+)	Low fodder value
Cassia siamea	Semi-arid to sub-humid	Shrub to 8 m; coppices vigorously; drought tolerant	FW, SC, FW, A	(−)	Good for alley cropping
Dalbergia sissoo	Tropical and sub-tropical midlands; sub-humid to humid	Tree to 30 m	T, FM, ST, A	(+)	Indian teak-wood
Erythrina spp.	Humid lowlands to highlands	Tree to 20 m; often thorny; coppices well; propagated by stem cuttings	GM, ST, Or, WB, A	(+)	Used as live standard for black pepper
Flemingia macrophylla	Humid lowlands	Shrub to 3 m	GM, A	(+)	Common in SE Asia as a green manure crop in plantations
Gliricidia sepium	Humid to sub-humid lowland tropics	Tree to 20 m; vigorous coppicing; fast growth	GM, A, FW, ST, SC,	(+)	Very commonly used multipurpose species

Table 34.2. (continued).

Species	Ecological adaptation	Growth form and characteristics	Major uses/functions (see footnote for explanation of notations)	N_2-fixations (nodulation) capability	Other remarks
Hardwickia binata	Dry tropics; drought-tolerant	Tree to 30 m; slow-growing	W, SC, A, FW, DS, Fi	(o)	Valued heavy wood
Leucaena leucocephala	Humid- to sub-humid lowlands	Tree to 20 m; vigorous coppicing; fast growing; not acid tolerant	GM, A, FW, ST, SC, PW, F	(+)	Widely studied and extensively used
Pithecellobium dulce	Wide adaptability from dry to humid zones	Tree to 20 m; thorny	A, FW, Or	(+)	Pods and leaves browsed
Pongamia pinnata (*Derris indica*)	Low- and mid-land humid tropics	Small tree to 8 m; salt-tolerant	FW, A, CT, ST, Fi	(−)	
Prosopis cineraria	Dry zones, heat resistant	Tree to 8 m; thorny	SF, GM, A, T, DS, FW	(o)	Highly valued in Indian desert
Prosopis juliflora	Dry zones, heat and alkali resistant	Tree to 10 m; coppices	FW, GM, A, DS, SC, WLR	(−)	Live fences

Pterocarpus marsupium	Dry to subhumid lowland tropics	Tree to 30 m; coppices well	A, FW, T	(+)	Widely lopped for fodder in India
Samanea saman	Highland to lowland tropics	Spreading tree to 40 m; fast growth	T, Or, CT, A, F	(−)	Pods good for human as well as animal consumption
Sesbania spp. *bispinosa grandiflora rostrata sesban*	Lowland humid to midland semi-humid	Low trees, very fast growth; some are annuals (*S. sesban*)	GM, A, SC, SF, FW, PW, Or	(+)	Widely used
Tamarindus indica	Wide adaptability	Large trees to 30 m	F, A, CT, FW, ST	(−)	Pods rich in vitamin C

A – animal feed (pods, leaves, bark, etc.)
BF – bee forage
CT – construction/craft timber
DS – dune stabilization
F – food (human consumption)
Fi – fibre
FW – firewood
GM – green (leaf) manure
Or – ornamental
PW – pulp wood
T – timber
SC – soil conservation
SF – soil fertility improvement
ST – shade tree (over cacao, coffee, tea)
WLR – waste-land reclamation

(+) = reported to nodulate
(−) = reported not to nodulate
(o) = no report available

Source: Nair (1987b), based on NFTA (Nitrogen Fixing Tree Association) and ICRAF Library data base on N_2-fixing/nodulating trees, ICRAF, Nairobi.

2. Nitrogen-fixing trees

Nitrogen-fixing trees are mentioned as one of the most promising sets of components of existing – and more importantly, potential – agroforestry systems. By virtue of their ability to fix atmospheric nitrogen and contribute nitrogen to the soil via leaf and fallen litter (litter *sensu stricto*), or the release of root debris and nodules (root litter), this group of trees and shrubs has a dominant role to play in the maintenance of soil fertility in the systems of which they form a part.

Nair (1987b) examined the N-fixing trees in Asian farming systems and found that several of these trees are already important components of existing systems providing a variety of services and benefits (Table 34.2). The situation is similar in other parts of the tropics as well (Dommergues 1987). Reviewing the role of nitroge-fixation in agroforestry, Dommergues (1987) concluded that the potential direct and ancillary benefits from the N-fixing trees vary greatly depending on the species, climate, soil and management practices. He suggested that six concepts seemed important in optimal utilization of biological nitrogen fixation in agroforestry:

1. It should be mandatory to use species, provenances and/or clones exhibiting a high nitrogen-fixing potential and adapted to the site conditions;
2. Improving nitrogen fixation is a leading research priority and a goal that can be achieved not only by selecting the most efficient *Rhizobium* or *Frankia* strains, but also by improving the host plant, one of the quickest methods being through clonal multiplication of elite trees.
3. Nitrogen-fixing trees improved in the laboratory, glasshouse or even in the nursery are not necessarily able to reach their maximum potential in the field. Therefore, before deciding to include a nitrogen-fixing tree or shrub in an agroforestry system, its nitrogen-fixing ability in field situations should be tested. This type of evaluation obviously presupposes the availability of accurate, simple methods to measure nitrogen fixation *in situ*. Progress has been made recently in developing such methods for annual crops, but more investigations are urgently needed to overcome the difficulties specific to perennial plants.
4. Even the least demanding nitrogen-fixing trees exhibit requirements for nutrients other than nitrogen that should be met so that their nitrogen-fixing potential can be fully realized. Fertilizer needs (mostly phosphate) are generally reduced, especially if the root system of the trees is properly infected with efficient mycorrhizal fungi.
5. Secondary effects should not be overlooked, especially those resulting in the development or the control of micro-organisms pathogenic to companion crops, or in allelopathic interferences.

6. Finally the fact that research in agroforestry is a lengthy undertaking should be kept in mind. Banking only on short-term effects (namely the immediate yield increase of associated crops) without recognizing long-term effects (maintenance or progressive increase of soil fertility) is like not seeing the forest for the trees.

3. Nutrient cycling in agroforestry systems

One of the advantages commonly attributed to agroforestry technologies is the potential for soil-fertility improvement via more efficient cycling of nutrients (Nair 1984), and it is often recommended to include nitrogen-fixing trees and shrubs in such technologies (Nair *et al.* 1984; Lundgren and Nair 1985; Young 1987).

Reviewing the available information on the topic, Sanchez (1987) reported good evidence from some experiments for nutrient cycling potential of agroforestry systems on Alfisols and Andepts of moderate to high fertility. Such systems as the *Erythrina poeppigiana* shade trees over *Coffea arabica* in Costa Rica are a good example (Glover and Beer 1986; Russo and Budowski 1986; Alpizar *et al.* 1986). Similarly, Roskoski (1981) reported that *Inga jinicuil*, a leguminous shade tree in coffee plantations, fixed around 40 kg N ha^{-1} yr^{-1}.

Juo and Lal (1977) compared the effects of a leucaena fallow versus a bush fallow on selected soil chemical properties on an Alfisol in western Nigeria. After three years, during which leucaena was cut annually and left as mulch, the leucaena fallow resulted in significantly higher effective cation exchange capacity and levels of exchangeable Ca and K as compared to the bush fallow. Similarly, in another experiment, an agroforestry system involving oil palm with leguminous cover crops (*Centrosema pubescens* and *Pueraria phaseoloides*) appeared more efficient at nutrient cycling than an oil palm plantation with no cover crop. In addition to fixing about 150 kg N ha^{-1} yr^{-1}, the loss of nitrate nitrogen via leaching was significantly lower in the agroforestry system than in the sole crop of oil palm (Agamuthu and Broughton 1985).

After six years of alley cropping with *Leucaena leucocephala* on a pH 6 Entisol, plots receiving prunings had a higher nutrient status and twice the organic-matter content than plots not receiving prunings (Kang *et al.* 1984) (Table 34.3). This is a highly successful agroforestry system.

However, attempts to extrapolate the IITA-leucaena alley cropping model to a highly weathered, sandy Ultisol in the Amazon basin of Yurimaguas, Peru, were not as successful (TropSoils 1987). The main differences between the IITA and Yurimaguas situations are (1) the susceptibility of *Leucaena leucocephala* to Al toxicity, and (2) the low nutrient base content of the Yurimaguas subsoil which reduced the recycling pool.

Table 34.3. Effect of six years of alley cropping maize and cowpea with *Leucaena leucocephala* and nitrogen application on some chemical properties of surface soil of Apomu loamy sand (Psammentic Ustorthent).

Treatments (kg N/ha)	Leucaena prunings	pH (H_2O)	Org. C (%)	Exchangeable K	Exchangeable Ca (me 100 g $^{-1}$)	Exchangeable Mg	Bray P-1 (ppm)
0	Removed	6.0	0.65	0.19	2.90	0.35	27.0
0	Retained	6.0	1.07	0.28	3.45	0.50	26.2
80	Retained	5.8	1.19	0.26	2.80	0.45	25.6
LSD.05		0.2	0.14	0.05	0.55	0.11	5.3

Source: Kang *et al.* (1984).

The poor performance of leucaena had been anticipated and a number of other woody species were evaluated in alley-cropping trials. These include *Inga edulis*, *Codariocalyx* (*Desmodium*) *gyroides* and *Erythrina* spp. Although yield data and soil properties are still under analysis, *Inga edulis* appears to be a highly promising agroforestry species for acid soils in the tropics.

Although alley cropping works well in moderately fertile soils, current experience suggests that it will be necessary to use inputs such as lime, and possibly P, to allow successful establishment of alley cropping species and subsequent recycling of nutrients on acid infertile Ultisols and Oxisols (Trop-Soils 1987). Much further study is required before this particular agroforestry system can be considered widely applicable to the humid and subhumid tropics.

Some tree and shrub species can selectively accumulate certain nutrients even in soils containing very low amounts of these nutrients. Thus palms and palm litter are rich in potassium (Foelster *et al.* 1976), tree ferns accumulate nitrogen (Mueller-Dombois *et al.* 1984), *Cecropia* spp. appeared to accumulate Ca and P on acid sites (Odum and Pigeon 1970) and *Gmelina* accumulates Ca (Sanchez *et al.* 1985). It is important for researchers looking to incorporate such nutrient-conserving species into agroforestry technologies to appreciate the fact that such plant-nutrient responses will change with location and site/soil characteristics (Golley 1986).

In addition to translocation of nutrients from soil layers beyond the reach of annual crops or pasture species, enhancement of nutrient status beneath tree canopies has also been attributed to canopy capture of precipitation inputs (Kellman 1979). Therefore, such factors may enhance nutrient recycling in agroforestry systems, but they need to be evaluated in such systems.

4. Trees and soil conservation

A review of measurements of erosion under agroforestry and related forms of land use has been made by Wiersum (1984), which was further improved by

Young (1986), and the present summary is based upon the latter. The review is divided into two parts, the effects of trees on the separate factors of erosion, and observed erosion rates under agroforestry practices.

4.1. *Effects of trees on the factors of erosion*

Rainfall erosivity

Energy is often increased by a high tree canopy through coalescence of raindrops into larger drops, which can reach their terminal velocity when falling from a canopy more than 30 m high. Higher erosivities have been recorded under forest plantations. Severe erosion has occurred under teak plantations, where the canopy is high and the leaves drop during part of the rains. An increase in erosion as compared with forest has been recorded for a homegarden (Soemarwoto 1987) and multistorey tree garden. It may be supposed that a low and dense canopy would reduce erosivity, but there are no measurements from agroforestry systems. Under alley cropping, although the canopy is low, it is not vertically above the cropped land.

Soil erodibility

It is widely observed that soil structure is of a higher grade and more stable, detachability lower and infiltration capacity higher under forest than under cultivation. Under shifting cultivation, organic matter decreases and erodibility increases during the cropping period. Under taungya systems, there is usually a decrease in organic-matter content and infiltration capacity and higher erosion during the cropping period as compared with a forest plantation without taungya. Higher erodibility has been recorded for a homegarden in Tanzania and a multistorey tree garden in Java, as compared with natural forest in the same areas. For the practice of trees in fields, under *Acacia albida* in Senegal, no significant differences in structural stability were found between sandy soils beneath and beyond trees. Alley cropping has the potential to maintain organic matter, or limit the rate at which it declines, compared with the almost invariable decline under pure cropping. After six years of maize-leucaena alley cropping at Ibadan, Nigeria, topsoil organic carbon was 1.1%, compared with 0.65% when leucaena prunings were removed (Kang *et al.* 1985).

Reduction of runoff

Where trees are planted on soil-conservation works, including grass strips, bunds and terraces, this of course reduces runoff and erosion, but no specific

added effect can be attributed to the presence of trees. Barrier hedges appear to be effective in limiting runoff, although there are limited data on this. Where alley cropping is established along the contour, the tree rows will possibly limit erosion to the same extent as grass barrier strips, but again data are lacking.

The ground surface cover

Under plantation-crop combinations, erosion is substantially reduced where the prunings are laid on the ground surface. In a multistorey tree garden in Tanzania, when crop residues were left as mulch, less erosion occurred than under forest. The surface litter cover is far more important than the leaf canopy in controlling erosion. Under trees on pastures, there are two reports of higher erosion than in pure pastures, but there is no information on the reasons for this. Alley cropping can potentially provide surface cover from prunings.

4.2. *Observed erosion rates under agroforestry practices*

Recorded erosion rates under agroforestry practices and other relevant forms of land use are shown in Table 34.4. If rates of erosion are classed as low = < 2 t/ha/yr, moderate = 2–10 t/ha/yr, and high = > 10 t/ha/yr, the results may be summarized as follows:

Low

Natural rain forest
Forest fallow in shifting cultivation
Multistorey tree gardens
Most forest plantations, undisturbed
Tree plantation crops with cover crop and/or mulch

Moderate or high

Cropping period in shifting cultivation
Forest plantations, litter removed or burned.

A feature of the data is that in the systems which have high erosion potential, the range of values is large, indicating the importance of management practices rather than the intrinsic properties of the practices.

In summary, it can be said that the tree canopy frequently does not reduce the erosive impact of falling rain, and may increase it. Soil erodibility is generally lower under agroforestry than pure arable cropping owing to the

Table 34.4. Reported rates of erosion in tropical forest and tree crops systems.

Land-use system	Erosion, t ha^{-1} yr^{-1}		
	Minimum	Median	Maximum
Multistorey tree gardens	0.01	0.06	0.14
Natural rain forest	0.03	0.30	6.16
Shifting cultivation, fallow period	0.05	0.15	7.40
Forest plantations, undisturbed	0.02	0.58	6.20
Tree crops with cover crop or mulch	0.10	0.75	5.60
Shifting cultivation, cropping period	0.40	2.78	70.05
Taungya, cultivation period	0.63	5.23	17.37
Tree crops, clean weeded	1.20	47.60	182.90
Forest plantations, burned or litter removed	5.92	53.40	104.80

Source: Wiersum (1984).

better maintenance of soil organic matter. By far the greatest effect in reducing erosion, however, can be achieved by maintaining a ground surface cover of litter, which many agroforestry systems have the capacity to achieve.

Among agroforestry practices, only multistorey tree gardens are by their nature always likely to control erosion (but even this could be untrue for a farmer with a passion for clearing away all plant residues!). Other practices, notably planted tree fallows, alley cropping, plantation crop combinations, multipurpose woodlots and reclamation forestry have the potential to reduce erosion to acceptable levels, given good management.

Trees, and hence agroforestry systems, do not necessarily lead to control of erosion. What matters is the way in which the systems are designed and managed.

In the design of agroforestry systems for erosion control, the primary aim should be to establish and maintain a ground cover of plant litter. From the aspect of erosion control alone, maintenance of soil organic matter, and hence of soil physical properties and erosion resistance, is also important. It will not usually be possible to achieve erosion control by tree-canopy protection, unless possibly under systems having a low and dense cover.

4.3. *Examples of agroforestry in erosion control*

Examples where agroforestry practices have been employed or recommended with erosion control as a major objective are presented schematically in Figs. 34.2 and 34.3. These include experimental systems from Rwanda, Burundi, the Philippines, Indonesia, Nepal, Kenya, Cameroun, Malawi, Ethiopia and Vietnam (Young 1986).

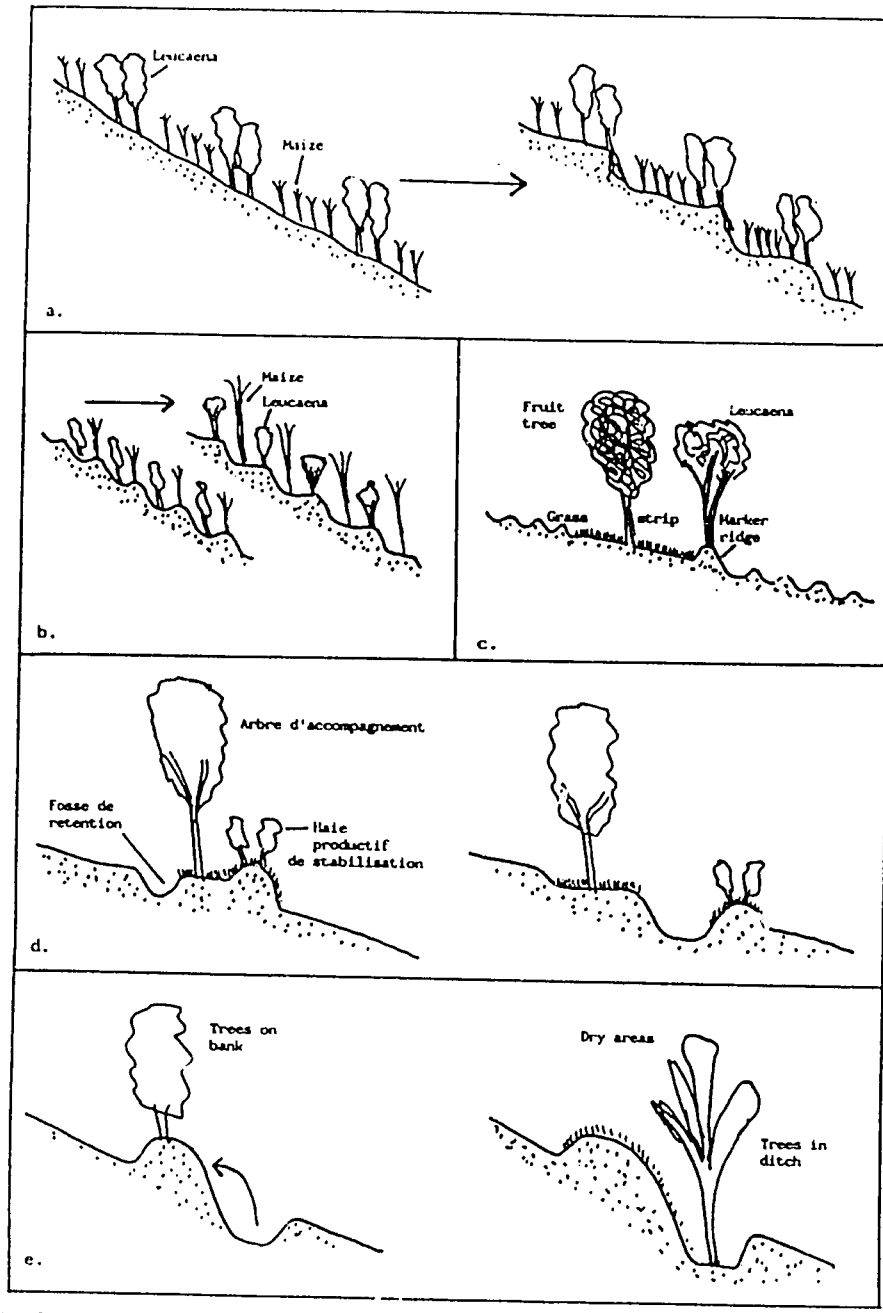

Fig. 34.2. Examples of agroforestry in erosion control. *a:* Barrier hedges of double rows of *Leucaena* with maize, developing rows of maize into terraces, Philippines. *b:* Leucaena barrier hedges planted at 90 cm spacing in furrows betweens rows of maize, developing into terracettes, Malawi (A. Young, personal observation). *c:* Trees on conservation works, Malawi; fruit trees on grass strips, and *Leucaena* on marked ridges (ridges laid out along contour to guide cultivation ridges below) (A. Young, personal observation). *d:* Alternative arrangements for treees on conservation works, Cameroun; *fosse de retention* – ditch for retaining runoff; *arbre d'accompagnement* – associated tree; *haie productif de stabilisation* – productive hedge for stabilization. *e:* Alternative positions for trees on *fanya juu* structures, Kenya; *fanya juu* (literally inchthrow (earth) upwardsinch) are bunds in which the bank is above the ditch, promoting natural terrace formation.

Source: Young (1986).

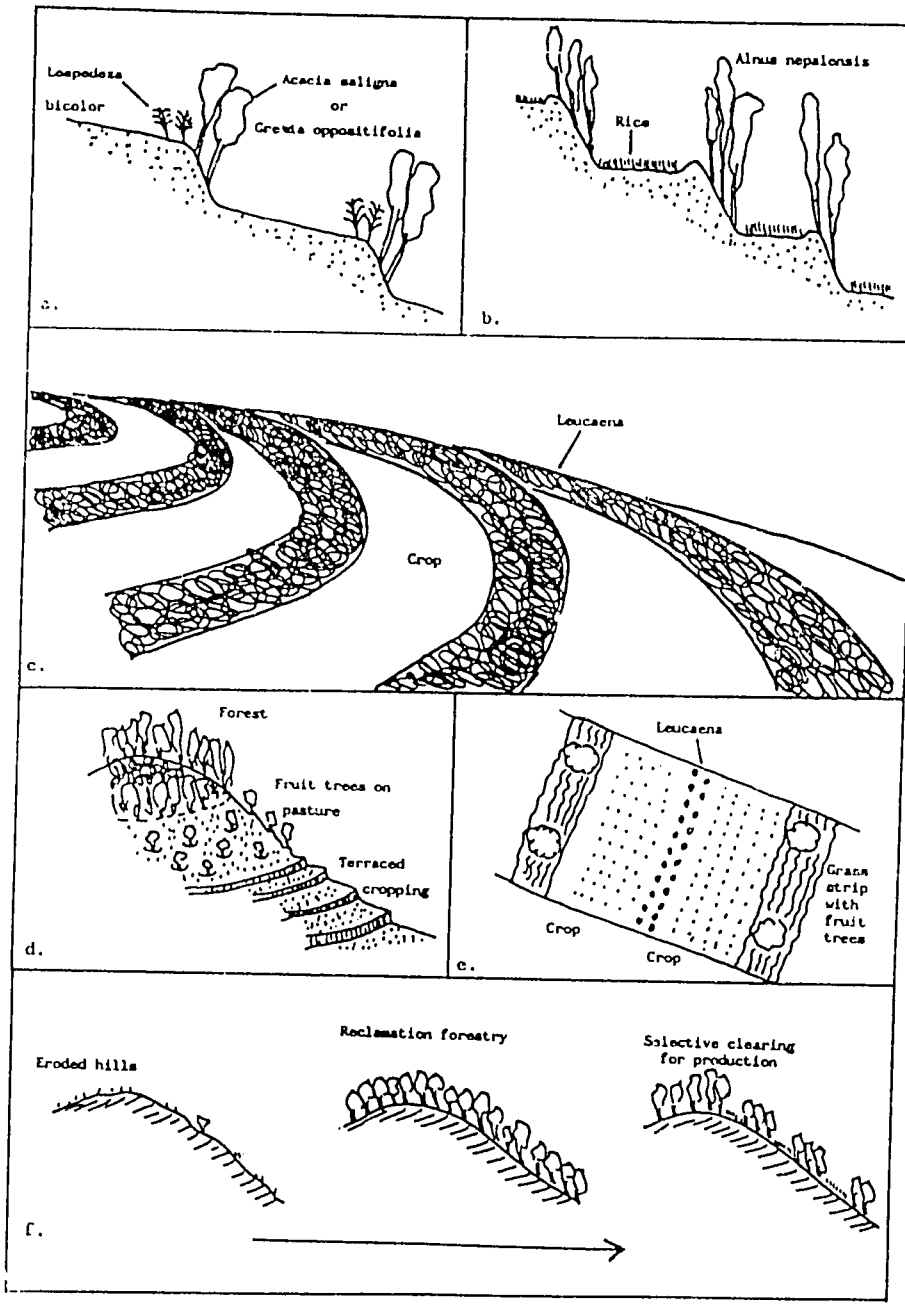

Fig. 34.3. Examples of agroforestry in soil erosion control. *a:* Trees on terrace, Ethiopia. *b:* Trees on risers of irrigated terraces, Nepal (A. Young, personal observation). *c:* Alley cropping with *Leucaena* laid out on a slope; after a photograph in Kang *et al.* (1984). *d:* Model for land use as an alternative to shifting cultivation, North-Eastern Hill region, India. *e:* Plan view of suggested land use on slopes combining barrier hedges with trees on grass barrier strips, Philippines. *f:* Possible development of reclamation forestry into productive use by selective clearance of contour strips.

Source: Young (1986).

5. Trees as windbreaks and shelterbelts

5.1. *Description*

Windbreaks are narrow strips of trees, shrubs and/or grasses planted to protect fields, homes, canals and other areas from the wind and blowing sand. Shelterbelts, a form of windbreak, are long rows of trees and shrubs planted many rows wide and perpendicular to the prevailing wind. Where wind is a major cause of soil erosion and moisture loss, windbreaks can make sustainable production possible. When properly designed and maintained, a windbreak reduces the velocity of the wind, and thus its ability to carry and deposit soil and sand. It can improve the microclimate in the area it protects by decreasing water evaporation from the soil and plants. In some cases windbreaks have been shown to increase the productivity of the crops they protect. In addition to these soil- and water-conservation effects, windbreaks can also provide a wide range of useful products, from poles and fuelwood to fruit, fodder, fibre and mulch.

Windbreaks usually consist of multistorey strips of trees and shrubs planted at least three rows deep. They are placed on the upwind side of the land to be protected, and are most effective when oriented at right angles to the prevailing winds. While their extent may vary dramatically, it is common in the dry savannas and steppes of Africa to plant windbreaks 100 m long or more, with a peak height of 10 m.

Small living fences and hedgerows can also act as windbreaks for small sites such as homegardens and nurseries. However, windbreaks are distinguished from boundary plantings and living fences by their orientation, which must face the wind, and by their multistorey, semi-permeable design. They may coincide with roadside, boundary, and floodplain planting sites, but must be specifically designed to slow down the wind. Very dense windbreaks may do more harm than good since they will tend to create strong turbulence that will scour the soil on the windward side and damage crops on the leeward side. Gaps in the trees will channel the wind actually increasing the velocity on the leeward side and promoting soil erosion and damaging crops.

Throughout the African continent farmers use windbreaks to protect crops, water sources, soils and settlements on plains and gently rolling farmlands. Hedgerows of *Euphorbia tirucalli* protect maize fields and settlements in the dry savannas of Tanzania and Kenya. Tall rows of *Casuarina* line thousands of canals and irrigated fields in Egypt. In Chad and Niger multi-species shelterbelts protect wide expanses of cropland from desertification. The practice is not new, although the design of multipurpose windbreaks for smallholders will require new agroforestry skills.

The protective and productive benefits of windbreaks at a given site should be weighed against the costs before proceeding with detailed plans and

planting. Aside from the direct costs for labour and planting material, windbreaks will take some land out of crop production, and will compete for water, light and nutrients. Increased crops yields, soil improvement and by-products must be sufficient to cover these costs and still produce a net benefit.

The distance between windbreaks is determined mainly by the height of the tallest trees in the row. A properly designed windbreak can protect a field at least 10 times as long as the height of the tallest trees. So if the trees are 10 m tall, crops up to 100 m in the leeward direction will be protected. The protective influence will diminish with distance from the windbreak. A more permeable windbreak will shelter a longer stretch of cropland than a dense windbreak.

5.2. *Species*

The most effective windbreaks provide a semi-permeable barrier to wind over their full height, from the ground to the crowns of the tallest trees. Since their shapes change as they grow it is usually necessary to mix several species of different growth rates, shapes and sizes in three or more rows. Some fast-growing species should be used to establish the desired effect as rapidly as possible. *Eucalyptus*, *Cassia*, *Prosopis*, *Leucaena* and *Casuarina* are often planted for this reason. However, no tree will grow rapidly if it is not well adapted to the environmental conditions of the site. In addition, some of these genera are not as long-lived as slower growing trees. Fast- and slow-growing species should thus be mixed to extend the useful life of the windbreak. Mixing species also provides protection against attack from diseases or insects that can easily destroy single-species stands.

Diversifying the species in the windbreak can also bring a wider variety of useful products to local users. A fully developed windbreak can yield wood, fruit, fodder, fibre and honey for sale and home use. Where animals are allowed to graze nearby, at least some of the lower, outer trees or shrubs should be relatively unpalatable, while fodder species may fit closer into the centre or along an inside edge where they are not exposed to animals but can be cut by hand. Neem (*Azadirachta indica*) has been used in Niger where its unpalatable leaves protect it from damage by livestock.

Although some trees such as neem, *Casuarina* spp. and *Eucalyptus* spp. are widely used in windbreaks, they should be used selectively. *Eucalyptus* should not be used alone as it has a sparse understorey and may negatively affect water availability and crop productivity in the vicinity. Neem is known to shade crops and thus reduce the land available for crop production. On the other hand, people have constructed successful windbreaks with such unlikely trees as cashew (*Anacardium occidentale*) and indigenous *Acacia*. The species

selected must fit together as a group into a larger overall design that in turn fits into the local landscape and land-use system.

While diversity is important, there are constraints on species choice both for indigenous and exotic species. The species selected will have to meet the growth form, size and growth rate required for the windbreak as well as the production priorities of the local people. Environmental hazards such as insect pests (especially termites), wild and domestic animals, poor soil and drought will narrow the choice as well as reduce the trees' growth rate. Water management, especially during establishment, will be important, as in any attempt to establish trees in a dry environment. Microcatchments, hand watering or irrigation should be planned.

5.4. *Anticipated benefits*

Although very little information is available on the quantities of wood (as fuelwood, poles or other form) from trees growing in windbreaks, some preliminary results are encouraging. In windbreak tests in the Majjia Valley in Niger (with favourable soils and 425 mm mean annual precipitation), an "average" neem tree yielded between 3 and 7 kg of usable fuelwood per year. In this calculation the yield was averaged over the lifetime of the tree and proper management was assumed. Based on these calculations, a 100 m strip of a double-row windbreak where trees are spaced 4 m apart within each row, would provide:

> 5 kg wood (average) × 25 trees × 2 rows = 250 kg of wood, or enough to give a family of five enough firewood to last for almost two months. This same strip would protect roughly one hectare of cropland. If the same family protected 6 ha of cropland with windbreaks they would also meet their fuelwood needs for the year.

It should be noted that wood cannot be harvested for several years after planting.

Cashews used in a windbreak in Senegal are yielding a fair amount of fruit and nuts. Although not in sufficient quality and quantity to make it commercially viable on a large scale, this windbreak by-product provides an important addition to local diets. *Acacia scorpioides* trees planted in windbreaks in Niger are now producing seed pods used for traditional leather tanning. Since there is a steady market for this product, the windbreaks make a modest but much appreciated contribution to the local economy. In other cases where windbreaks have been established with *Prosopis*, seed pods are collected daily for supplemental livestock feed and some are sold on the local markets.

In north-west China multi-row shelterbelts of *Paulownia* have been planted to stop desert encroachment. A 21–55% decrease in wind speed was measured in the protected area, together with increases of 12.5% in air humidity and 19.4% in soil humidity (in the top 50 cm). Maximum summer and winter temperatures were reduced, crop yields increased and wood produced.

The reported effects of windbreaks on crop yields vary considerably. In some cases grain yields have increased significantly, in other cases the competition for water and light, the land "lost" to the tree planting, or changed microclimate have been found to be slightly detrimental. The effect on yield is clearly dependent in large part on the design of the windbreak, and the particular crop and environment involved. Because of this, the multiple tree products and long-term soil conservation should be considered to be the primary benefits.

In the Sahel, windbreaks seem to have a positive effect on the crop yield of protected fields. Though statistically valid results are still not available, it appears that millet and sorghum yields in fields protected by windbreaks of neem can be as much as 23% higher than in unprotected fields nearby (Bognettean-Verlinden 1980). In a year with poor rainfall, even relatively small differences in crop yields can be significant for the local population. It was estimated that pollarding these windbreaks every four years would bring Majjia Valley residents US$ 800 worth of construction poles and wood per kilometre of windbreak (USAID 1987).

Planners working on windbreaks for the Gezira irrigation scheme in the Sudan have estimated that windbreaks could increase the yield of existing irrigated fields and could save enough water to irrigate more land. A crop yield increase of 5% would be enough to cover all establishment and maintenance costs of the shelterbelt. Additional crop yield increases, plus wood, fodder, honey and soil improvement would be clear profit. Planners estimate that a family with 10 ha of land would harvest 7.5 m^3 of wood, 0.41 tons of extra cotton, and 1 ton of fodder from shelterbelts on their property. In addition, the savings in irrigation water would allow 2,000 new families (at 10 ha each) to join the Gezira scheme on expanded acreage under irrigation (K. Openshaw, personal communication).

A mini-version of windbreaks may also be quite useful for local vegetable gardens as well as small irrigation schemes. In these cases, they could be best combined with living fences. Here the design would have to take the relatively small size of the plots and their geometric layouts into consideration. The tree height will be less than the larger-scale versions designed to cover the entire plain or valley. Different species may also be more appropriate: *Moringa oleifera*, for example, or *Gliricidia*, *Markhamia* or fruit trees. Especially if supplemental irrigation water is available, the most productive (and marketable) fruit trees are likely to interest farmers the most. For example, passion fruit (*Passiflora edulis*) functions as a windbreak on small farms in Kenya where it is trained along wire fences (USAID 1987).

5.5. *Examples of successful activities*

A fairly extensive windbreak research and testing programme is being carried out in the Majjia Valley of Niger (Tahoua Department) by the Niger Government, USAID and CARE. Yields from individual trees cut under different management cycles and farm crops (with and without windbreaks), and the distribution of benefits are being studied. The project began in 1975 with the establishment of large-scale windbreaks. A total of over 300 km of windbreaks have been established to date, eventually protecting over 3,000 ha of farmland. These originally consisted of double rows of neem, but were later replaced and/or mixed with *Acacia scorpioides* and *Prosopis* spp.

Large-scale windbreak programmes have also been undertaken in the central parts of Senegal, in some cases using cashew trees (*Anacardium occidentale*).

In the Singida District of Tanzania farmers have used tall hedges of *Euphorbia* to protect croplands. Throughout the highlands of Kenya tall shelterbelts of *Grevillea robusta* are used to protect tea plantations. Insect pests infesting the tea have been known to take refuge in these trees, reducing the popularity of shelterbelts. In the dry and sub-humid savannas of Kenya, *Eucalyptus*, *Casuarina* and cypress species have been planted in windbreaks for large commercial farms and homesteads. While there have been many systematic experiments on species performance, very little is known about the actual effects on crop yields and soil erosion in Kenya.

Some farmers and researchers also question whether shelterbelts will encourage tsetse flies in infested savanna areas. Kenyan and Tanzanian experience suggests that windbreaks need not shelter tsetse flies if the proper species are chosen and they are well managed. If the understorey is relatively open, the overstorey high and the ground surface clean-weeded, then tsetse infestation is not likely.

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35. Agroforestry and biomass energy/fuelwood production*

P.K.R. NAIR

The fuelwood situation in many developing countries has become so alarming that any discussion on farm productivity and land use cannot be complete without a treatment of this subject. This is particularly so in a discussion involving trees, and therefore forestry and agroforestry, because trees and shrubs constitute the main source of firewood and other forms of biomass energy.

Examining the role of agroforestry (primarily the woody components) in energy production, Raintree and Lundgren (1985) identified the following as the major areas of its potential contribution:

1. Woodfuels for direct combustion: firewood, sawmill wastes, etc.;
2. Pyrolytic conversion products: charcoal, oil, gas;
3. Producer gas from wood or charcoal feedstocks;
4. Ethanol from fermentation of high carbohydrate fruits (e.g., babassu palm, breadfruit, carob or prosopis pods) or other tree parts (e.g., sago palm);
5. Methanol from destructive distillation or catalytic synthesis processes using woody feedstocks;
6. Other potential fuels from experimental technologies on biomass energy using tree products as feedstocks.

Needless to say, the woody components involved in these systems, by virtue of their multiple output and multipurpose nature, will also play other functions. These include not only direct production roles (including production of other basic needs), but also indirect service and/or protective roles (whereas the tree enhances the output of other components as well as the long-term sustainability of production of the overall system).

Although all the productive and protective functions of agroforestry are important in biomass energy concerns, the most conspicuous energy issue for millions of rural people throughout the developing countries is the daily scramble to find the wood they need to cook a meal. The terms "firewood" and "fuelwood" are used almost synonymously to refer to such wood. Although fuel for cooking is the most important use of firewood, there are

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also other uses such as heating and lighting. Wood remains the main fuel source even in areas where forests are rapidly disappearing. The situation with respect to fuelwood availability and supply is worsening day by day, and several studies have recently been published to highlight the gravity of the situation and draw governmental and international attention to methods of tackling it.

The problem of fuelwood shortage cannot be tackled in isolation from other aspects of rural development. The rather unimpressive performance of large-scale forestry and reafforestation programmes in the developing countries offers a good lesson. Benefits resulting from forestry programmes are not often readily and rapidly forthcoming so that it is difficult to secure the co-operation of governments and the people, for whom the short-term perceived needs such as increasing production of food crops and livestock frequently outweigh the long-term importance of forest resources. Recent studies have indicated that fuelwood cutting is second only to clearing land for agriculture as a major cause of deforestation (FAO/SIDA 1983). It seems, therefore, that the chances of a programme for fuelwood production being successful are greatly enhanced if it can tackle the production not only of fuelwood *per se* but also of food crops. Agroforestry offers great scope in this context because one of its underlying concepts is simultaneous production of food and wood (King 1979; Lundgren and Raintree 1982). Integration of appropriate fuelwood species on crop- and livestock-production units thus seems to be one of the best strategies for fuelwood production in the rural areas of the developing countries.

1. Firewood species

Any woody material can be considered firewood, and therefore any woody plant can be a firewood species. However, the term firewood species, as used in the current literature, denotes plant species suitable for deliberate cultivation, especially in developing countries, to provide firewood for cooking, warmth (heating) and sometimes lighting. An international expert panel on firewood crops constituted by BOSTID (Board on Science and Technology for International Development) of the US National Academy of Sciences identified over 1,200 firewood species. Of these, about 700 were given top ranking signifying that they are the potentially valuable ones which deserve increased research attention, and 87 of them were described in some detail in two volumes of a treatise on the topic (NAS 1980, 1983). In preparing these reports, special considerations were given to plants that:

- have uses other than providing fuelwood;
- establish easily and require little care;

- adapt well to different ecological conditions as well as problem environments such as nutrient-deficient or toxic soils, sloping areas, arid zones, tropical highlands; and
- have special desirable characteristics such as nitrogen-fixing ability, rapid growth, coppicing ability, ability to produce wood of high calorific value that burns without sparks or toxic smokes.

Most of the plants described in these reports are little known in traditional forest production, some being many-branched, short-lived woody shrubs rather than majestic forest trees. The primary emphasis in these compilations was the suitability of the species for growing as firewood for individual family needs. There are also several other reports on relatively little-known or underexploited species with immense value as firewood species (Nair 1987).

2. Firewood production in agroforestry systems

It has already been pointed out that a large number of woody perennial plants can be grown as firewood species. But recent experience with low-input farm forestry efforts have amply illustrated that the small farmer's preference is always for trees that yield multiple outputs however serious the fuelwood shortage is. Foley and Barnard (1984) put the problem in the correct perspective:

> Numerous programmes . . . have been based on the belief that because fuelwood scarcities appear to be getting worse, people will automatically want to plant fuelwood species. Hence eucalyptus and other fast growing trees have been promoted, often with very poor results. It now appears that people, in many cases, would have been more enthusiastic about planting trees to meet their animal fodder and other needs, with fuelwood being a subsidiary benefit rather than the prime motive.

One of the prime considerations in the choice of trees in agroforestry is their capability for improving microsite qualities and imparting sustainability of production, so that the land on which they grow is made a better medium for not only their own growth but also of the other companion herbaceous species. As Hall and Coombs (1983) observed, "the problem with integrated fuel-food systems is that, since all parts of the plant can be used, all parts could be removed". Leguminous trees are particularly important in this context because of their ability to fix atmospheric nitrogen. A large number of such leguminous woody perennials with agroforestry potential have been identified (Nair *et al.* 1984; Doebereiner 1984) and the Nitrogen Fixing Tree Association (NFTA, P.O. Box 680, Waimanalo, Hawaii 96795, USA) and

several other agencies are involved in promoting research and development efforts on this important group of plants.

3. Programme options – lessons from forestry initiatives

While considering agroforestry approaches to fuelwood production we need to draw from the experience and results of the recent efforts in tropical forestry and other tree-based land-use systems. Such results include not only the failures and pitfalls of conventional forestry but also the strengths and achievements of some non-conventional approaches. The accumulated experience to date has recently been reviewed by Foley and Barnard (1984), and using that review as a basis, Raintree and Lundgren (1985) have identified ways in which agroforestry might be used to improve existing programme approaches in rural biomass energy production.

3.1. *Farm forestry*

Farm forestry, which is one of the major forestry initiatives of recent times, refers, in common usage, to growing of trees by individual farmers on their farmland, usually as cash crops. When undertaken by relatively resource-rich farmers, the basic strategy is to maximize the profit from the investment. This is accomplished through commercial production using higher levels of inputs, better technical packages and short-rotation species. These approaches to maximize profits can lead to effects such as low labour needs (and therefore reduction of local employment opportunities), failure to increase local supplies of fuelwood and fodder (because the target is the more lucrative urban market), and likely use of productive agricultural land rather than the so-called marginal lands for tree planting (and thereby defeating the expected environmental objectives of tree growing). On the contrary, the low-input approach to farm forestry is for relatively resource-poor farmers, with the objectives of obtaining small, yet attractive returns with minimum additional investment. The number of trees per farm is low, and they are planted around the house and/or along the boundaries at very little extra cash cost to the farmer. Agroforestry can improve this small farm variant of farm forestry by better integration of trees with other components of the farming system through agrisilvicultural options as, for example, in Nepal (Fonzen and Oberholzer 1984; Chapter 7) or silvopastoral practices such as, for example, in Venezuela (Escalante 1985; Chapter 31), and thereby reduce the opportunity cost of trees as well as make it possible for the trees to benefit, in a non-competitive way, from the inputs normally given to the crops.

3.2. *Community forestry*

A wide range of activities falls under this general heading of community forestry, all with a common element of the use of public or communal lands for tree growing, though for a variety of objectives and often with considerably varying degrees of community participation. Although they have the potential to address a wider range of community needs than private initiatives, these activities are more difficult to design and implement effectively, mainly because of the difficulty of mobilizing a genuine community interest among diverse segments of the local population. It will also be difficult to ensure equitable distribution of the communal resources, resulting in individuals and groups with better social and other "powers" becoming disproportionately larger beneficiaries at the cost of the poorer or weaker sections. Coupled with this, some poorer sections of society who depend on such communal lands for free collection of fodder and fuel will be deprived of this meagre source of income if such communal lands are commercialized.

Nevertheless, in spite of these drawbacks, community programmes offer opportunities for broad-based rural development planning. The scope for firewood production through agroforestry in community forestry lies mainly in the silvopastoral and agrisilvicultural (living hedges) practices. The tree species selected for the plantation could themselves be MPTs with high fuel and fodder values such as many species of the genera *Acacia* and *Prosopis*. Careful management, including appropriate thinning and pruning regimes, can lead to production of large volumes of high-quality feed material without any significant reduction in the eventual yield of firewood (or timber).

3.3. *Woodlots*

Woodlots are block plantings of trees. On most occasions, foresters think about tree planting as some forms of block planting, so that "community forestry" and "farm forestry" are generally perceived as community woodlots and farm woodlots. However, in areas where land is scarce, most farmers cannot afford the luxury of farm woodlots. The situation could be different if marginal and degraded lands that are unsuitable for food production were available. In such situations, there are at least two tree arrangement alternatives, namely, block planting and row planting on farm or plot boundaries. There can also be zonal arrangements of blocks of trees and crops in alternate or regular strips, as well as mixed tree – herbaceous-crop associations. Obviously, the choice of the arrangement will depend on site-specific factors. But, as Raintree and Lundgren (1985) have pointed out, woodlots are unlikely to be the first resort of agroforestry project planners, although they will continue to play a significant role in meeting rural energy needs in developing countries.

4. Some socio-economic factors

4.1. *Subsistence vs. commercial production*

In most developing countries, infrastructure for markets and communication is so poor that commercial production of fuelwood is still a distant dream. In many cases, the scarcity situations have only recently come to be recognized so that there has not been enough time for a marketing infrastructure to develop adequately. Moreover, in many impoverished rural areas people still take free collection of firewood for granted and do not consider buying it. However, in some situations refined fuels such as charcoal may be bought, which can minimize the transportation constraint to some extent.

Potential agroforestry and other tree-based systems span a wide range of opportunities, from commercial to purely subsistence systems. The emphasis at present is more towards the subsistence end of the scale, and the situation is likely to remain so in the foreseeable future. Therefore, research and development efforts that are planned will have to be oriented primarily to the subsistence farmers.

4.2. *Fuelwood production in the context of competing land-use options*

Experts in biomass energy seem to accept that possibilities for diverting large areas of arable land for energy production exist only where land is abundant and the national need for indigenous production of energy, especially liquid fuels (Hall and Coombs 1983), is great. Forest lands are usually committed to certain forms of forest management designed to meet national targets for forest products. Policy planners also often repeat some "magic" statistics of a certain percentage of total land area that must be under certain types of forest, apparently without either examining alternative ways of producing the desired outputs with smaller areas under forest, or assessing whether such forested lands are being efficiently managed. At the same time, the demand for more land to produce food is increasing tremendously, not only as a consequence of the increase in population but also because vast areas of cultivable lands are being rendered unsuitable for sustained production because of defective land-management practices. Forestry departments are, therefore, finding it extremely difficult to keep their lands under forest, and they often regard farmers as their "enemies". Taking agriculture or, for that matter, firewood crops to forest land with the blessing of the forestry departments, therefore, seems to be an uphill task. Moreover, shortages of appropriately skilled manpower and sufficient numbers of properly trained labour can also be a bottleneck in forestry departments' efforts to undertake innovative forest management.

Thus, the scenario is such that forests (land under forestry departments'

control) are unlikely to be available for fuelwood production through the agroforestry approach in most developing countries. Similarly, food production will continue to be of top most priority so that it may not be prudent or feasible to envisage any substantial fuelwood production schemes on arable agricultural lands at the cost of food production. However, agroforestry can be of value in this context by:

(i) Incorporating and integrating appropriate species of woody perennials on farmlands along with other components of the farming system not in a competitive but in a complementary way;
(ii) Integrating herbaceous crops and livestock on forest land according to the agroforestry management schemes so as to facilitate simultaneous production of wood and food crops; and
(iii) Employing agroforestry techniques for reclamation of degraded lands and proper utilization of "wastelands".

Some prototype agroforestry technologies for each of these situations are now available. Most of these have evolved through the trial-and-error approach of local farmers with practically no scientific input to improve them. The greatest scope for improving their efficiency and obtaining tangible results in such a programme lies with the integrated food and fuelwood production initiatives in smallholdings.

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Part 7

The state-of-the-art of agroforestry

36. Institutional and policy aspects of agroforestry*

B.O. Lundgren

1. Land-use institutions today

The basic institutional structures established to deal with the use of land in virtually all the countries of the world today originate from temperate Europe and North America. There, in the late nineteenth and early twentieth centuries, the modernization of agriculture and forestry, which was necessitated by and dependent upon the rapid industrialization, led to the gradual emergence of government and private institutions to support the land users. Crop production and industrial wood production, which were carried out on separate types of land, required different professional skills, had different aims, and very often were managed by different owners (farmers versus governments or private companies). It was entirely rational, therefore, that agricultural and forestry institutions developed independently of each other. In the few cases where it was deliberately planned that trees, crops and/or animals should interact in specific technologies or land-use practices, for example in windbreaks, shelterbelts, hedges, grazing in fruit orchards, or game management for meat production in forests, there was never any difficulty in establishing which institutional sector was "responsible" for the technology or practice. With very few exceptions, anything done on designated farmland, even if it involved tree growing, was (and is) the responsibility of the agricultural/horticultural sector, and any use of forest land, including game management, rational utilization of wild berries, mushrooms, etc., falls under the forestry sector.

As a result of these separate institutional developments, there are today different laws and policies governing agricultural and forest land use; there are separate training, education and research institutions; advice to land users is provided through separate extension services; agriculture and forestry normally fall under different ministries or, if they are under the same ministry, under separate departments.

Another important aspect of the land-use legacy from the industrialized countries is that all policies and disciplinary R & D efforts are aimed at *maximizing*, in a sustainable way, the output of products per unit of land – this applies as much to wheat, maize, milk and meat as it does to timber and pulpwood. Commercially-oriented monocropping dominates the use of land

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and has been seen as very successful as markets for agricultural and forest products have continuously increased in volume over the last century. Subsistence use of land, in the sense of people being dependent on their own land for food, has virtually disappeared in industrialized countries.

When the European colonial powers established their administrations in Africa and elsewhere in tropical and subtropical regions, the institutional structures, policies and aims related to land use and development used in the home countries were simply copied in the colonies. This applied also to those countries which were not colonies, e.g., in Latin America, where governments chose to adopt the industrialized countries' institutional structure in land use. The model has been continued after independence in all tropical countries and the post-war international organizations that were set up to assist the emerging nations in improving and rationalizing the use of their land resources are all oriented on conventional-discipline lines. There is little doubt that the concentration of R & D efforts on the particular commodities, technologies and practices which the monodisciplinary approach leads to, has resulted in some remarkable success stories in tropical countries during this century in agriculture, forestry and other land-use disciplines. However, in spite of these limited successes, there are, quite obviously, many aspects of land use which are not successful: to mention a few: declining food production per capita in most of Africa over the last 25 years, alarming rates of increase in man-made desert conditions, erosion and flooding, existing or imminent energy crises due to lack of fuelwood, etc. It is open to discussion whether the main causes of these conditions are demographic, political, technological, economic or environmental. It is generally agreed, however, that there is no single cause but rather a complex interaction among several factors – interactions which are different from place to place and country to country.

A significant contributor to the failure to solve many important land-use problems is the inappropriateness of conventional- discipline-oriented institutions for identifying and addressing *real* problems in land-use systems in most developing countries. This particularly applies to the multitude of subsistence or mixed subsistence/cash farming and pastoral systems in which the vast majority of rural land users live and from which they eke out a living. They differ, of course, with ecological and socio-cultural conditions, from the purely nomadic pastoral systems of the arid to semi-arid zones to the sedentary mixed-farming systems on upland soils in subhumid areas and the shifting cultivation in the humid zones. Some features are shared by most of them, e.g., low cash incomes and, hence, little ability to invest in improvements requiring money, and marginal ecologies, such as infertile or erosive soils, or marginal climates. Often, land tenure is insecure or non-existent. Common lands, which often serve as important sources for fuelwood, building material, grazing, etc., are diminishing in area or are being degraded through overuse as a result of increasing populations.

The subsistence land user's strategy and aims are to use his labour and land resources to *optimize*, with minimum risk, the production of various products and services required to satisfy *all* his basic needs.

2. Why are today's institutions inadequate?

The fundamental inadequacy of conventional-discipline-oriented institutions lies in the failure to acknowledge and understand these basic facts, strategies and aims, and in the inability to adapt to them. These institutions are geared to the *maximization* of individual components, be they food crops, cash crops, animals or trees. There is little understanding that the land user needs to share out his resources for the production of other commodities or services. Even if such an understanding appears to exist – the forester may generously agree that food production is essential and the agronomist may not disagree that fuelwood is needed – there is very little technical comprehension of the requirements for producing commodities outside one's own discipline. The inability of technical institutions and experts to understand how social, religious, cultural and traditional beliefs and preferences can nullify a convincing cost/benefit analysis has been so well documented by social scientists that there is no need to elaborate the point.

It is, quite obviously, this lack of understanding of the complexities of many land-use systems, which is built in to the very foundation of conventional institutions, that is the basic cause of the many failures and frustrations in trying to solve the land-use problems of developing countries today. Land users are generally not conservative or "primitive"; they are not adamantly unwilling to improve their lot; they are not opposed to increasing their yields or cash incomes; nor are they hostile to planting and caring for trees on their land - *provided* we understand how technology changes and improvements fit into *their* problems, priorities, beliefs and aims. The situation today can be summarized as in Figure 36.1 (Lundgren 1987).

There are a large number of more or less narrowly specialized sectors, disciplines, institutions, scientists and experts, laws, policies, etc., all dedicated to maximizing (within limits known to and identified by themselves) "their" product, i.e., which look at *one* segment of the land-use system only.

There is *no* institution today which has both the mandate and the competence to identify solutions to land-use problems based on an interdisciplinary analysis of interactive constraints and potentials *within* land-use systems, and the power to assign resources in a way that will cut across institutional boundaries in order to implement such solutions.

There are, nevertheless, a few positive signs that awareness of the need to address the institutional constraints to real problem-solving is increasing. For example, the recently published report of the *World Commission on*

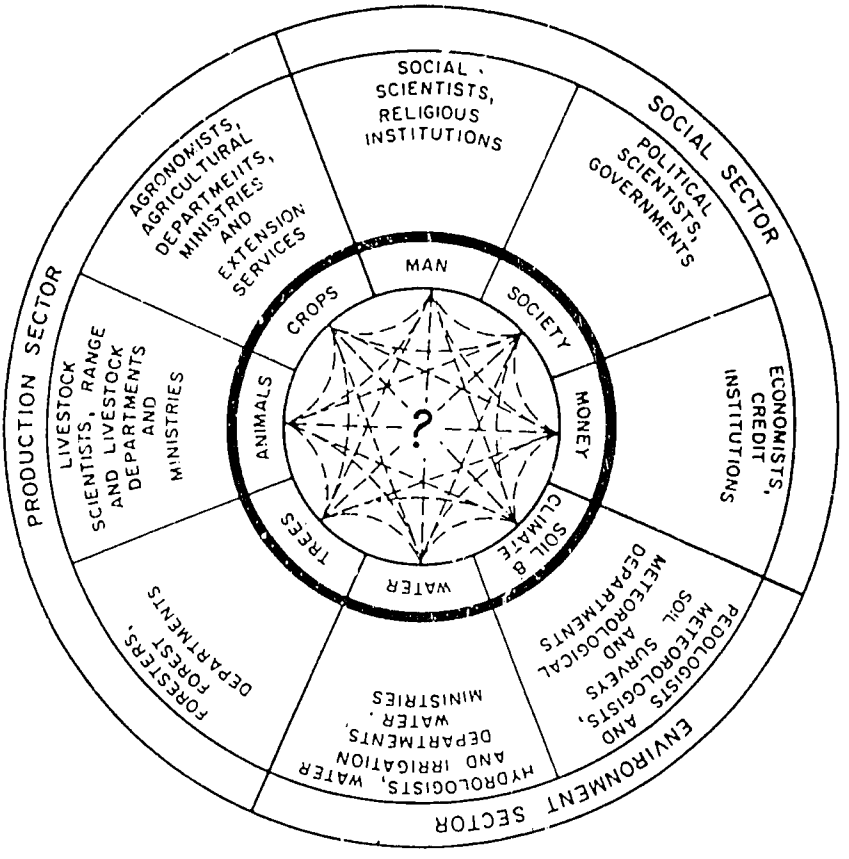

Fig. 36.1. Institutional dilemma of land development? Disciplinary institutions look at specific compartment of a land-use system only and normally do not consider the complex interactions within the system.

Source: Lundgren (1987).

Environment and Development (the "Brundtland Commission") (1987) concluded:

> The integrated and interdependent nature of the new challenges and issues contrasts sharply with the nature of the institutions that exist today. These institutions tend to be independent, fragmented, and working to relatively narrow mandates with closed decision processes.

Less encouraging, however, is the fact that virtually all recent policy and planning documents from international institutions, even if they pay lip service to the need for multidisciplinarity, integrated approaches and holistic views, end up making conventional recommendations such as increased use of fertilizers, irrigation and genetically improved crop varieties, increased tree planting, etc. None contain any critical analysis of the adequacy of existing

institutions for addressing the totality of the problems and for contributing to their solution. This applies as much to agricultural (TAC 1987) and forestry (Adams and Dixon 1986; Carlson and Shea 1986) research, as to development statements, again both agricultural (FAO 1986a, 1986b, 1987; OAU 1985) and forestry (FAO 1985, WRI 1987).

One reason for the slowness with which the institutional problems are being addressed has probably been the lure of the statistics on "global problems" which have emerged over the past 15 years, e.g., on environmental and developmental problems such as desertification, deforestation, the fuelwood crisis and declining food production. As a result of improved techniques of survey, monitoring and other statistical methods, it has been possible to break down an almost infinite number of complex, local problems into their component effects and to add up these effects into global perspectives. Since it is easy to express the magnitude of these problems in conspicuous and alarming global figures, such as the numbers of hectares of forests that are lost, or land that is turned into desert, or the distance people will have to walk every day to collect their fuelwood, it becomes imperative and even very attractive to politicians, decision-makers and institutions to look for simple solutions to these problems and to extrapolate the likely benefits to a global scale. Disciplinary-sector institutions have been very successful in exploiting this situation to increase resource allocation to themselves by promising simple solutions to what appear to be straightforward problems – more tree plantations will solve the fuelwood and deforestation problems; more fertilizers and irrigation will increase food production, and so on.

The fact, however unappealing and complex it may be, is that just as the "global problems" are the sum of the effects of a large number of local problems, the solutions can only be achieved by adopting an equal number of sound land-use practices and political and economic measures (Lundgren 1985). Problems *must* be identified, diagnosed and solved where they occur. It does not help small-scale mixed farmers in district x of country y, to know that 300 million people in the developing world do not have adequate supplies to meet their fuelwood or protein requirements. There is an urgent need to re-think and re-evaluate the situation. The conclusions arrived at must direct the relevant institutions from the discipline-oriented maximization thinking that is fuelled by global statistics to the multidisciplinary optimization thinking that is geared to solving local problems.

3. Land-use institutions tomorrow

It would be presumptuous to propose an "ideal" structure and set of objectives for tomorrow's land-use-related institutions. No such ideal institution will ever exist because of the enormous variety in conditions, policies and

institutions among regions, countries, economies, etc. Some general thoughts on directions may, however, be relevant here.

1. In the short and medium term, and within existing institutional structures, collaborative programmes which cut across disciplinary boundaries and address concrete land-use problems must be encouraged and given more support, both at the national level and at the level of international agencies such as donors, UN bodies, and International Agricultural Research Centres (IARCs). It would be appropriate if the international institutions took the initiative in this. Unfortunately, such is not the case today: most international bodies and institutions are firmly entrenched in disciplinary thinking and actions. Although there are a few very encouraging exceptions, integrated approaches still seem far away.
2. It must be strongly emphasized that in the future we will still need specialized institutions and experts – the plea for multidisciplinary, inter-institutional approaches and integrated thinking must not lead to the formation of super institutions manned exclusively by generalists. Undoubtedly there will be a need for crop physiologists, maize breeders, tree geneticists, fertilizer experts, insect ecologists, and so on, and for specialized institutions that provide a working environment for such experts. Even the most "perfect" interdisciplinarily-derived research or development programme must, when being implemented, be broken up into its component parts, and then resynthesized. If there is inadequate expertise on the structure and function of the component parts, then the whole entity (the improved land-use system, or whatever) will never be fully operational and optimized.
3. What will be needed are new institutional functions for problem identification, priority setting and resource allocation, without necessarily making fundamental changes of structure. Such new functions can be created within or between existing land-use ministries and departments, or as independent bodies with existing institutions subordinate to them. It would probably be best to start by creating inter-institutional committees for planning but which will become more and more executive as experience is gained. Depending on the problems to be addressed, these committees can then create appropriate task forces of existing disciplinary institutions and resources.

These may not sound very fundamental changes but they will require fundamental rethinking among disciplinary scientists, institutions and decision-makers. The sooner this process starts, *the faster can some of the key* land-use problems of the world be solved.

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37. A decade of developments in agroforestry

P.K.R. NAIR

Writings on agroforestry are replete with statements to the effect that "agroforestry is a new name for an old practice". For example, many authors in the commemorative volume for ICRAF's tenth anniversary (Steppler and Nair 1987) subscribe to this view, and trace the origin of the word "agroforestry" to the Bene Committee's report (Bene *et al.* 1977) that led to the establishment of ICRAF. But there is evidence that even the word agroforestry – no, "agriforestry" – is not that new. A report in *The Hindu*, a respected national newspaper of India published from Madras, dated 6 November 1936 reads as follows:

> *Agriforestry scheme*
> A scheme known as agriforestry which was a combination of agricultural and forestry was adopted at the meeting of Central Fodder and Grazing Committee of the Imperial Council of Agricultural Research,* which met at New Delhi. The Committee which urged the necessity of controlling the number of cattle allowed on grazing grounds passed the following resolutions:
> 'The Committee strongly approves of the scheme put up by the United Provinces Forest Department for a preliminary survey to examine the possibilities of creating fuel and fodder plantations in the plains districts. Forestry-cum-agriculture known as the Taungya in the United Provinces† has proved in forest areas most beneficial to the cultivator as a means of supplying poles, firewood and fodder, as also giving good land for cultivation and at the same time allowing of regulated forest development. The possibility of applying this system to lands remote from forests and private lands is now to be explored. The Central Fodder and Grazing Committee comments this method for consideration in other parts of India also'.

Similarly, Jameson's book *Agriculture in Uganda* (Jameson 1970, pp. 197–198) describes a demonstration of shade effects on robusta coffee planted at Bukalasa, Mengo, in 1935. Treatments applied to six large plots were:

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* Now Indian Council of Agricultural Research (ICAR).
† Now Uttar Pradesh State.

P.K.R. Nair (ed.), Agroforestry Systems in the Tropics, 609–616.
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(i) no shade;
(ii) natural shade of *Acacia* sp.;
(iii) *Ficus* (barkcloth) shade;
(iv) *Erythrina* shade.

The results of this trial are described in that book. Although this practice was not called agroforestry at that time, nobody would disagree that it comes under what is called agroforestry today.

There are also several other such earlier reports on "agroforestry-type" trials and efforts.

So, neither the word nor the concept of agroforestry is new. What is relatively new is the development of agroforestry as a science and as a focus for systematic development effort. The concept of *optimization* of the production of various products and services, with minimum risk, from a unit of land, as opposed to *maximization* of a single commodity in monocultural production systems (Lundgren 1987) is perhaps new in agroforestry as we know it today. This concerted effort to develop agroforestry as a sustainable approach to land management gathered momentum only in the mid-1970s and it was institutionalized with the establishment of ICRAF in 1977. The developments in agroforestry have been substantial since then. These developments can be grouped under a few categories such as collection and synthesis of information, conceptual and methodological developments, technology-generating research, socio-economic aspects, research networks, and training and education.

ICRAF has been (and continues to be) the lead institution in agroforestry. Therefore the developments in agroforestry are inseparably mixed with those of ICRAF.

The ten years of useful and successful existence of ICRAF were celebrated in a befitting manner in September 1987. The highlights of the celebrations included an international conference and a technical seminar attended by over 100 participants (scientists, administrators, policy planners, donor representatives, students, etc.) from different parts of the world. Two significant publications were brought out on that occasion: one a book titled *Agroforestry: a decade of development* (Steppler and Nair 1987), and the other a special issue of *Agroforestry Systems* (Vol. 5, No. 3). The former consists of 17 chapters authored by leaders in their respective fields and active in the promotion of agroforestry, and covers a wide array of subjects. The special issue of *Agroforestry Systems* includes 12 articles written by ICRAF staff and summarizes a decade of ICRAF's work. These two publications embody the most significant developments in agroforestry over the past decade. It is neither feasible nor necessary to repeat all aspects of these developments here. However, the salient features will be mentioned briefly.

1. Collection and synthesis of information

The most significant ICRAF activities in this direction are the Agroforestry Systems Inventory (AFSI) and the Multipurpose Tree and Shrub (MPTS) database. A summary of the former is given by Nair (1987) and the results of the inventory are described in this book. The MPTS database and information system have assembled an enormous amount of information on several hundred multipurpose trees and shrubs in agroforestry systems (von Carlowitz 1987). These inventories show a bewildering array of agroforestry systems worldwide. They also show that there are relatively few rigorous experimental data pertaining to the performance of agroforestry systems, that the number of multipurpose trees being used in various systems is in excess of 2,000, and that the systems vary from relatively simple with two or three components to the complex homegardens which may contain upwards of 50 species plus animals and fish. Other aspects of agroforestry on which some information has been gathered at ICRAF include environmental data and economic aspects. There is also an elaborate computerized agroforestry bibliography at ICRAF.

Notable among other institutions that have made significant progress in agroforestry information is CATIE (Centro Agronomico Tropical de Investigacion y Ensenanza), Turrialba, Costa Rica. The Spanish book *Sistemas Agroforestales*, produced jointly by CATIE and OTS (Organization of Tropical Studies, a consortium of mostly US universities and scientific institutions; OTS CATIE 1986) is a comprehensive volume on agroforestry in Latin American countries. There are also several other regional and national institutions/research groups dealing with agroforestry, and one of the common tasks in all such cases is collection and synthesis of information on indigenous agroforestry systems.

2. Conceptual and methodological developments

As mentioned in the early sections of this book, the early part of the last decade (the late 1970s and early 1980s) represented an era of conceptualization of agroforestry. Many definitions were proposed, many concepts were elucidated and many hypothesis (albeit mostly speculative and sometimes exaggerated) were advanced on the potential role and benefits of agroforestry. It soon became evident that the *science* of agroforestry was beset with much anecdotal material (Steppler 1987). Most experimental methodologies and designs in land-use disciplines had been developed for monocultures and, as such, were not applicable to agroforestry research.

Therefore one of the early scientific activities at ICRAF has been the development of appropriate research methodologies. These pertain to both

agroforestry systems *per se* as well as to specific components (Huxley 1987). ICRAF's "diagnostic and design (D&D)" methodology embodies a common-sense, problem-solving approach to diagnosing land-management problems and design agroforestry solutions (Raintree 1987). But the problem is complex because of the multiple outputs and direct and indirect benefits of agroforestry systems, as well as their location-specific nature.

3. Technology-generating research

Despite the above-mentioned complexities and difficulties of doing research in agroforestry, several research initiatives in various aspects of agroforestry are under way in different places around the world. Prominent among these include research on alley cropping (Kang and Wilson 1987), nitrogen fixation and nitrogen-fixing trees (Dommergues 1987) and soil productivity and protection (Young 1987). Some species of multipurpose trees have also been relatively well studied, notable among them being the genus *Leucaena* (Brewbaker 1987) (although the amount of such work pales when compared to that done on maize or wheat).

4. Economic aspects

Reviewing the economic considerations in agroforestry, Arnold (1987) stated that the established presence of agroforestry practices in many land-use systems today has perhaps been overshadowed by the concerns of particular contemporary problems that underlie much of the recent interest in it. As a result, we may have been more concerned with developing new or improved agroforestry practices to cope with such issues as fuelwood shortages than with increasing our understanding of how existing activities function, and what economic contributions they make. Yet some of the most dynamic changes that have occurred in the recent past have been in existing agroforestry systems.

Most of the descriptions of existing agroforestry systems given in Chapters 7–31 contain information, to varying extents, on related benefits and costs of constraints. These positive and negative economic features and the underlying hypotheses about agroforestry are summarized in Table 37.1.

Agroforestry practices contribute to a wide variety of existing farming systems. In a number of these, farmers have been responding to growing pressures on their land and other resources by intensifying or increasing various agroforestry activities. These have proved to be particularly important in enabling them to intensify use of certain types of land as sizes of land holdings decrease, and to reduce the intensity of management as labour

Table 37.1. The main benefits and costs of agroforestry.

Benefits and opportunities	Costs and constraints
Maintains or increases site productivity through nutrient recycling and soil protection, at low capital and labour costs.	Reduces output of staple food crops where trees compete for use of arable land and/or depress crop yields through shade, root competition or allelopathic interactions
Increases the value of output on a given area of land through spatial or inter-temporal intercropping of tree and other species	Incompatibility of trees with agricultural practices such as free grazing, burning, common fields, etc., which make it difficult to protect trees
Diversifies the range of outputs from a given area, in order to (a) increase self-sufficiency, or and (b) reduce the risk to income from adverse climatic, biological or market impacts on particular crops	Trees can impede cultivation of monocrops and introduction of mechanization, and so (a) increase labour costs in situations where the later is appropriate and/or (b) inhibit advances in farming practices
Spreads the needs for labour inputs more evenly seasonally so reducing the effects of sharp peaks and troughs in activity characteristic of tropical agriculture	Where the planting season is very restricted, e.g., in arid and semi-arid conditions, demands on available labour for crop establishment may prevent tree planting
Provides productive applications for underutilized land, labour or capital	The relatively long production period of trees delays returns beyond what may be tenable for poor farmers, and increases the risks to them associated with insecurity of tenure
Creates capital stocks available to meet intermittent costs or unforeseen contingencies	

Source: Arnold (1987).

becomes scarcer and more costly. The appropriateness of agroforestry as a response to these changing pressures is often related to the concurrent shift in farmer production objectives towards income generation as farm size falls below the level at which they can meet their basic household food needs. These ongoing changes suggest the need for closer look at access to land, labour and capital as ways of promoting some agroforestry activities, and at the place of other activities as population densities increase. In particular, the growing importance of income generation as a production objective of farmers points to the need to give greater attention to the markets for agroforestry products and to the intermediate stages between production and the market. Increased economic research has an important role to play in clarifying and extending the understanding of these and other economic considerations in agroforestry.

5. Agroforestry extension

A recent analysis of the social aspects of agroforestry by Hoskins (1987) discusses a number of issues and points out the particularly important ones

that must now be taken into consideration if new techniques in agroforestry are to be adopted. These include: local uses and knowledge, tenure, organization, conservation, landlessness/distance, enterprises and marketing, labour, nutrition, and gender/age. The combinations of these social and political factors which are involved in promoting trees in traditional farming and livestock systems are unique, and as such deserve special emphasis. Some specific elements are similar to those found in organizing community development or in water-resource management. Agroforestry extension, however, is more commonly compared to agricultural extension, with which a number of the more temptingly obvious similarities prove to be superficial. Current agricultural extension methods are not tailored to include consideration of the special legal status which trees may have compared to crops, the time horizon for farmers before tree benefits may be available, the different seasonal rhythm of labour and other requirements of perennials compared to annuals, as well as the changing availability of many specific trees and tree products which have formerly been available as a free good. If methods commonly used in agricultural promotion programmes are adopted without careful modification for use with agroforestry, they may indeed defeat the promotion of farmer adoption, causing such programmes to come to a dead end, if they begin at all.

As newly designed agroforestry techniques move out into farmers' fields, overall development issues will also become increasingly apparent. At this juncture, there is need for serious examination of policy issues. At this juncture, there is need for serious examination of policy issues. Agroforestry cannot become the development tool of choice only when poor land-use practices by commercial loggers or by poorly designed irrigation or other large-scale agricultural schemes have created denuded hillsides or marshes. If the services of the poor are used to reconstitute wasted land, their rights to the rehabilitated resource must be protected. Policies need to be designed to support agroforestry as an intregral part of better land-use planning and to strengthen access to these new technologies for the poor not only on wasted lands. As a development tool, agroforestry will be helpful only if it can be put effectively into the hands of men and women farmers, and if the political decision-makers see this as a tool for achieving equity in development.

6. Research networks

Agroforestry cuts across different land-use disciplines such as agriculture, forestry and range management. Compartmentalization of these component land-use disciplines, with few or no mechanisms for inter-institutional collaboration, is the order of the day in most national and even international research bodies. This is a major impediment to the development of

agroforestry. Secondly, the multitude of variables for research and the location-specific nature of agroforestry problems set limits to the extent to which international research organizations can make an impact on technology generation in agroforestry. Therefore it has been realized that one of the effective ways of promoting research in agroforestry is through the mechanism of networking which encourages inter-institutional collaboration at national and regional levels. The key elements of the approach are to stimulate and assist (technically, and, sometimes, financially) national forestry, agriculture and other institutions to work together in analysing land-use problems and designing research programmes to solve them. ICRAF's AFRENA (Agroforestry Research Networks for Africa) programme, launched in 1986, is a major effort in agroforestry networking (Torres 1987). Other functional networks in agroforestry include the Nitrogen Fixing Tree Association (NFTA), based in Waimanalo, Hawaii, USA. There are also agroforestry networks in information and documentation, and training.

7. Training and education

Education and training programmes are key elements in agroforestry development. ICRAF held a workshop on education in agroforestry in 1982 which brought together experts from different parts of the world and discussed the major issues involved in developing educational programmes in agroforestry (Zulberti 1987a). ICRAF has also organized several training courses and programmes in agroforestry (Zulberti 1987b), especially to provide training in the use of its diagnosis and design methodology.

There are now an increasing number of universities, both in the tropical area and in the temperate, that are beginning to offer programmes in agroforestry some at the undergraduate and some at the postgraduate level. Further, and most encouragingly, students from both agriculture and forestry are preparing for careers in agroforestry. The need for development of appropriate curricula (rather than an optimum curriculum) in agroforestry has been well recognized and efforts to develop them are under way.

These are some of the major initiatives that have taken place in research and development of agroforestry during the past decade (1977–1987). These developments, however modest they might appear, are encouraging and in many respects impressive, given the limitations and constraints. The represent the coming of age of a new scientific discipline with prehistoric roots.

Several constraints and problems in the development of agroforestry have also been identified during this period. One of the major difficulties, the resolving of which is crucial to the development of all aspects of agroforestry, is the "institutional dilemma". In view of the importance of this issue, it is dealt with in some detail in the concluding chapter of this book.

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Appendices

Appendix I

THE AGROFORESTRY SYSTEMS DATABASE AT ICRAF*

1. The rationale of the database

When ICRAF's Agroforestry Systems Inventory (AFSI) got under way (Chapter 3), various difficulties were encountered in collecting information on the multitude of traditional systems from various parts of the world by different types of people. The basic survey instrument for the inventory was a questionnaire (Appendix 3.1 to Chapter 3), which consisted of a long list of subject areas, broadly categorized into:

- general description of the system
- geographical location
- bio-physical characteristics
- socio-economic aspects
- components and their uses
- evaluation of the system
- identification of research gaps.

Although the questionnaire was designed to be quite flexible, the data collected varied considerably in complexity, content, extent of details, etc. Several hundreds of these forms filled in by informants with site-specific data, plus a few comprehensive reports on some systems formed the primary information source for the inventory.

In spite of the shortcomings, these primary results from the inventory became a very useful set of information, especially because it was the first such comprehensive assemblage of data on existing agroforestry systems from different places in a unified form. Naturally, there was immediate and steadily increasing interest to make use of this unique information base for various purposes. It became necessary to retreive the information quickly and efficiently to enable ICRAF to play its expected advisory role in agroforestry research development. Besides, this information base soon proved to be a dependable and useful source for providing information on and building up the capability for making rational choices concerning the suitability of various agroforestry systems and species for specific sites and functional requirements. Simultaneously, new and/or up-dated information started coming in on new/already-surveyed systems. This need for efficient storage and quick

* Adapted from: Oduol, P.A., Muraya, P., Fernandes, E.C.M. and Nair, P.K.R. The agroforestry systems database at ICRAF, *Agroforestry Systems* 6: 253–270.

P.K.R. Nair (ed.), Agroforestry Systems in the Tropics, 619–655.
© 1989, Kluwer Academic Publishers, Dordrecht – Printed in the Netherlands.

retrieval of this massive information was the basis for starting the AFSI database.

2. Structure and operation of the database

2.1. *Procedure*

In order to narrow down the differences and heterogeneity of the primary data sheets, they were evaluated and transformed to successive sets of secondary data forms. By repeated "trial and error" procedure, an appropriate computer format was then developed and refined. This format of the database is outlined schematically in Fig. (Appendix) 1.

2.2. *Hardware configuration*

The database is currently on an IBM PC, 640K bytes RAM. The mass storage devices are two 5.25 inch (13.34 cm) floppy disk drives and one external 20 Mb, Tall Grass Technologies hard disk and tape streamer. The operating system is a single user IBM PC DOS 3.1. the printing device being an Epson LQ 1500.

2.3. *Structure*

The database contains raw data files and linking databases (Fig. (Appendix) 2).

The key file is *AFSystem* which contains the general description and geographical location of the system, biophysical and socio-economic data of the system, information on component arrangement, and a general evaluation of the system. The other key file is the *Species* file which contains all species details, technical (scientific) name, nature of species – annual or perennial, woody (tree/shrub) or herbaceous (annual or perennial) species –, common name of the species as generally known within the locality (system) or globally, and the role and uses of the species within the system.

All the files in the database are linked together by an *AFCODE*, by which the computer is able to address all of them together enabling as many search combinations as possible, in order to get a wide array of outputs. Samples of a few system printouts are appended. Comprehensive lists of woody and herbaceous species of plants that have been reported from existing agroforestry systems are also appended.

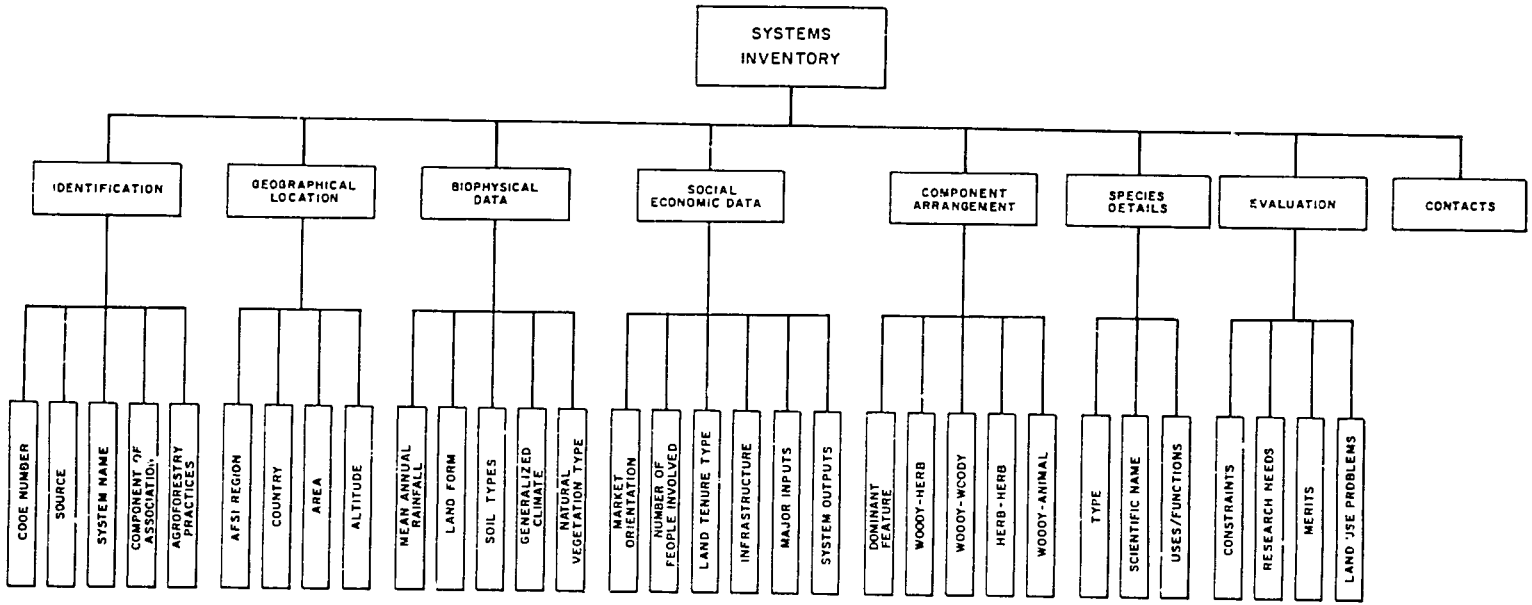

Fig. (Appendix) 1. Schematic outline of the format of AFSI database.

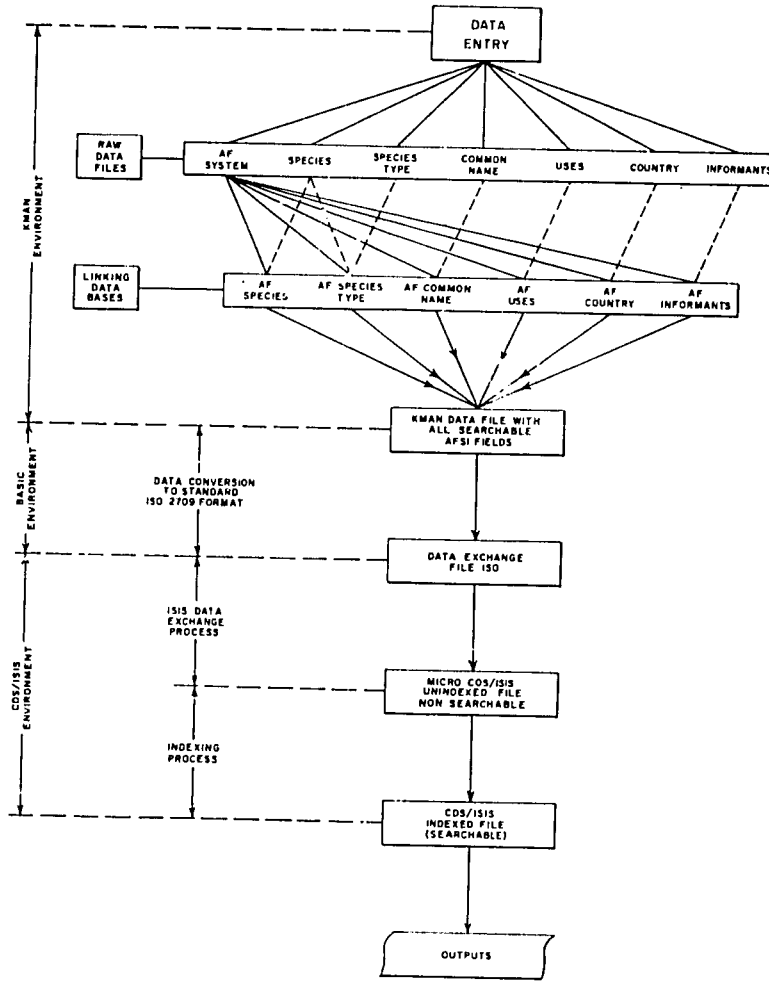

Fig. (Appendix) 2. Organization and general operations of AFSI database files.

2.4. *Operation*

There are basically two phases of the AFSI data base operation:

1. Data entry/manipulation
2. Data retrieval.

Data entry involves transferring information from a completed questionnaire or report into the computer; manipulation includes sorting by specific criteria and/or reorganization of the data to emphasize a desired parameter. The software for the two different operations has been selected with a view to

optimising their use. Thus the single user Knowledgeman 2 Database management software has been selected for data entry and manipulation. The splitting of the database into several different files is to maximize flexibility, but this causes some difficulties in data retrieval. Special programs in Basic/PASCAL have been developed to reorganize the information, allowing for a more user friendly data searching software – micro CDS/ISIS developed by UNESCO for quick retrieval (Fig. (Appendix) 2).

Information dissemination from the data base is very important and the database is now fully operational at ICRAF. It has been used widely for answering queries from within ICRAF as well as external sources. The most frequently sought information is on the agroforestry systems in specified geographical regions of the world or defined ecological zones, and information on species in various agroforestry systems. Cross matching of agroforestry systems with particular land-use characteristics is also a common exercise that is done to satisfy user requests.

The answers are usually in the form of specific computer outputs. However, some analytical thoughts are also incorporated into these outputs before sending them out so that as many examples and answers as possible are given for satisfying the request.

2.5. *Drawbacks*

The information storage method has problems in that only people who know the database structure can do the searches. In order to overcome this problem the data needs to be reformated to a form acceptable by the Micro CDS/ISIS program which is a user-friendly data searching program but CDS/ISIS is not flexible for programming, so there is always a need once new data is logged in to reformat data from Knowledgeman 2 files to CDS/ISIS files. This is a time- and memory-consuming process, but this process is not frequently done. The outcome enables people without knowledge on how the data base is structured to do searches.

Agroforestry system description

Code number: 0004/ECMF
Source: Michon et al (1983). [site specific]
System name: "Damar" (resin) tree gardens: Shorea javanica – rice – coffee – cloves – fruit trees
Mean management unit: 0.60 Ha
Range of management unit: 0.25–1.20 Ha
Components of association: Natural woody vegetation, Tree or shrub crops, Field crops (seasonal)
Agroforestry practices: mixed garden/

GEOGRAPHICAL LOCATION

AFSI region: South-east Asia
Country: Indonesia
Province: South Sumatra
Area: Lampung
Latitude: 03.4–06.0 S
Longitude: 103.5 E
Altitude: 100 m

BIOPHYSICAL DATA

Koppen class: Humid tropics, permanently humid
Mean and annual rainfall: 3000–3500 mm
Mean annual temperature: 25.0 C
Landform: Moderately sloping
Drainage: Seasonally waterlogged
Soil types: alluvial/
Generalized climate: Humid tropics
Natural vegetation type: Rainforest
Primary land use keywords: Forestry (natural)
Derived land use keywords: Rotational (managed fallow). Field cropping (rainfed)

SOCIAL ECONOMIC DATA

Market orientation: Subsistence with subsid commercial
Population density: 85/Sq.Km
Land availability: Scarce
Land tenure type: State owned
Market facilities: Fair
Credit facilities: Fair
Infrastructure: Poor
Cooperatives: Present
Capital intensity: Low
Labour intensity: High
Mechanization level: Hoe & spade
Input intensity: Low
System outputs: Damar resin, rice, cloves, fruit, coffee
Major inputs: capital/
Land operation: *Land holders*
Status: Locally established/evolved
Incentives to participate: not applicable/

COMPONENT ARRANGEMENT

Dominant feature: Time
Arrangement of woody perennial-herb species in time: Discrete (rotation)
Horizontal arrangement of woody perennial-herb species: N/A
Vertical arrangement of woody perennial-herb species: N/A
Arrangement of woody-woody species in time: Static
Horizontal arrangement of woody-woody species: Mixed
Vertical arrangement of woody-woody species: More than three layers
Herb-herb arrangement in time: Static
Herb-herb horizontal arrangement: Block
Herb-herb vertical arrangement: One layer
Woody-animal arrangement dominant feature: N/A
Woody-animal arrangement in time: N/A
Location of woody species: N/A
Horizontal arrangement of woody species: N/A
Vertical arrangement of woody species: N/A
Animal feed method: N/A

SPECIES DETAILS

Type	Common name	Scientific name	Uses/functions
Natural woody vegetation	Damar tree	*Shorea javanica*	Soil conservation/resin/fuelwood/crop shade/gum/
Tree crops	Durian	*Durio zibethinus*	Food fruit/crop shade/
Tree crops		*Baccaurea dulcis*	Food fruit/fuelwood/
Tree crops	Mangosteen	*Garcinia mangostana*	Fuelwood/food fruit/
Tree crops	Duku	*Lansium domesticum*	Food fruit/fuelwood/
Tree crops	Jack fruit	*Artocarpus heterophyllus*	Food fruit/food vegetables/fuelwood/building material/crop shade/
Tree crops		*Achras sapota*	Food fruit/fuelwood/
Natural woody vegetation	Soursop	*Annona muricata*	Fuelwood/food fruit/beverages/
Natural woody vegetation	Sweetsop, custard apple	*Annona squamosa*	Food fruit/fuelwood/
Natural woody vegetation		*Mangifera caesia*	Fuelwood/food fruit/
Natural woody vegetation		*Mangifera odorata*	Food fruit/fuelwood/
Natural woody vegetation		*Eugenia polycephala*	Fuelwood/food fruit/
Natural woody vegetation		*Eugenia malaccense*	Food fruit/fuelwood/
Natural woody vegetation		*Eugenia aquea*	Fuelwood/food fruit/
Natural woody vegetation	Rambuten	*Nephelium iappaceum*	Food fruit/
Natural woody vegetation		*Garcinia nervosa*	Food fruit/fuelwood/
Natural woody vegetation		*Eugenia polyantha*	Fuelwood/food spices/food herbs/
Natural woody vegetation		*Artocarpus elasticus*	Fuelwood/fibres/
Natural woody vegetation		*Arenga saccharifera*	Beverages/
Natural woody vegetation		*Tristania* sp.	Fuelwood/timber/building material/
Natural woody vegetation		*Alstonia angustifolia*	Building material/fuelwood/timber/
Natural woody vegetation		*Peronema caneseens*	Timber/fuelwood/building material/
Natural woody vegetation		*Terminalia* sp.	Building material/fuelwood/timber/
Natural woody vegetation		*Actinodaphne* sp.	Timber/fuelwood/building material/
Tree or shrub crops	Coffee	*Coffea* sp.	Beverage/
Tree or shrub crops	Clove	*Syzigium cumini*	Food spices/crop shade/
Field crops (seasonal)	Rice	*Oryza sativa*	Food seeds/

EVALUATION

Constraints: (1) Over mature gardens result in declining resin production. (2) Poor resin prices. (3) Land pressure.

Potential: The potential of existing gardens could be enhanced by incorporation of fast growing N fixing trees/shrubs (e.g. Leucaena leucocephala, Calliandra calothyrsus, Mimosa scabrella) for green manure. In addition, the use of improved fruit tree germplasm and appropriate livestok breeds could significantly improve productivity.

Research needs: Better management/harvesting of the damar to optimise resin production while ensuring a long productive life span for the tree. (2) Improved harvesting tools to minimise damage to the tree. (3) Improved germplasm of damar and other fruit/spice trees.

Merits: Damar gardens closely resemble the natural rainforest, thus soil conservation is good. (2) There is a diverse production (resin, cloves, coffee, fruit and rice) from the same unit of land.

Extrapolability: The establishment of Damar tree requires precise knowledge of its ecological & silvicultural requirements. In addition resin markets will need to be established. The system type, however, closely resembles the homegarden/mixed garden. Thus other valuable tree species could be substituted for damar trees depending on local ecological and market conditions.

Land use problems: (1) High intensity rainfall leading to erosion of unprotected soil. (2) Slow regeneration of soil fertility of cropped soils.

System history/background: Originally, natural stands of Shorea javanica were tapped. In the last century, however, cultivation of the tree (damar gardens) has become common.

Additional information: Clearings (about 1 ha) are made in the forest around the village & planted with rice for 2 years. From third year, damar, clove and fruit tree seedlings are interplanted. In some cases, coffee is planted after cropping with rice. The coffee is harvested for three years and then interplanted with damar, clove and fruit trees.

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Agroforestry system description

Code number: 0006/ECMF
Source: Sabine Miehe. ASP 19. [literature]
System name: Acacia albida and Butyrospermum parkii tree gardens.
Extent of system: 3000 Sq.Km
Mean management unit: 3 Ha
Components of association: Natural woody vegation, Field crops (seasonal. semi-perennial), Livestock.
Agroforestry practices: tree garden/

GEOGRAPHICAL LOCATION

AFSI region: Africa (Sahel & S)
Country: Burkina Fasso
Province: Mossi plateau
Area: Yako
Latitude: 12.5 N
Longitude: 002.1–002.2 W
Altitude: 500 m

BIOPHYSICAL DATA

Koppen class: Semi-arid, hot
Mean annual rainfall: 650–800 mm
Landform: Moderately sloping
Drainage: Seasonally waterlogged
Soil types: shallow/
Rainfall regime: Unimodal, high sun
Generalized climate: Semi-arid
Natural vegetation type: Savanna
Primary land use keywords: Grazing systems (nomadism, natural vegetation)
Derived land use keywords: Rotational (managed fallow), Complex cropping (mixed), Grazing systems (natural vegetation)

SOCIAL ECONOMIC DATA

Market orientation: Subsistence with subsid commercial
Number of people involved: 300,000
Population density: 125/Sq.Km
Ethnic group: Mossi
Dominant religion: Animism
Land availability: Scarce
Land tenure type: Freehold, tenancy
Credit facilities: None
Capital intensity: Low
Labour intensity: High
Mechanization level: Hoe & spade
Input intensity: Low
System outputs: Sorghum, millet, groundnuts, tobacco
Major inputs: seed/
Land operation: Land holders
Status: Locally evolved/established
Incentives to participate: not applicable/

COMPONENT ARRANGEMENT

Dominant feature: Space
Arrangement of woody perennial-herb species in time: Concurrent rotation
Horizontal arrangement of woody perennial-herb species: Mixed, sparse
Vertical arrangement of woody perennial-herb species: More than three layers
Arrangement of woody-woody species in time: Static
Horizontal arrangement of woody-woody species: Mixed
Vertical arrangement of woody-woody: More than two layers
Herb-herb arrangement in time: Overlapping
Woody-animal arrangement dominant feature: Time
Woody-animal arrangement in time: Concurrent rotation
Location of woody species: Inside animal management unit
Horizontal arrangement of woody species: Mixed
Vertical arrangement of woody species: More than two layers
Animal feed method: Grazing, browsing

SPECIES DETAILS

Type	Common name	Scientific name	Uses/functions
Natural woody vegetation		*Acacia albida*	Feed leaves/feed fruits/fuelwood/fencing material/animal shade/crop shade/ritual/
Natural woody vegetation		*Butyrospernum parkii*	Food/fruit/food oil/fuelwood/crop shade/
Natural woody vegetation		*Adansonia digitata*	Food/fruit/fibres/
Natural woody vegetation		*Tamarindus indica*	Food/fruit/fuelwood/tools & utensils/ritual/
Natural woody vegetation		*Khaya senegalensis*	Fuelwood/ritual
Natural woody vegetation		*Ceiba pentandra*	Fibres/
Natural woody vegetation		*Bombax costatum*	Fibres
Natural woody vegetation		*Mangifera indica*	Food/fruit/fuelwood
Natural woody vegetation		*Psidium guajava*	Tools & utensils/food/fruit/fuelwood/
Natural woody vegetation		*Bauhinia rufescens*	Live fence/feed leaves/fuelwood/
Natural woody vegetation		*Ficus gnaphalocarpa*	Feed leaves/
Natural woody vegetation		*Balanites aegyptiaca*	Food/fruit/food oil/fuelwood/feed leaves/
Natural woody vegetation		*Cassia sieberiana*	Fuelwood/
Natural woody vegetation		*Terminalia macroptera*	Fuelwood/
Natural woody vegetation		*Combretum elliotii*	Fuelwood/
Natural woody vegetation		*Grewia mollis*	Feed leaves/fuelwood/tools & utensils/
Field crops (seasonal)		*Sorghum vulgare*	Food/seeds/feed leaves/
Field crops (seasonal)		*Panicum* sp.	Food/seeds/feed leaves/
Field crops (seasonal)		*Oryza* sp.	Food/starch/
Field crops (seasonal)		*Zea mays*	Food/starch/feed leaves/
Field crops (seasonal)		*Arachis hypogaea*	Food/nuts
Natural herb vegetation		*Sporobolus pyrimidalis*	Feed leaves/
Natural herb vegetation		*Setaria pallidifusca*	Feed leaves/green manure/
Natural herb vegetation		*Andropogon gayanus*	Feed leaves/green manure/
Natural herb vegetation		*Aristida adscensionis*	Feed leaves/
Natural herb vegetation		*Cenchrus ciliaris*	Feed leaves/
Natural herb vegetation		*Cymbopogon schoenathus*	Feed leaves/
Livestock (grazed)	Cattle	*Bos indicus*	Meat/milk/manure/
Livestock (grazed)	Sheep	*Ovis aries*	Meat/milk/
Livestock (browsed)	Goats	*Carpa hircus*	Meat/

EVALUATION

Constraints: (1) Low inherent soil fertility. (2) Severe drought.
Potential: To be assessed
Research needs: To be assessed
Merits: (1) A. albida is important in soil conservation and restoration of soil fertility in addition to providing dry season fodder supplement.
Extrapolability: To be assessed
Land use problems: (1) Low soil fertility. (2) Water erosion on slopes. (3) Wind erosion due to Harmattan winds in Mar-Apr. (4) Grazing/browsing difficult to control.

CONTACTS

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Agroforestry system description

Code number: 5C20
Source: Weinstock. J.A. (1981) in Economic Botany. (37) 1, 58–68 [Literature].
System name: Rattan-swidden system
Components of association: Field crops (seasonal), Natural woody vegetation, forestry species.
Agroforestry practices: soil conservation tree/

GEOGRAPHICAL LOCATION

AFSI region: S E Asia
Country: Indonesia
Province: East and Central Kalimantan
Area: Between Barito River and Mahakam River
Latitude: 1 S to 1 N
Longitude: 114 to 116 E
Altitude: 0 to 2000

BIOPHYSICAL DATA

Koppen class: Humid tropics. permanent
Mean annual rainfall: 3000 to 5000 mm
Soil types: latosols/
Soil name: Orthic and humic acrisols
Rainfall regime: Uniform
Generalized climate: Humid tropics
Natural vegetation type: Rainforest
Primary land use keywords: Rotational (shifting cult. forest fallow)
Derived land use keywords: Rotational (planted fallow)

SOCIAL ECONOMIC DATA

Market orientation: Subsistence with subsid commercial
Population density: 0.4 to 2 per sq
Dominant religion: Islam
Land tenure type: Freehold
Market facilities: Fair

Credit facilities: Fair
Infrastructure: Fair
Cooperatives: Absent
Capital intensity: Low
Mechanization level: Hoe and spade
Input intensity: Low
System outputs: Rattan
Major inputs: Labour/
Land operation: Land holders
Status: Established/evolved
Incentives to participate: Land tenure/

COMPONENT ARRANGEMENT

Dominant feature: Time
Arrangement of woody perennial-herb species in time: Discrete
Horizontal arrangement of woody perennial-herb species: Not applicable
Vertical arrangement of woody perennial-herb species: Not applicable
Animal feed method:

SPECIES DETAILS

Type	Common name	Scientific name	Uses/functions
Natural woody vegetation	Rattan	*Calanus* sp.	Soil conservation/ tools & utensils/
Field crop, seasonal	Rice	*Oryza sativa*	Food seeds/

EVALUATION

Constraints: Expioitation. Overexploitation and cycle shortened for greater gain as traders exploit peasants. Social and religious obligations may lead to premature cutting of rattan.

Research needs: Enable farmers rather than traders to harvest and sell rattan. Investigate; legume/green manure species plus rattan fallows to increase soil fertility; cooperatives; legislation to increase soil fertility; other perennial cash crops

Merits: Produces cash and food; protects soil; rattan provides a financial buffer against crop failure and maintains land tenure; Good market for rattan

System history/background: Increase in rattan-swidden farming in recent years as demand for rattan increasing

Additional information: Fallow period = 7–15 years. cropping period = 1–2 years. Planting rattan enables farmers to maintain tenure of the land during fallow period. After cropping natural forest regenerates, but rattan is also planted. Farmer plants new swidden and rattan garden every year and harvests rattan (or sells crop to traders) and crops.

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Appendix II

LIST OF MAJOR HERBACEOUS SPECIES REPORTED AS COMPONENTS OF EXISTING AGROFORESTRY SYSTEMS AND THEIR MAIN USES IN DIFFERENT REGIONS

SPECIES	REGION	CLIMATE CLASS	USES
Abelmoschus esculentus	Pacific Islands/S. Asia	Humid tropics	Food/fruit/vegetable
Abelmoschus manihot	Pacific Islands	Humid tropics	Food
Allium cepa	American Tropics/Sahel & C. Africa/Sahel & W. Africa	Humid subtropics/semi arid/subhumid tropics/arid	Food/flavouring/cash
Allium sativum	Sahel & W. Africa	Arid	Flavouring/food
Alocasia macrorrhiza	Pacific Islands	Humid tropics	Food
Aloe volkensis	E. Africa	Subhumid tropics	Medicinal value/ritual
Amaranthus peniculatus	Pacific Islands	Temperate maritime	Food
Amaranthus sp.	S. E. Asia/W. Africa	Humid tropics	Food
Ananas comosus	American Tropics/Pacific Islands/ S. Asia/S. E.Asia	Subhumid tropics/humid tropics	Food/beverage/fruit
Ananas sativa	American Tropics	Subhumid tropics	Food
Andropogon gayanus	Sahel & W. Africa	Semi arid/subhumid tropics	Food/green manure/animal fodder
Arachis hypogaea	American Tropics/S. Asia/S. E. Asia/Sahel & N. Africa	Humid subtropics/humid tropics/semi arid/subhumid	Food/soil conservation/fat/oil/cash/leaf fodder
Aristida adscensionis	Sahel & W. Africa	Semi arid	Food
Avena sativa	Mediterranean		Food
Basella alba	W. Africa	Humid tropics	Food
Brachiaria spp.	American Tropics	Subhumid tropics	Food
Brassica napus	S. Asia	Humid subtropics	Food/grazing
Brassica oleracea	American Tropics/E. Africa	Subhumid tropics/humid subtropics	Food
Brassica sp.	Pacific Islands	Humid tropics	Food
Brassica spp.	Pacific Islands	Humid tropics	Food
Cajanus cajan	S. Asia/Sahel & N. Africa	Humid tropics/subhumid tropics	Food
Calopogonium mucunoides	S. Asia	Subhumid tropics	Food
Capsicum annuum	American Tropics	Humid tropics/semi arid	Cover crop/fruit
Capsicum sp.	Pacific Islands/S. Asia./S. E. Asia/ W. Africa	Humid tropics	Food Spice/food

SPECIES	REGION	CLIMATE CLASS	USES
Carica papaya	American Tropics/S. Asia/S. E. Asia/W. Africa	Humid tropics	Food
Cenchrus biflorus	Sahel & N. Africa	Semi arid	Food/soil conservation
Cenchrus ciliaris	Sahel & W. Africa	Semi arid	Food
Centrosema pubescens	S. Asia	Subhumid tropics	Cover crop
Ceratotheca sesamoides	W. Africa	Semi arid	
Citrullus lanatus	S. Asia/S. E. Asia/Sahel & W. Africa	Humid tropics/humid, subhumid/semi arid	Food/fruit
Citrullus vulgaris	American Tropics/W. Africa	Humid subtropics/semi arid	Food
Coelococcus amicarum	Pacific Islands	Humid tropics	Roofing
Coleus parviflorus	S. Asia	Humid tropics	Food
Colocasia antiquorum	Pacific Islands	Temperate maritime	Food
Colocasia esculenta	Pacific Islands/S. E. Asia/W. Africa	Humid tropics/humid subtropics	Food/fruit
Colocasia sp.	S. Asia	Humid tropics	Food
Corchorus olitorius	W. Africa	Humid tropics	Food
Corchorus sp.	S. Asia		Cash/sugar
Crotalaria micans	Pacific Islands	Temperate maritime	Crop shade/shade
Crytosperma chamissonis	Pacific Islands	Humid tropics	Food
Cucumis melo	Pacific Islands/S. E. Asia/Sahel & C. Africa/Sahel	Humid tropics/arid	Food/fruit
Cucumis sativa	Pacific Islands/S. Asia	Humid tropics	Food
Curcurbita sp.	American Tropics/Pacific Islands/W. Africa	Semi arid/humid tropics	Food
Curcurbita maxima	Pacific Islands	Humid tropics	Food
Curcurbita pepo	W. Africa	Semi arid	
Cucurma longa	S. Asia		Food
Curcuma domestica	Pacific Islands	Humid tropics	Dye/spice
Cymbopogon schoenanthus	Sahel & W. Africa	Semi arid	Food
Cynodon dactylon	American Tropics/E. Africa	Humid tropics/subhumid tropics	Grazing/food
Cynodon mienfuensis	American Tropics	Humid tropics/subhumid tropics	Food/forage/grazing
Cyperus esculentus	W. Africa	Humid subtropics	Food
Cyrtosperma sp.	Pacific Islands	Humid tropics	Food

Dactylis castellana	Mediterranean		Cover crop/grazing
Daucus carota	E. Africa/Pacific Islands/W. Africa	Humid subtropics/semi arid	Food/vegetable/cash
Desmodium ovalifolium	S. Asia	Subhumid tropics	Cover crop
Digitaria exilis	Sahel & W. Africa	Semi arid	Beverage/food
Digitaria ibura	W. Africa	Subhumid tropics	Food
Dioscorea alata	American Tropics/W. Africa	Subhumid tropics/humid tropics	Food
Dioscorea bulbiferum	W. Africa	Humid tropics	Food
Dioscorea dumetorum	W. Africa	Humid tropics	Food
Dioscorea elephantipes	S. Asia		Food
Dioscorea rotundata	W. Afria	Humid tropics/subhumid tropics	Food
Dioscorea sp.	American Tropics/Pacific Islands/ S. Asia/Sahel &	Subhumid tropics/humid tropics/semi arid	Food
Dolichos uniflorus	S. Asia	Humid tropics	Food
Echinocloa polistachya	American Tropics		Food
Echinocloa sp.	W. Africa	Semi arid	Food
Elettaria cardamomum	S. Asia	Humid tropics	Condiment/food/spice
Eleucine coracana	S. Asia/Sahel & N. Africa/Sahel & W. Africa/N. Africa	Humid subtropics/subhumid tropics/ arid/semi arid	Food/stalks for fuel
Eleucine typhoidum	Sahel & W. Africa/N. Africa	Subhumid tropics/humid subtropics	Food
Elionorus sp.	American Tropics	Humid tropics	Grazing
Glycine max	American Tropics/S. Asia/S. E. Asia	Humid subtropics	Food/soil conservation
Glycine maxima	American Tropics	Subhumid tropics	Food/soil protection
Gossypium hirsutum	American Tropics		Fiber
Gossypium sp.	Sahel & W. Africa/W. Africa	Semi arid/subhumid tropics	Cash/fiber
Hibiscus abelmoschus	Sahel & W. Africa	Semi arid	Food
Hibiscus cannabinus	S. E. Asia	Humid, sub-humid	Fiber
Hibiscus esculentus	Sahel & W. Africa	Semi arid/subhumid tropics	Food
Hibiscus sabdariffa	Sahel & W. Africa/W. Africa	Semi arid/subhumid tropics	Beverage/food
Hordeum sp.	S. Asia	Humid subtropics	Food
Hordeum vulgare	Mediterranean/Sahel & C. Africa/ Sahel & W. Africa	Arid	Food
Hyparrhenia rufa	American Tropics	Humid tropics	Forage
Imperata cylindrica	S. E. Asia	Humid tropics	Fuelwood
Ipomoea batatas	E. Africa/Pacific Islands/S. Asia/ S. E. Asia/Sahel	Humid subtropics/humid tropics/temperate maritime	Food/beverage

SPECIES	REGION	CLIMATE CLASS	USES
Lactuca sativa	American Tropics/Pacific Islands	Subhumid tropics/humid tropics	Food
Lagenaria siceraria	Sahel & W. Africa	Semi arid	Food
Lemaireocereus griculs	American Tropics	Semi arid	Grazing
Lolium perenne	Mediterranean		Cover crop/grazing
Loudetia togoensis	Sahel & W. Africa	Subhumid tropics	Grazing
Lycopersicon esculentum	American Tropics/Pacific Islands/Sahel & C. Africa	Humid subtropics/semi arid/subhumid tropics/humid	Food/vegetable/cash
Manihot esculenta	American Tropics/Pacific Islands/S. Asia/S. E. Asia	Humid subtropics/semi arid/subhumid tropics/humid	Food/vegetable
Manihot utilissima	W. Africa	Humid tropics	Food
Maniok esculenta	Sahel & W. Africa	Subhumid tropics	Food
Maranta arundinacea	Pacific Islands/S. Asia	Humid tropics	Food/medicinal value
Medicago sativa	American tropics/Mediterranean	Arid	Forage/grazing/animal fodder
Meliconia sp.	Pacific Islands	Humid tropics	Food
Melilotus alba	American Tropics		Forage
Mentha arvensis	American Tropics		Beverage
Merremia sp.	Pacific Islands	Humid tropics	Food
Momordica charantia	S. Asia	Humid tropics	Fruit/vegetable
Musa paradisiaca	Pacific Islands/S. Asia/S. E. Asia/W. Africa	Temperate maritime/humid tropics	Food
Musa sapientum	American Tropics		Food
Musa sp.	American Tropics/Pacific Islands	Humid subtropics/humid tropics	Food
Nicotiana tabacum	W. Africa	Humid subtropics/semi arid	Cash
Oenanthe javanica	Pacific Islands	Temperate maritime	Food
Oryza gambica	Sahel & W. Africa	Subhumid tropics	Food
Oryza sativa	S. Asia/S. E. Asia/Sahel & W. Africa/W. Africa	Humid tropics/humid, sub-humid/semi arid/subhumid	Food/wood craft
Oryza sp.	S. Asia/Sahel & N. Africa/Sahel & W. Africa	Humid tropics/subhumid tropics/semi arid	Food
Panicum maximum	American Tropics/S. Asia	Humid tropics/subhumid tropics	Forage/grazing food
Panicum miliaceum	Sahel & C. Africa	Arid	Food
Panicum purpurescens	American Tropics		Food

Panicum purpureum	S. Asia	Humid tropics	Animal fodder
Panicum sp.	Sahel & W. Africa	Semi arid/subhumid tropics	Food
Panicum sp.	Sahel & W. Africa	Semi arid	Food/soil conservation
Paspalum dilatatum	American Tropics	Humid tropics	Grazing
Paspalum fasciculatum	American Tropics	Subhumid	Grazing
Passiflora edulis	Pacific Islands/S. Asia	Humid tropics/subhumid tropics	Beverage/food/fruit
Pennisetum esculentus	Sahel & W. Africa	Subhumid tropics	Food
Pennisetum gambicum	Sahel & W. Africa	Semi arid	Food
Pennisetum polystachyum	Sahel & W. Africa	Semi arid	Food
Pennisetum purpureum	American Tropics/E. Africa	Subhumid tropics	Food/grazing
Pennisetum spicatum	W. Africa	Humid subtropics	Food
Pennisetum typhoides	Sahel & N. Africa/Sahel & W. Africa/W. Africa	Semi arid/subhumid tropics	Food
Phalaris aquatica	Mediterranean	Humid tropics/semi arid	Grazing
Phaseolus sp.	Pacific Islands/Sahel & W. Africa	Humid subtropics/subhumid tropics/humid tropics	Food
Phaseolus vulgaris	American Tropics/E. Africa/Pacific Islands/Sahel	Humid subtropics	Food
Pimento dioica	W. Africa	Humid tropics	Oil
Piper betle	S. Asia	Subhumid tropics/humid subtropics	Masticant
Piper nigrum	S. Asia	Humid subtropics	Food
Pisum sativum	American Tropics/Sahel & W. Africa/W. Africa	Temperate maritime/humid tropics	Food/soil conservation/vegetable
Polygonum sp.	S. Asia	Humid tropics	Food
Psophorcarpus tetragonolobus	Pacific Islands/S. Asia	Subhumid tropics/humid tropics/temperate maritime	Food/vegetable
Ricinus communis	W. Africa	Subhumid tropics/humid tropics	Food
Saccharum officinarum	American Tropics/Pacific Islands	Humid tropics/humid, sub-humid/semi arid/subhumid	Sugar/food
Saccharum sp.	American Tropics/Pacific Islands/S. Asia	Semi arid	Sugar/food
Sesamum indicum	S. Asia/S. E. Asia/Sahel & N. Africa/Sahel & W. Africa		Fat/oil/food
Setaria pallidifusca	Sahel & W. Africa		Food/green manure

SPECIES	REGION	CLIMATE CLASS	USES
Setaria palmifolia	Pacific Islands	Temperate maritime	Food
Setaria sphacelata	E. Africa	Subhumid tropics	Food
Solanum anomalum	W. Africa	Humid tropics	Food
Solanum melongena	Pacific Islands/S. Asia/S. E. Asia	Humid tropics	Food/vegetable
Solanum tuberosum	E. Africa/S. Asia/S. E. Asia/Sahel & W. Africa	Humid subtropics/arid	Food
Sorghum bicolor	Sahel & N. Africa/Sahel & W. Africa/W. Africa	Subhumid tropics/semi arid	Food
Sorghum caudatum	Sahel & W. Africa/W. Africa	Subhumid tropics/humid subtropics	Food
Sorghum guineense	Sahel & W. Africa	Subhumid tropics	Food
Sorghum sp.	Sahel & N. Africa/Sahel & W. Africa	Subhumid tropics	Food/live fence
Sorghum vulgare	American Tropics/Sahel & N. Africa/Sahel & W. Africa	Subhumid tropics/semi arid/humid tropics	Food
Sporobolus pyrimidalis	Sahel & W. Africa	Semi arid	Food
Sporolobus sp.	American Tropics	Humid tropics	Grazing
Stylosanthes guianensis	S. Asia	Humid tropics	Animal fodder
Tephrosia vogelii	Pacific Islands	Temperate maritime	Crop shade/shade
Theobroma cacao	American Tropics	Humid tropics	Beverage/crop shade
Trichosantes cucumerina	S. Asia	Humid tropics	Vegetable
Tripsacum laxum	S. Asia	Humid tropics	Animal fodder
Triticum aestivum	Mediterranean/S. Asia/S. E. Asia/Sahel & C. Africa	Humid subtropics/arid	Food
Vanilla fragrans	Pacific Islands		Beverage/food
Vanilla planifolia	American Tropics		Condiment
Vetiveria zizanoides	S. Asia	Humid tropics	Food
Vigna catyang	Sahel & W. Africa/W. Africa	Subhumid tropics/semi arid	Food
Vigna radiata	S. Asia	Humid tropics	Food
Vigna sinensis	American Tropics	Subhumid tropics	Food
Vigna unguiculata	S. Asia/Sahel & N. Africa/Sahel & W. Africa/W. Africa	Humid subtropics/human tropics/subhumid tropics/S	Food
Voandzeia subterranea	Sahel & W. Africa/W. Africa	Subhumid tropics/humid subtropics/humid tropics/S	Food

Xanthosoma sagittifolium	Pacific Islands/W. Africa	Temperate maritime/humid tropics	Food
Xanthosoma sp.	Pacific Islands/W. Africa	Humid tropics/semi arid	Food
Zea mays	American Tropics/E. Africa/Pacific Islands/S. Asia	Humid subtropics/semi arid/subhumid tropics/humid	Food/mulch/forage/shade
Zingiber officinale	Pacific Islands/S. Asia	Humid tropics	Spice/food/condiment
Zingiber officinale	W. Africa	Temperate maritime/humid tropics	Fuelwood

Number of observations: 166

Appendix III

LIST OF MAJOR WOODY PERENNIAL SPECIES AS REPORTED AS COMPONENTS OF EXISTING AGROFORESTRY SYSTEMS AND THEIR MAIN USES IN DIFFERENT REGIONS

SPECIES	REGION	CLIMATE CLASS	USES
Acacia albida	Sahel & C. Africa/Sahel & W. Africa/ W. Africa	Arid/semi arid/subhumid tropics/humid subtropics	Building material/food/fuelwood/misc. farm timber
Acacia arabica	Sahel & W. Africa	Subhumid tropics	Shade
Acacia ataxacantha	Sahel & W. Africa	Semi arid	Fuelwood/soil conservation
Acacia campylacantha	Sahel & N. Africa	Semi arid	Firewood/poles/soil protection
Acacia caven	American Tropics	Humid tropics	Shade/shelterbelt
Acacia decurrens	S. Asia	Humid tropics	Shade
Acacia ehrenbergiana	Sahel & W. Africa	Arid	Building material/fuelwood/tools & utensils
Acacia flava	Sahel & C. Africa/Sahel & W. Africa	Arid	
Acacia mellifera	Sahel & N. Africa	Semi arid	Bee forage/food/fuelwood/misc. farm timber
Acacia nilotica	S. Asia/Sahel & C. Africa	Arid	Beverage/fuelwood/fuel
Acacia nubica	Sahel & W. Africa	Semi arid	Food/fuelwood/misc. farm timber
Acacia penatula	American Tropics		Crop shade/shade
Acacia pruinosa	S. Asia	Humid tropics	Shade/shelterbelt
Acacia raddiana	Sahel & C. Africa/Sahel & W. Africa	Arid	Building material/food/fuelwood/misc. farm timber
Acacia senegal	Sahel & N. Africa/Sahel & W. Africa	Semi arid	Bee forage/dune fixation/food/fuelwood/gum/misc.
Acacia seyal	Sahel & N. Africa/Sahel & W. Africa	Semi arid/arid/subhumid tropics	Food/fuelwood/gum/misc. farm timber/soil conservation
Acacia sieberiana	Sahel & W. Africa	Semi arid/subhumid tropics	Animal fodder/shade
Acacia sp.	Pacific Islands	Humid tropics	Fuelwood
Acacia tortilis	Sahel & W. Africa	Semi arid	Animal fodder/fuelwood
Achras zapota	S. Asia/S. E. Asia/Sahel & W. Africa	Humid tropics/subhumid tropics	Fruit/food/fuelwood
Acioa barterii	W. Africa	Humid tropics	Food/live fence/soil conservation/ stake/tools & utensils

Acrocomia totai	American Tropics	Humid tropics	Food
Actinodaphne sp.	S. E. Asia	Semi arid/subhumid tropics/humid subtropics	Building material/fuelwood/timber
Adansonia digitata	Sahel & N. Africa/Sahel & W. Africa/W. Africa	Humid tropics	Fiber/food/ritual/shade/fence/fuelwood/fruit
Adenthera pavonina	Pacific Islands	Humid subtropics	Fuelwood/shade
Adhatoda vasica	S. Asia		Live fence/soil conservation
Aegle marmelos	S. Asia	Humid tropics	Fruit
Afzelia africana	W. Africa	Humid tropics	Food
Afzelia bella v. *bella*	W. Africa	Temperate maritime	Food
Albizia chinensis	Pacific Islands	Humid tropics	Crop shade/shade
Albizia moluccana	S. Asia	Subhumid tropics	Shade
Albizia schimperiana	E. Africa		Building material/fuelwood
Albizia sp.	S. Asia	Humid tropics	Timber
Aleurites moluccana	S. E. Asia	Humid tropics	Timber
Aleurites trisperma	S. E. Asia	Subhumid tropics	Timber
Aleurites fordii	American Tropics		Crop shade/fuelwood/shade/windbreak/oil/pellets
Alstonia angustifolia	S. E. Asia	Humid tropics	Building material/fuelwood/timber
Amoora rohitura	S. Asia		Timber
Anacardium occidentale	American Tropics/Pacific Islands/S. Asia/S. E. Asia	Subhumid tropics/humid tropics/humid, sub-humid	Firewood/fruit nuts/shade/fuelwood/food/fruit
Andropogon gayanus	Sahel & W. Africa	Subhumid tropics	Fence/mats
Annona muricata	S. E. Asia	Humid tropics	Beverage/food/fuelwood
Annona squamosa	S. E. Asia	Humid tropics	Food/fuelwood
Anogeissus leiocarpus	Sahel & W. Africa/W. Africa	Semi arid/humid subtropics	Shade/animal fodder/building material/timber
Anona sp.	S. Asia	Humid tropics	Fruit
Antidesma diandrum	S. Asia	Humid subtropics	Fuelwood
Araucaria angustifolia	American Tropics/E. Africa	Subhumid tropics/humid subtropics	Lumber/pulp/windbreak/timber
Areca catechu	Pacific Islands/S. Asia/S. E. Asia	Humid tropics/humid, sub-humid	Fruit nuts/crop support/food/fruit/building materials
Areca macrocalyx	Pacific Islands	Temperate maritime	Food
Arenga saccharifera	S. E. Asia	Humid tropics	Beverage

SPECIES	REGION	CLIMATE CLASS	USES
Artocarpus altilis	American Tropics/Pacific Islands/ S. Asia/S. E. Asia	Humid tropics	Food/fuelwood/fruit/stake
Artocarpus communis	W. Africa	Humid tropics	Food
Artocarpus elasticus	S. E. Asia	Humid tropics	Fiber/fuelwood
Artocarpus heterophyllus	S. Asia/S. E. Asia	Humid tropics/humid, sub-humid	Fruit/food/builing material/crop shade/fuelwood
Artocarpus hirsuta	S. Asia	Humid tropics	Fruit
Artocarpus lakoocha	S. Asia	Humid subtropics	Food/fuelwood
Arundinaria alpina	E. Africa	Humid subtropics	Misc. farm timber
Arundinaria sp.	S. Asia	Humid subtropics	Building material/food/fuelwood
Averrhoa carambola	S. E. Asia	Humid tropics	Fruit
Azadirachta indica	S. Asia/Sahel & W. Africa	Semi arid	Timber/lumber/manure/oil/fuel
Baccaurea dulcis	S. E. Asia	Humid tropics	Food/fuelwood
Balanites aegyptiaca	Sahel & C. Africa/Sahel & N. Africa/ Sahel & W. Africa	Arid/semi arid/subhumid tropics/humid subtropics	Building material/food/fuelwood/tools & utensils
Balfourodendron riedelianum	American Tropics		Fuelwood/timber
Bambusa arundinacea	S. Asia	Humid tropics	Fence/poles
Bambusa nutans	S. Asia		Wood craft
Bambusa sp.	S. Asia/S. E. Asia	Humid subtropics/humid, sub-humid	Building material/food/fuelwood/ poles/tools & utensils
Bambusa vulgaris	S. Asia		Fruit/wood craft
Barringtonia acutangula	S. Asia	Humid subtropics	Fuelwood
Bassia butyracea	S. Asia	Semi arid	Food
Bauhinia rufescens	Sahel & W. Africa	Humid subtropics	Food/fuelwood/live fence
Bauhinia vahlii	S. Asia	Humid subtropics	Food/fuelwood
Bauhinia variegata	S. Asia	Humid subtropics	Food/fruit/fuelwood
Berchemia floribunda	S. Asia	Humid subtropics	Food/fuelwood
Bilghia sapida	Sahel & W. Africa	Subhumid tropics	Shade
Bixa orellana	American Tropics		Dye/fuelwood
Bombax costatum	Sahel & W. Africa	Semi arid	Fibre
Borassus aethiopium	W. Africa	Humid subtropics/semi arid	Food/ritual
Borassus flabellifer	S. Asia/Sahel & W. Africa	Humid tropics/semi arid/subhumid tropics	Food/beverage/building material/fuelwood
Bosqueia angolensis	W. Africa	Humid tropics	Food

Brassaiopsis hainla	S. Asia	Humid subtropics	Food fuelwood
Bridelia micrantha	E. Africa	Subhumid tropics	Building material/medicinal value/poles
Bridelia retusa	S. Asia	Humid subtropics	Food fuelwood
Bulsenia arborea	American Tropics	Subhumid tropics	Firewood/forage/shade
Burkea africana	Sahel & W. Africa	Subhumid tropics	Fiber fuelwood
Bursec. simarouba	American Tropics		Live fence/timber
Butryospermum parkii	W. Africa	Semi arid	Fat/food oil
Butyrospermum parkii	Sahel & W. Africa/W. Africa	Semi arid/subhumid tropics/humid subtropics	Crop shade/food/fuelwood/catterpillar habitat/fruit
Cabrela oblongifolida	American Tropics	Humid tropics	Crop shade/shade/timber/lumber
Caesalpinia decapetala	E. Africa	Subhumid tropics	Live fence
Calamus sp.	S. E. Asia	Humid tropics/humid, sub-humid	Soil conservation/tools & utensils/building material
Calliandra calothyrsus	S. E. Asia	Humid tropics	Lumber
Callicarpa arborea	S. Asia	Humid subtropics	Food/fuelwood
Calpurnia aurea	E. Africa	Subhumid tropics	Anti-pest/crop shade/poles/tools & utensils
Camellia sinensis	S. Asia	Humid tropics	Beverage
Campnosperma brevipetiolata	Pacific Islands	Humid tropics	Lumber/misc. farm timber
Cananga odorata	Pacific Islands	Humid tropics	Perfume
Canarium schweinfurthii	W. Africa	Humid tropics	Food/veneer
Capparis caloratissima	American Tropics	Semi arid	Firewood/forage/shade
Carica papaya	American Tropics/E. Africa/Pacific Islands/S. Asia	Subhumid tropics/humid tropics/semi arid	Food/shade/anti-pest/fruit
Caryota urens	S. Asia	Humid tropics	Beverage
Cassia didymobotyra	E. Africa	Subhumid tropics	Medicinal value
Cassia sieberiana	Sahel & W. Africa	Semi arid	Fuelwood
Castanopsis indica	S. Asia	Humid subtropics	Food/fuelwood/timber
Casuarina cuningamiana	American Tropics	Subhumid tropics	Firewood/lumber/windbreak
Casuarina equisetifolia	Sahel & N. Africa	Subhumid tropics	Charcoal/fuelwood/timber
Casuarina oligodon	Pacific Islands	Temperate maritime	Crop shade/fuelwood/shade/timber
Casuarina sp.	Pacific Islands	Humid tropics	Timber
Cecidium praecox	American Tropics	Semi arid	Animal fodder
Cedrela angustifolia	American Tropics	Subhumid tropics	Firewood/lumber/shade

SPECIES	REGION	CLIMATE CLASS	USES
Cedrela odorata	American Tropics	Subhumid tropics	Fuelwood/shade/timber/firewood/lumber
Cedrela tubiflora	American Tropics		Crop shade/shade/timber
Ceiba pentandra	American Tropics/Sahel & W. Africa	Semi arid	Fuelwood/timber/fibre
Celtis australis	S. Asia	Humid subtropics	Food/fuelwood/timber
Celtis integrifolia	Sahel & W. Africa/W. Africa	Semi arid	Animal fodder
Celtis spinosa	American Tropics	Humid tropics	Firewood
Ceratonia siliqua	Mediterranean		Lumber/soil improvement
Cercidium pracoax	American Tropics	Semi arid	Firewood/forage/shade
Chlorophora excelsa	E. Africa/Sahel & N. Africa	Subhumid tropics	Timber
Chlorophora regia	Sahel & W. Africa	Subhumid tropics	Shade
Chrysophyllum albidum	W. Africa	Humid tropics	Food/ritual/soil conservation/tools & utensils
Cinnamon sp.	S. Asia	Humid subtropics	Food/fuelwood
Citrus aurantifolia	Pacific Islands	Humid tropics	Fruit
Citrus aurantium	American Tropics	Humid subtropics	Essential oil
Citrus grandis	S. E. Asia	Humid tropics	Fruit
Citrus limon	American Tropics	Subhumid tropics	Food
Citrus paradisi	American Tropics	Subhumid tropics	Food
Citrus sinensis	American Tropics/Pacific Islands	Subhumid tropics/humid tropics	Food/shade/firewood/fruit
Citrus sp.	American Tropics/Pacific Islands/ S. Asia/Sahel &	Subhumid tropics/humid tropics	Food/firewood/shade/fruit/beverage
Cocos nucifera	American Tropics/Pacific Islands/ S. Asia/S. E. Asia	Subhumid tropics/humid tropics/humid tropics, subhumid	Fiber/food/shade/fruit/beverage/cash/ timber/fruit
Coffea arabica	American Tropics/Pacific Islands	Subhumid tropics/humid tropics/temperate maritime	Beverage/fuelwood/food
Coffea sp.	American Tropics/S. Asia/S. E. Asia	Subhumid tropics/humid tropics	Beverage/food
Cola acuminata	W. Africa	Humid tropics	Food/ritual
Combretum elliotii	Sahel & W. Africa	Semi arid	Fuelwood
Combretum glutinosum	Sahel & W. Africa	Semi arid	Soil conservation
Commiphora sp.	E. Africa	Subhumid tropics	Anti-pest/food/misc. farm timber/stake
Cordia abyssinica	E. Africa/W. Africa	Subhumid tropics/semi arid	Building material/crop shade /fuelwood/misc. farm

Cordia alliodora	American Tropics/Pacific Islands	Humid tropics/subhumid tropics	Fuelwood/shade/timber/building material/crop shade
Cordia apurensis	American Tropics	Subhumid tropics	Lumber
Cordia myxa	Sahel & W. Africa	Subhumid tropics	Fuelwood
Cordia trichotoma	American Tropics	Humid subtropics	Crop shade/shade/timber/building material/fuelwood
Crescentia cujete	W. Africa	Humid tropics	Ornamental/tools & utensils
Croton macrostachys	E. Africa	Subhumid tropics	Anti-pest/crop shade/food/fuelwood
Cupressus lusitanica	E. Africa	Humid subtropics	Pulp/timber
Dacroydes edulis	W. Africa	Humid tropics	Building material/food
Datura arborea	E. Africa	Subhumid tropics	Anti-pest/bee forage
Dendrocalamus strictus	S. Asia	Humid subtropics	Building material/food/fuelwood
Desmodium velutinum	W. Africa	Humid tropics	Food
Detarium senegalense	Sahel & W. Africa	Semi arid	Shade
Dialium guineense	Sahel & W. Africa/W. Africa	Subhumid tropics/humid tropics	Shade/charcoal/food timber/tools & utensils
Diospyros mespiliformis	E. Africa/Sahel & W. Africa	Subhumid tropics	Timber/fuelwood/shade/soil conservation
Diphysa robinoides	American Tropics		Crop shade/fuelwood/live fence/poles/shade/timber
Dracena afromontana	E. Africa	Subhumid tropics	Boundary planting/live fence
Dracena usambarensis	E. Africa	Subhumid tropics	Boundary planting/live fence
Durio zibethinus	S. E. Asia	Humid tropics	Crop shade/food/fruit
Ehretia sp.	E. Africa	Subhumid tropics	Medicinal value/poles/tools & utensils
Elaeis guineensis	Sahel & W. Africa/W. Africa	Subhumid tropics/humid tropics	Beverage/building material/fibre/fuelwood/leaves
Elaeocarpus carolinensis	Pacific Islands	Humid tropics	Lumber/misc. farm timber
Emblica officinalis	S. Asia	Humid tropics	Fruit
Enterolobium contortisiliquum	American Tropics	Humid subtropics	Fuelwood/nitrogen fixation/poles/soil conservation
Eriobotrya japonica	E. Africa	Subhumid tropics	Building material/food/live fence
Erythrina fusca	American Tropics		Crop shade/food/fuelwood/live fence/shade
Erythrina indica	Pacific Islands/S. Asia	Humid tropics	Shade/fuelwood/soil fertility
Erythrina lithosperma	S. Asia	Humid tropics	Shade/soil fertility

SPECIES	REGION	CLIMATE CLASS	USES
Erythrina pentaphylla	American Tropics	Subhumid tropics	Shade/soil protection
Erythrina sp.	American Tropics/Pacific Islands/S. Asia	Subhumid tropics/humid tropics	Fuelwood/shade/soil conservation/ manure/soil fertility
Erythrina variegata	S. Asia	Humid subtropics	Food/fuelwood
Erythrophleum guineense	Sahel & W. Africa	Subhumid tropics	Shade
Erythrophleum suaveolens	W. Africa	Humid tropics	Fish poison/soil conservation
Eucalyptus camaldulensis	S. E. Asia	Humid, sub-humid	Timber/fuelwood
Eucalyptus deglupta	Pacific Islands	Humid tropics	Shade/timber
Eucalyptus globulus	Mediterranean		Lumber
Eucalyptus grandis	American Tropics		Esesential oil/poles/timber
Eucalyptus rostrata	Mediterranean		Lumber
Eucalyptus saligna	American Tropics	Subhumid tropics	Essential oil/poles/timber/firewood/ lumber/windbreak
Eucalyptus sp.	American Tropics/Pacific Islands/Sahel &. N. Africa	Subhumid tropics/humid tropics	Lumber/firewood/stake/timber/fuelwood
Eugenia aquea	S. E. Asia	Humid tropics	Food/fuelwood
Eugenia malaccense	S. E. Asia	Humid tropics	Food/fuelwood
Eugenia polyantha	S. E. Asia	Humid tropics	Food/fuelwood
Eugenia polycephala	S. E. Asia	Humid tropics	Food/fuelwood
Eugenia sp.	S. Asia		Fruit
Exorrhiza ponapensis	Pacific Islands	Humid tropics	Lumber/poles
Ficus capensis	Sahel & W. Africa	Subhumid tropics	
Ficus clavata	S. Asia	Humid subtropics	Food
Ficus gnaphalocarpa	Sahel & W. Africa	Semi arid/subhumid tropics	Animal fodder/food/shade/fibre/fruit
Ficus hispida	S. Asia	Humid subtropics	Food/fuelwood
Ficus lacor	S. Asia	Humid subtropics	Food/fuelwood
Ficus roxburghii	S. Asia	Humid subtropics	Food/fuelwood
Ficus semicordata	S. Asia	Humid subtropics	Food/fuelwood
Ficus sp.	E. Africa/Sahel & C. Africa/Sahel & W. Africa	Subhumid tropics/arid/semi arid	Charcoal/food/fuelwood/beverage/shade/ soil conservation
Flemingia congesta	S. Asia	Subhumid tropics	Cover crop/windbreak
Fragraea fragrans	S. Asia	Humid tropics	Shelterbelt
Fraxinus floribunda	S. Asia	Humid subtropics	Fuelwood/timber

Garcinia cola	W. Africa	Humid tropics	Food
Garcinia indica	S. Asia	Humid tropics	Fruit
Garcinia mangostana	S. Asia/S. E. Asia	Humid tropics	Food/fuelwood
Garcinia nervosa	S. E. Asia	Humid tropics	Food/fuelwood
Gardenia sp.	E. Africa	Subhumid tropics	Anti-pest/tools & utensils
Garuga pinnata	S. Asia	Humid subtropics	Food/fuelwood/timber
Gliricidia maculata	S. Asia	Humid tropics	Shade/soil fertility
Gliricidia sepium	American Tropics/Pacific Islands/ S. Asia	Humid tropics	Crop shade/food/fuelwood/live fence/ poles/shade
Gmelina arborea	American Tropics/Pacific Islands/ S. Asia	Subhumid tropics/humid tropics/humid subtropics	Firewood/lumber/shade/building material/food/fuel
Grevillea robusta	American Tropics/E. Africa/S. Asia	Subhumid tropics/humid tropics	Crop shade/shade/timber/building material/fuelwood
Grewia mollis	Sahel & W. Africa	Semi arid	Food/fuelwood/tools & utensils
Grewia optiva	S. Asia		Crop shade/food/shade/soil conservation/windbreak
Grewia sp.	S. Asia	Humid subtropics	Food/fuelwood
Haematoxylum campechianum	American Tropics		Fuelwood/live fence/poles
Hakea saligna	S. Asia	Humid tropics	Shade
Hevea brasiliensis	Pacific Islands/S. Asia/S. E. Asia	Humid tropics/subhumid tropics/humid, sub-humid	Latex/soil conservation/fuelwood
Hibiscus tiliaceus	Pacific Islands	Humid tropics	Stake
Holocalyx balansae	American Tropics	Arid/semi arid	Crop shade/poles/shade/timber
Hyphaene thebaica	Sahel & C. Africa/W. Africa	Subhumid tropics	Building material/food/fuelwood
Iboza multiflora	E. Africa	Humid subtropics/subhumid tropics	Anti-pest/live fence/medicinal value
Illex paraguarensis	American Tropics	Humid tropics	Beverage
Infsia bijuga	Pacific Islands		Food
Inga edulis	American Tropics		Crop shade/food/soil conservation
Inga leptoloba	American Tropics		Crop shade/fuelwood/shade/soil conservation
Inga sp.	American Tropics	Subhumid tropics	Crop shade/shade/soil conservation/ firewood/nitrogen fixation
Irvingia gabonensis v. *excelsa*	W. Africa	Humid tropics	Beverage/food

SPECIES	REGION	CLIMATE CLASS	USES
Irvingia gabonensis v. *gabonen*	W. Africa	Humid tropics	Beverage/food
Jatropha curcas	Sahel & W. Africa	Semi arid/subhumid tropics	Live fence/food
Khaya senegalensis	Sahel & W. Africa/W. Africa	Semi arid/subhumid tropics/humid subtropics Subhumid tropics/semi arid	Animal fodder/food/fruit/fuelwood/ritual/shade/fruit
Kigelia africana	Sahel & W. Africa/W. Africa	Semi arid	Fuelwood
Lagerstoremia speciosa	S. Asia		Soil conservation
Lannea acida	Sahel & W. Africa	Semi arid/subhumid tropics	Fuelwood
Lannea coromandelica	S. Asia	Humid tropics	Soil conservation/shade
Lannea microcarpa	Sahel & W. Africa	Humid subtropics/humid tropics	Food/fuelwood
Lansium domesticum	S. E. Asia		Fuelwood/poles/timber/food/soil conservation/man
Leucaena leucocephala	American Tropics/Pacific Islands/S. Asia/S. E. Asia	Humid tropics	Fuelwood
Leucaena sp.	Pacific Islands	Humid subtropics	Food/fuelwood/timber
Litsea polyantha	S. Asia	Humid subtropics	Food/fuelwood
Machilus gamblei	S. Asia	Humid subtropics	Food/fuelwood
Maesa chisia	S. Asia	Subhumid tropics	Timber
Maesopsis eminii	Sahel & N. Africa	Humid subtropics	Food/fuelwood
Mallotus phillipinensis	S. Asia	Arid	Fruit
Malus domestica	American Tropics	Humid tropics	Food/fuelwood
Mangifera caesia	S. E. Asia	Subhumid tropics/humid tropics/humid subtropics	Food/shade/fruit/cash/fuelwood
Mangifera indica	American Tropics/Pacific Islands/S. Asia/S. E. Asia	Humid tropics	Food/fuelwood
Mangifera odorata	S. E. Asia	Subhumid tropics	Crop shade/food/fuelwood/shade
Manilkara achras	American Tropics	Subhumid tropics/humid subtropics/humid, sub-humid	Fuelwood/poles
Markhamia platycalyx	E. Africa	Humid subtropics	Crop shade/fuelwood/shade/timber/firewood/lumber/
Melia azedarach	American Tropics/S. Asia/S. E. Asia		Crop shade/fuelwood/shade/timber
Melia azedarach v. *gigante*	American Tropics		Wood craft
Melocanna bambusoidea	S. Asia	Humid tropics	Food/ornamental
Monodora myristica	W. Africa		

Morinda tinctoria	S. Asia	Humid tropics	Timber
Moringa sp.	S. Asia	Humid tropics	Fruit/vegetable
Morus alba	E. Africa S. Asia	Subhumid tropics/humid subtropics	Food/fuelwood/live fence
Morus indica	S. Asia	Humid subtropics	Food/fuelwood
Musa paradisiaca	American Tropics	Subhumid tropics	Food
Musa sapientum	American Tropics	Subhumid tropics	Food/forage/shade
Musa sp	American Tropics/Pacific Islands/S. Asia S. E. Asia	Semi arid/subhumid tropics/humid tropics	Food/fruit/timber/beverage
Myristica fragrans	S. Asia	Humid tropics	Food/fruit
Myristica hypargyraea	Pacific Islands	Humid tropics	Lumber/poles
Nectandra saligna	American Tropics	Humid tropics	Firewood/lumber/shade
Nephelium lappaceum	S. E. Asia	Humid tropics	Food/fruit
Nerium odorum	S. Asia	Humid subtropics	Fuelwood/ritual
Newbouldia laevi	W. Africa	Humid tropics	Boundary planting/crop shade/ritual
Newtonia buchananii	E. Africa	Subhumid tropics	Fuelwood
Olea europea	Mediterranean		Lumber
Olea welwitschii	E. Africa	Subhumid tropics	Food/timber
Pachira acuatica	American Tropics		Live fence
Palaguium karrak	Pacific Islands	Humid tropics	Lumber/poles
Palmyra sp.	S. Asia		Fruit
Pandanus conoideus	Pacific Islands	Temperate maritime	Food
Pandanus julianettii	Pacific Islands	Temperate maritime	Soil conservation
Papaya carica	Sahel & W. Africa	Semi arid	Fruit
Parapiptania rigida	American Tropics	Humid tropics	Firewood/lumber/shade
Parinari excelsa	Sahel & W. Africa	Subhumid tropics	Shade
Parinarium glaberrimum	Pacific Islands	Humid tropics	Lumber/poles
Parkia biglobosa	Sahel & W. Africa/W. Africa	Semi arid/subhumid tropics/humid subtropics/humid	Food/fuelwood/shade/crop shade/fruit/fruit nuts
Parkia filicoidea	W. Africa	Semi arid	Food/fruit
Parkia javanica	S. E. Asia	Humid, sub-humid	Food/fuelwood
Parkia speciosa	S. E. Asia	Humid, sub-humid	Food/fuelwood
Paulownia sp.	American Tropics		Crop shade/fuelwood/shade/timber
Pavetta indica	S. Asia	Humid subtropics	Fuelwood
Peltophorum dubium	American Tropics	Humid subtropics	Fuelwood/nitrogen fixation/poles/soil conservation

SPECIES	REGION	CLIMATE CLASS	USES
Pentaclethra macrophylla	W. Africa	Humid tropics	Food/fuelwood/soil conservation/stake/windbreak
Peronema canescens	S. E. Asia	Humid tropics	Building material/fuelwood/timber
Persea americana	American Tropics/E. Africa/Pacific Islands/S. Asia	Subhumid tropics/humid tropics	Food/fuelwood/cash/firewood/shade/fruit
Persea guatemalense	American Tropics	Subhumid tropics	Firewood/food
Phoenix dactylifera	S. Asia Sahel & C. Africa/Sahel & W. Africa	Arid	Fruit/building material/crop shade/food/fuelwood
Piliostigma reticulatum	Sahel & W. Africa	Subhumid tropics	Fuelwood/shade
Pine sp.	American Tropics	Subhumid tropics	Food/lumber
Pinus caribaea	American Tropics/Pacific Islands	Subhumid tropics/humid tropics	Lumber/pulp/timber
Pinus elliottii	American Tropics/E. Africa	Arid/subhumid subtropics/humid subtropics	Lumber/pulp/resin/windbreak/timber
Pinus ocarpa	American Tropics	Humid tropics	Pulp/timber
Pinus patula	E. Africa	Humid subtropics	Pulp/timber
Pinus pinea	Mediterranean	Humid tropics	Lumber
Pinus radiata	E. Africa	Subhumid tropics	Pulp/timber
Pinus sp.	American Tropics	Subhumid tropics	Firewood/lumber/shade
Pinus taeda	American Tropics	Semi arid	Lumber/pulp
Pithecolobium saman	American Tropics	Humid subtropics	Firewood/lumber/shade
Pithecolobium unquiscate	American Tropics	Semi arid	Firewood/forage/shade
Podo sp.	E. Africa	Arid/semi arid	Timber
Poponax sp.	American Tropics	Arid/semi arid	Firewood/forage
Populus deltoides	S. E. Asia	Humid subtropics	Timber
Populus euroamericana	American Tropics	Semi arid/subhumid tropics	Lumber/poles/windbreak/firewood
Populus nigra	American Tropics	Semi arid, arid	Lumber/poles/windbreak/firewood
Premna sp.	S. Asia	Semi arid/subhumid tropics	Food
Prosopis africana	Sahel & W. Africa	Humid tropics	Animal fodder/fuelwood/nitrogen fixation/fodder/shade
Prosopis cineraria	S. Asia		Shade/soil conservation/windbreak
Prosopis juliflora	American Tropics		Animal fodder/firewood/shade/forage
Prosopis nigra	American Tropics		Firewood/food/poles

Prunus cerasitoides	S. Asia	Humid subtropics	Food/fuelwood/timber
Prunus domestica	S. Asia	Humid subtropics	Food/fuelwood
Prunus persica	American Tropics/S. Asia	Arid humid subtropics	Fruit/food/fuelwood
Psidium guajava	E. Africa/Pacific Islands/S. Asia/S. E. Asia/Sahel	Subhumid tropics/humid tropics/humid subtropics	Food/fuelwood/fruit/tools & utensils
Pterocarpus milbraedii	W. Africa	Humid tropics	Dye/food
Pterocarpus osun	W. Africa	Humid tropics	Dye/food
Pterocarpus santalinoides	W. Africa	Humid tropics	Food
Pterocarpus soyauxii	W. Africa	Humid tropics	Dye/food
Pterogyne nitens	American Tropics	Humid subtropics	Crop shade/shade/timber/fuelwood/poles
Punica granatum	S. Asia/S. E. Asia	Humid subtropics/humid tropics	Food/fuelwood/fruit
Pyrus communis	American Tropics	Arid	Fruit
Pyrus pasha	S. Asia	Humid subtropics	Fuelwood/live fence/timber
Pyrus serotina	S. Asia	Humid subtropics	Food/fuelwood
Quercus faginea	Mediterranean		Cork/lumber
Quercus incana	S. Asia		Food
Quercus rotundifolia	Mediterranean		Acorn production/lumber
Quercus sp.	American Tropics	Humid tropics	Firewood/shade
Quercus suber	Mediterranean		Charcoal/cork/tannin/timber
Raphia hookerii	W. Africa	Humid tropics	Beverage/roofing
Rauwolfia caffra	E. Africa	Subhumid tropics	Anti-pest/crop shade/food/fuelwood
Rhus javanica	S. Asia	Humid subtropics	Food/fuelwood
Rhus succedanea	S. Asia	Humid subtropics	Food/fuelwood
Ricinodendron heudelotii	W. Africa	Humid tropics	Food/ritual/stake
Ricinus communis	E. Africa	Subhumid tropics	Anti-pest/medicinal value
Saba florida	W. Africa	Humid tropics	Food
Salix chilensis	American Tropics		Fuelwood/live fence/shade
Salmalia malabarica	S. Asia	Humid subtropics	Fuelwood/food/timber
Salvadora persica	Sahel & C. Africa	Arid	Food/fuelwood
Samanea saman	S. Asia		Soil conservation/timber
Schima wallichii	S. Asia	Humid subtropics	Food/fuelwood/timber
Schinopsis balansae	American Tropics	Humid tropics	Lumber
Sclerocarya birrea	Sahel & W. Africa	Subhumid tropics	
Securinege samoense	Pacific Islands	Humid tropics	Boundary planting/stake

SPECIES	REGION	CLIMATE CLASS	USES
Shorea javanica	S. E. Asia	Humid tropics	Crop shade/fuelwood/gum/resin/soil conservation
Shorea robusta	S. Asia	Humid subtropics	Food/fuelwood/timber
Spondias mombin	W. Africa	Humid tropics	Boundary planting/food
Sterospermum kuthianum	W. Africa	Semi arid	
Switenia macrophyla	American Tropics/S. Asia	Humid tropics	Fuelwood/timber
Switenia mahogani	American Tropics	Subhumid tropics	Firewood/lumber/shade
Syzigium africanum	E. Africa	Subhumid tropics	Food/fuelwood
Syzigium cumini	S. E. Asia	Humid tropics	Crop shade/food
Syzigium sp.	S. Asia	Humid subtropics	Food/fuelwood
Syzigium aromaticum	S. Asia	Humid tropics	Food/spice
Tabebuia crysantha	American Tropics		Fuelwood/timber
Tabebuia rosae	American Tropics	Subhumid tropics	Fuelwood/live fence/poles/shade/timber/firewood
Tabebuia serratifolia	American Tropics	Subhumid tropics	Firewood/forage/shade
Tamarindus indica	Pacific Islands/S. Asia/Sahel & W. Africa/W. Africa	Humid tropics/semi arid/subhumid tropics/humid subtropics	Beverage/fuelwood/fruit/food/ritual/shade/tools &
Tamarix articulata	Sahel & C. Africa	Arid	Food/fuelwood
Tectona grandis	American Tropics/E. Africa/S. Asia/S. E. Asia/Sahel	Subhumid tropics/humid tropics/humid, sub-humid	Firewood/lumber/shade/timber
Terminalia brownii	W. Africa	Humid subtropics	Building material
Terminalia macroptera	Sahel & W. Africa	Semi arid	Fuelwood
Terminalia sp.	S. E. Asia	Humid tropics	Building material/fuelwood/timber
Test species			Acorn production
Tetracarpidium conophorum	W. Africa	Humid tropics	Food
Theobroma cacao	American Tropics/Pacific Islands/S. Asia/S. E. Asia	Subhumid tropics/humid tropics	Beverage/cash/firewood/food/stake

Thespesia populenea	S. Asia	Humid tropics	Fruit/timber
Tinospora malabarica	S. Asia	Humid subtropics	Fuelwood
Treculia africana	W. Africa	Humid tropics	Food/fuelwood/poles/pulp/windbreak
Trema guineensis	E. Africa	Subhumid tropics	Anti-pest/food/medicinal value
Trichilia connaroides	S. Asia	Humid subtropics	Food/fuelwood
Trichilia emetica	E. Africa	Subhumid tropics	Anti-pest/fuelwood
Triplaris meridansis	American Tropics	Subhumid tropics	Firewood/lumber/shade
Tripsacum laxum	S. Asia	Subhumid tropics	Windbreak
Tristania sp.	S. E. Asia	Humid tropics	Building material/fuelwood/timber
Uvaria chamae	W. Africa	Humid tropics	Food
Uvaria sp.	E. Africa	Subhumid tropics	Fuelwood
Vangueria tomentosa	E. Africa	Subhumid tropics	Food/medicinal value
Vernonia amygdalina	W. Africa	Humid tropics	Food/live fence
Vitex doniana	W. Africa	Humid tropics	Food
Widdringtonia whytei	E. Africa	Humid subtropics	Timber
Wrightia antidyserterica	S. Asia	Humid subtropics	Live fence
Xylopia parviflora	W. Africa	Humid tropics	Food
Ziziphus mauritiana	Sahel & W. Africa	Semi arid/subhumid tropics	Animal fodder/food/shade
Zizyphus jujuba	S. Asia	Humid subtropics	Fruit/food/fuelwood
Zizyphus mauritiana	W. Africa	Semi arid	Food/fruit
Zizyphus spina-christi	Sahel & N. Africa	Semi arid	Food/fuelwood
Zizyphus spina-christi	W. Africa	Semi arid	Windbreak

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