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FRUIT TREES IN TROPICAL AGROFORESTRY SYSTEMS

(A joint ICRAF/EWC Working Paper)

P.K.R. Nair
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FOREWORD

A soils scientist by training and a Senior Research Scientist of the International Council for Research in Agroforestry (ICRAF) by designation, Dr. P. K. R. Nair has been focussing his research attention upon foodcrops/woody perennials/soils relationships and their influence on the productivity and sustainability of agroforestry systems. It was on these bases that he was invited, from July to September 1984, to serve as a Research Fellow in the Environment and Policy Institute (EAPI) of the East-West Center. His terms of reference during his three-month visit included the preparation of this Working Paper covering the use of fruit trees as the perennial component of tropical agroforestry systems.

The topic is far from trivial. It has been noted that, for obvious socio-economic reasons, farmers prefer using fruit trees over forest trees in their agroforestry farms. On the other hand, foresters have voiced strong objections to the use of "non-forest trees," primarily because they fear the conversion of hilly forest lands into agricultural lands, and because they believe that the wide spacing necessary for fruit trees would effectively reduce their protective role on sloping lands. Dr. Nair's working paper would clarify some of the conflicting issues and indicate in greater detail both the productive and protective roles of fruit trees in agroforestry systems.

It is hoped that this paper would provide forestry land use planners and policy makers with a clearer understanding of the benefits of using fruit trees in place of the traditional forest tree

species in agroforestry. In gaining such an understanding, these resource administrators may become better inclined to accept agroforestry as a sustainable land use system that is compatible with the objectives of sustained-yield forestry management. This acceptance may lead eventually to the forging of a strong partnership between foresters and farmers in restoring the productive capacity of degraded uplands, or in maintaining the productivity of fragile highlands.

NAPOLEON T. VERGARA

Research Associate

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This Working Paper was prepared during my stay as a Research Fellow at EAPI, East-West Center, from July to September, 1984, on leave of absence from ICRAF. During the period, my main contact person at EAPI has been Mr. Napoleon Vergara, Research Associate.

Both Mr. Vergara and Dr. Lawrence Hamilton, another Research Associate of EAPI, read through and criticized the manuscript, for which I thank them.

I also thank the Director of EAPI, Dr. William Matthews, and his staff, notably Ms. Karen Ashitani, Secretary, for the excellent facilities and support; and Dr. B. Lundgren, Director of ICRAF for facilitating my stay at EAPI.

Some of the data used in the paper are the outputs from the Agroforestry Systems Inventory Project, an ICRAF project partially funded by USAID and coordinated by me. The sources of these as well as other data used in the paper have been duly acknowledged.

Honolulu, Hawaii

September, 1984

P.K.R. Nair

SUMMARY

A quick overview of the existence of agroforestry systems and practices around the world shows that a large number of trees and other woody perennials are essential components of many tropical land use systems. These include several fruit-and nut producing trees and shrubs ("fruit trees"), especially in the integrated smallholder farming systems of the Asia-Pacific region and other thickly-populated areas of the tropics. Most of such species are under-exploited and are therefore only used on a limited scale. The paper examines the environmental and socio-economic advantages of such fruit trees in comparison with other woody perennials as components of tropical agroforestry systems and discusses the problems and prospects of popularizing such systems. Most of the fruit trees are eminent multipurpose species because, in addition to their environmental protection value, they also produce various products of immense nutritive value. A summary account is given of the growth form and crop profiles of 30 fruit trees that are most commonly used in tropical agroforestry systems. While most other woody components of agroforestry can be harvested periodically for their vegetative mass as fuelwood, fodder or mulch/green manure, fruit trees are seldom harvested for such non-edible vegetative parts.

The environmental merits of fruit trees in agroforestry systems stem from their micro-site enrichment and macro-site amelioration capabilities. There are strong indications of better organic matter relations (and all consequential benefits) and improved nutrient cyclying (and therefore a better nutrient economy) in the soil-plant system of fruit tree-based agroforestry practices. Moreover appropriate planting and management schedules can be devised for using fruit trees for soil conservation and as windbreaks and shelterbelts.

The major socio-economic benefits of using fruit trees as components of agroforestry systems can be summarized as: production of various products and by-products, regular contribution to the cash economy of the farmer, possibility of staggered production of minor foodstuffs during lean periods of staple food availability, generation of additional employment potential for the farmer, risk minimization and economic complementarity in the sharing of scarce resources of production. Because of the location specificity of these values and benefits and their strong links with the prevailing social habits of the locality, these values cannot be precisely assessed and explicity expressed in quantitative terms.

The extent to which the suggested advantages can be realized depends on a large number of environmental factors and management considerations. Although the location-specific nature of these factors precludes any specific recommendations on these, a general account is presented of the criteria in the choice of species, pattern and density of their planting and their management schedules.

Agroforestry research demands a thorough modification of conventional norms and procedures of disciplinary research. The approach should be to strike a balance between such accepted procedures on the one hand and deriving the maximum information with limited use of resources in as short a time as possible on the other. Similarly while interpreting research results and extrapolating them to other regions, the social values of the products and benefits also will have to be taken into account.

The potentials offered by fruit tree-based agroforestry systems seems to be so promising that there is an urgent need for mobilizing resources and intensifying research and development efforts in this very promising, but least-studied field.

1. AGROFORESTRY SYSTEMS OVERVIEW

An inventory of agroforestry (AF) systems and practices existing in different parts of the world, with special emphasis on the developing countries is currently (1982 - —) being undertaken by the International Council for Research in Agroforestry (ICRAF). The project aims at collecting, collating and synthesizing information on prominent and promising AF and other related land use systems with a view to preparing a state-of-the-art of global AF, identifying the constraints, weaknesses and merits of major AF systems and assessing their research needs. A large number of active AF enthusiasts and other knowledgeable individuals and institutions around the world are collaborating in the task, mainly as resource sources for data gathering. Before initiating the formal data gathering for the project, available information on the subject was put together as an "AF Systems Overview Table" by a group of representatives from different geographic regions of the developing world who attended a planning meeting in Nairobi in December 1982. Though it did not contain the structural and functional details of the systems mentioned, the Table gave a summary account of the diversity of AF systems and practices as known at that time and it was widely publicized as a basic document (see Agricultural Systems, 11 (1983):191-194; Agroforestry Systems 1(1983):269-273, and so on).

The "Systems Overview Table" was updated recently (Nair, 1984b) incorporating new information that has since accumulated from the project. It is presented as Table 1. It is an abstract Table, derived from detailed information gathered and stored at ICRAF. As an amplification of the Table, a more detailed account of some of the

TABLE 1. SOME EXAMPLES OF PROMINENT AGROFORESTRY SYSTEMS AND PRACTICES IN THE DEVELOPING COUNTRIES (NAIR, 1985)

SYSTEMS		EXAMPLES FROM DIFFERENT GEOGRAPHIC REGIONS*						
Major Systems	Sub-Systems/Practices	Pacific	Southeast Asia	South Asia	Middle East and Mediterranean	East and Central Africa	West Africa	American Tropics
AGROSILVICULTURAL SYSTEMS	Improved "Fallow" (in shifting cultivation areas)		Forest villages of Thailand (Various fruit trees + plantation crops used as "fallow" species in Indonesia	Improvements 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	Acacia fallows, Anthonotha macrophylla, Cliri-sidia sepium, etc. tried as "fallow" species	Several forms
	The Taungya System	(e.g. Teak with Gliricidia and Anthocephalus trees)	Widely practised; Forest villages of Thailand is an improved form	Several forms, several names		The "Shamba" System	Several forms	Several forms
	Tree Gardens	Levuleing fruit trees	Dominated by fruit trees	In all ecological regions	The Dehesa system, "Park arboreal"			e.g. "Parklike woodlot" of Paraguay
	Hedgerow Intercropping (Alley Cropping)		Extensive use of Leucaena, Gliricidia, Leucaena leucocephala and Calliandra calothyrsus	Several experimental approaches e.g. Conservation farming in Sri Lanka		The Corridor System of Zaire	Experimental systems on alley cropping with Leucaena and others	
	Multipurpose Trees and Shrubs on Farmlands	Widely fruit or nut trees (e.g. Canarium, Dimocia, Barringtonia, Pandanus, Artocarpus altilis)	Dominated by fruit trees; also Acacia auriculiformis - cropping system, Indonesia	Several forms both in lowlands and highlands e.g. Hill farming in Nepal, "Bhojri" - based system in the dry parts of India	The Hasik system, Crop combinations with the Carob tree; The Dehesa system, Irrigated systems, Olive trees + cereals	Various forms; The Chagga system of Tanzanian highlands; The Ayubtlands system of Rwanda	Acacia albida-based food production systems in dry areas; Multipurpose + Fuelwood systems; "Park arboreal"	Various forms in all ecological regions
	Crop Combination with Plantation Crops	Plant. crops and other multipurpose trees; e.g. Canarium and taro in the highlands of PNG, also Gliricidia and Leucaena with cocoa	Plant. crops + fruit trees; smallholder systems of crop combinations with plantation crops; plantation crops with spice trees	Integrated production system in smallholdings, shade trees in plantations; other crop mixtures including various spices	Irrigated systems; Olive trees + cereals	Integrated production; shade trees in commercial plantations; mixed systems in the highlands	Plantation crop mixtures; smallholder production systems	Plantation crop mixtures; shade trees in commercial plantations; mixed system in smallholdings; spice trees
	Af Fuelwood Production	Multipurpose fuelwood trees around settlements	Swamp champion in different ecological regions	Various forms		Various forms	Common in the dry regions	Several forms in the dry regions
	Shelterbelts, Windbreaks, Soil Conservation Hedges	Canarium oleiferum in the highlands as shelterbelts and soil improver	Terrace stabilisation in steep slopes	Use of Casuarina spp. as shelterbelts; several windbreaks	Tree spices for erosion control	The Ayubtlands system of Rwanda	Various forms	Live fences, windbreaks especially in highlands
SILVOPASTORAL SYSTEMS	Protein Bank (Cut-and-carry Fodder Production)		Very common, especially in highlands	Multipurpose fodder trees on or around farmlands especially in highlands		Very common	Very common	Very common
	Living Fence of Fodder Trees and Hedges		Leucaena, Gliricidia, etc. used extensively	Sesbania, Agathis, Spondias etc. common		Very common in all ecological regions		Very common in the highlands
	Trees and Shrubs on Pastures	Cattle under coconuts, pines and Eucalyptus Deglupta	Grazing under coconuts and other plantations	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. Grazing under plantation crops in Brazil
AGROSILVOPASTORAL SYSTEMS	Woody Hedges for Browse, Mulch, Green Manure, Soil Conservation, etc.	Various forms; Canarium oleiferum widely used to provide mulch and compost	Various forms	Various forms especially in lowlands			Very common	
	Home Gardens (Involving a large number of herbaceous and woody plants with or without animal.)		Very common, some home gardens often quoted as good examples	Common in all ecological regions	The Hasik system	Various forms (the Chagga home gardens, the Ayubtlands system)	Compound farms of humid lowlands	Very common in the thickly populated areas
OTHER SYSTEMS	Agro-Silvo-Fishery ("Aquaforestry")		Silviculture in mangrove areas; trees on the bunds of fish-breeding ponds					
	Various forms of Shifting Cultivation	Common	e.g. Sulabata farming	Very common, various names		Very common	Very common in the low lands	Very common in all ecological regions
	Apiculture with trees	Common	Common		Common	Common	Common	

* See table 2 for a list of the common tree species and practices referred to each of the sub-systems/practices.

prominent examples of such AF systems and practices with emphasis on the woody species involved, is given in Table 2.

These two Tables give a summary overview of AF systems. They indicate that AF is wide-spread in the developing countries in almost all ecological regions. If viewed with the broad concept of AF as an approach to land use involving deliberate retention or inclusion of trees and other woody perennials in the crop/animal production fields (Lundgren and Raintree, 1983; Nair, 1983a; b), it can be found that several of the existing land use systems encompass the concept of AF although they have been in existence over a long period of time, without being known by this relatively new name. However, the greatest difficulty in describing AF systems is that quantitative information does not exist on the structure, function, dynamics and other operational aspects of the systems so that a concise and critical assessment on the role and contribution of AF to the economy and development of the countries concerned is possible at the moment only in qualitative terms, which is not often very appealing.

2. WOODY PERENNIAL PLANTS IN AGROFORESTRY

2.1. Agroforestry Species

Since agriculture and forestry (in the widest sense of the terms) are the two major land use activities, most of the economic plants that are widely cultivated by man are also usually considered to belong to these two categories. And, though not based on any precise criteria, there is an apparent distinction between these two groups of

TABLE 2. FIELD EXAMPLES OF SOME COMMON AGROFORESTRY SYSTEMS AND PRACTICES IN THE TROPICS (after NAIR, 1984 b)

Sub-system/ Practice	Country/ Region	Some examples of the woody species involved	Remarks/ Major references
I.A. AGROSILVICULTURAL SYSTEMS - Humid/Sub-humid Lowlands			
Improved "Fallow" (in shifting cultivation areas)	Indonesia	*Aleurites moluccana* *Erythrina* spp. *Styrax* spp.	Kunstadter et al. (1978)
Woody species planted and left to grow during the "Fallow phase"	Nigeria	*Acacia barteri* *Anthonotha macrophylla*	Getahun et al. (1982)
Tree Gardens	Nigeria	*Daniellia oliveri* *Gliricidia sepium* *Parkia clappertoniana* *Pterocarpus africana*	Getahun et al. (1982)
Multilayer, multi-species plant associations with no organized planting arrangement	Pacific Islands	*Dracontomelon edulis* *Morus nigra* *Spondias dulce*	Richardson (1982)
	India, Sri Lanka	*Areca catechu* *Artocarpus* spp. *Cocos nucifera* *Mangifera indica*	Coconut intercropping: Nair (1979; 1983); Liyanage et al. (1984)
	Paraguay	*Melia azedarach*	The Paraiso woodlot (Evans and Rombold, 1984)
	SE Asia	*Albizia falcataria* *Artocarpus* spp. *Bambusa* spp. *Durio zibethinus* *Nephelium lappaceum*	Amber (1982) Forest Villages of Thailand (Bocnaird et al., 1984)
Hedgerow intercropping (Alley cropping)	SE Asia	*Calliandra calothyrsus*	
Woody species in hedges; agri. species in between hedges (alleys)	Nigeria	*Leucaena leucocephala*	Wilson and Kang (1981)
Multipurpose trees and shrubs on farmlands	Brazil	*Cassia siamea* *L. leucocephala* *Mimosa scabrella*	
Trees scattered haphazardly or according to some systematic patterns	India	*Dorrie indica* *Emblica officinalis* *Moringa oleifera* *Tamarindus indica*	NAS (1980)
	Kenya	*Anacardium occidentale* *Cordia petandra* *Mangifera indica* *Manilkara sahrea*	

TABLE 2 (CONT'D)

	SE Asia	*Acacia mangium*	
		Artocarpus spp.	
		Durio sibethinus	
		Gliricidia sepium	
		Sesbania grandiflora	
Crop combinations with plantation crops		Plantation crops	
		Anacardium occidentale	
1) Integrated production of plantation crops and other crops in intimate plant associations		*Camellia sinensis*	
		Cocos nucifera	
		Coffea arabica	
		Elaeis guineensis	
2) Mixtures of plantation crops e.g. coconut and cacao		*Hevea brasiliensis*	
		Piper nigrum	
		Theobroma cacao	
3) Shade trees for commercial plantation crops	Brazil	*Bertholletia excelsa*	Hecht (1982)
		Copernicia prunifera	Alvim and
		Cordia alliodora	Nair (1984)
		Inga spp.	
		Orbignya spp.	
		Samanea saman	
	Costa Rica	*Cordia alliodora*	Budowski (1983)
		Erythrina poeppigiana	Heuveldop and
		Gliricidia sepium	Lagemann (1981)
		Inga spp.	
	India	*Albizia* spp.	Coconut intercropping
		Cassia spp.	(Nair, 1979; 1983;
		Erythrina spp.	Liyanage et al., 1984)
		Grevillea robusta	
	SE Asia	Various fruit trees	
	West Indies	*Inga vera*	
	Western Samoa	*Erythrina variegata*	Richardson (1982)
		Gliricidia sepium	
		Leucaena leucocephala	
AF for fuelwood Production	India	*Albizia* spp.	ICAR (1979)
Interplanting fire-wood species on or around agricultural lands		*Cassia siamea*	NAS (1980)
		Derris indica	
		Dolichos officinalis	
	Indonesia	*Albizia falcataria*	NAS (1980)
		Calliandra calothyrsus	
		Sesbania grandiflora	
		Trema orientalis	

TABLE 2 (CONT'D)

Shelterbelts, windbreaks, soil conservation hedges	India	*Casuarina equisetifolia* *Syzygium cumini*	NAS (1980)
Planting around agricultural lands as windbreaks and shelterbelts; planting along contours for terrace stabilization and soil conservation	Indonesia (and other parts of SE Asia)	*Gliricidia sepium* *Leucaena leucocephala* *Sesbania grandiflora*	NAS (1980)
I. B. AGROSILVICULTURAL SYSTEMS - Tropical Highlands			
Multipurpose trees and shrubs on farmlands	India	*Albizia* spp. *Bauhinia variegata* *Dalbergia sissoo*	NAS (1980)
	Kenya	*Ceiba pentandra* *Eriobotrya japonica* *Grevillea robusta*	
	Nepal	*Bauhinia* spp. *Erythrina* spp. *Ficus* spp. *Litsea polyantha*	Hill farming in Nepal (Fonzen and Oberholzer, 1984)
	Paraguay	*Melia azedarach*	The Paraiso woodlot (Evans and Rombold, 1984)
	Tanzania	*Albizia* spp. *Cordia africana* *Croton macrostachys* *Ficus guineensis*	The Chagga system (Fernandes et al., 1984)
Crop combinations with plantation crops	Brazil	*Alnus acuminata* *Enterolobium contortisiliquum* *Erythrina velutina*	
	Costa Rica	*Alnus acuminata* *Erythrina poeppigiana* *Inga* spp.	Budowski (1983)
	India, Sri Lanka	*Albizia* spp. *Grevillea robusta*	
	Kenya Papua New Guinea Philippines	*Grevillea robusta* *Casuarina oligodon* *Ficus orientalis*	Bourke (1984)
	Rwanda Tanzania	*Albizia* spp. *Cordia africana* *Grevillea robusta* *Ficus guineensis*	Fernandes et al. (1984) Neumann (1983)

TABLE 2 (CONT'D)

AF Fuelwood Production	India, Nepal	*Albizia stipulata* *Bauhinia* spp. *Grewia* spp.	ICAR (1979) NAS (1980)
Shelterbelts, Windbreaks, Soil Conservation Hedges	(same as in lowlands)		
I.C. AGROSILVICULTURAL SYSTEMS - Arid and Semi Arid Regions			
Multipurpose Trees and Shrubs on Farmlands	Brazil	*Caesalpinia ferrea* *Prosopis juliflora* *Zizyphus joazeiro*	Johnson (1983)
	Central African Republic	*Adansonia digitata* *Balanites aegyptiaca* *Borassus aethiopium*	Yandji (1982)
	India	*Cajanus cajan* *Derris indica* *Prosopis cineraria* *Tamarindus indica*	NAS (1980)
	Kenya	*Acacia* spp. *Balanites aegyptiaca* *Cajanus cajan*	
	Tanzania	*Acacia* sp. *Combretum* spp.	
AF Fuelwood Production	Chile India	*Prosopis tamarugo* *Albizia lebbek* *Cassia siamea* *Prosopis* spp.	NAS (1980) Little (1983) ICAR (1979)
	Sahel	*Acacia albida* *A. senegal* *A. tortilis*	von Maydell (1984)
Shelterbelts and Windbreaks	India, Pakistan	*Azadirachta indica* *Cajanus cajan* *Cassia siamea* *Eucalyptus* spp. *Pithecellobium dulce* *Populus* spp.	Sheikh and China (1976). Sheikh and Khalique (1982)

TABLE 2 (CONT'D)

II. SILVOPASTORAL SYSTEMS - Humid/Sub-humid Lowlands			
Protein Bank (Multi-purpose Fodder Trees on or around Farmlands)	India,	*Artocarpus* spp.	ICAR (1979)
	Nepal,	*Anogeissus latifolia*	Pandey (1982)
	Sri Lanka	*Bombax malabaricum*	Singh (1982)
		Cordia dichotoma	
		Dalbergia sissoo	
		Eugenia jambolana	
		Samanea saman	
		Ziziphus jujuba	
Living Fences of Fodder Trees and Hedges	Costa Rica	*Diphysa robinoides*	
		Gliricidia sepium	
	Ethiopia	*Erythrina abyssinica*	
	SE Asia	*Sesbania grandiflora*	
Trees and Shrubs on Pastures (similar to multipurpose trees on farmlands)	Brazil	*Acacia* spp.	Hecht (1982)
		Anacardium occidentale	Johnson and Nair (1984)
		Cedrela odorata	
		Cordia alliodora	
	Costa Rica	*Enterolobium cyclocarpum*	De las Salas (1979)
		Erythrina poeppigiana	
		Samanea saman	
	India	*Derris indica*	Singh (1982)
		Dolichos afficinalis	
		Psidium guajava	
		Tamarindus indica	
II. SILVOPASTORAL SYSTEMS - Tropical Highlands			
Protein Bank	Indian subcontinent	*Albizia stipulata*	
		Bauhinia spp.	
		Ficus spp.	
		Grewia oppositifolia	
		Morus alba	
Living Fences	Costa Rica	*Gliricidia sepium*	
	Ethiopia	*Erythrina abyssinica*	
	East Africa	*Dovyalis caffra*	
		Euphorbia tirucalli	
		Ficus multiflora	
Trees and Shrubs on Pastures	Brazil	*Desmanthus virgatus*	
		Desmodium discolor	
	Costa Rica	*Alnus acuminata*	
	Indian subcontinent	*Albizia stipulata*	
		Alnus nepalensis	
		Grewia spp.	
		Robinia pseudoacacia	

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TABLE 2 (CONT'D)

II. C. SILVOPASTORAL SYSTEMS - Arid and Semi-arid Regions			
Protein Bank	India	*Acacia nilotica* *Ailanthus excelsa* *Opuntia ficus indica* *Prosopis* spp. *Rhus sinuata*	Singh (1982)
Living Fences	East Africa	*Acacia* spp. *Commiphora africana* *Euphorbia sirmahii* *Ziziphus mucronata*	
Trees and Shrubs on Pastures	India	*Acacia* spp. *Prosopis* spp. *Tamarindus indica*	
	Middle East and Mediterranean	*Acacia* spp. *Ceratonia siliqua* *Halimodendron* spp. *Prosopis cineraria* *Tamarix aphylla*	
III. AGROSILVOPASTORAL SYSTEMS			
Woody Hedgerows for Browse, Mulch, Green Manure and Soil Conservation	Indian subcontinent (Humid lowlands), SE Asia	*Erythrina* spp. *Leucaena leucocephala* *Sesbania* spp.	
Tree-Crop-Livestock Mix around Homestead (known as Home Gardens, these associations are found in almost all ecological regions and several countries; only some examples are given)	South and SE Asia (Humid lowlands)	Fruit trees and some plantation crops mentioned under Agro-silvicultural systems	e.g. Home Gardens of Java (Wiersum, 1982)
	Nigeria (Humid lowlands)	*Cola acuminata* *Garcinia kola* *Irvingia gabonensis* *Pterocarpus soyauxii* *Treculia africana*	
	Latin American countries	Several species mentioned under Agrosilvicultural systems	Wilken (1978)
	Tanzania (Highlands)	*Albizia* spp. *Cordia africana* *Morus alba* *Prunus persicaria*	Chagga Home-gardens (Fernandez et al. 1984)

crop plants. Thus, species regarded as belonging to agriculture have included mostly (but not exclusively) herbaceous ones that were cultivated with much managerial attention and harvested at frequent intervals for their most important economic produce, either through repeated generations of the same short-duration species, or by repeated harvesting from the same plant. Foresters, on the other hand, concentrated on woody perennial species that could be cultivated on a large scale, the main objective being the maximum return of the final product at the end of the fairly long production cycle. There are also specific groups of species like the so-called "horticultural" crops that transcend the limits of these criteria. But there are no "conventional" agroforestry species because the name agroforestry is new (although the practice is old). Therefore most plant species that are used/found in the various AF systems described above fall under one or the other of the conventional disciplinary groups. Besides, there are also other plants, especially woody ones, which have hitherto been little-studied, but which form important components of existing AF systems, or may prove valuable for potential AF systems. Before assessing the criteria for deciding the suitability of candidate species for potential AF systems, let us examine the species that are commonly found to exist in traditional AF systems.

Conceptually AF systems involve at least one woody species in more or less intimate and interacting association with other herbaceous or woody plants and/or animals, all on the same unit of land. Since this interactive presence of the woody species is the common denominator in all AF systems, the primary consideration on plant species in AF should involve the woody species. Some common

examples of such woody species in existing AF systems have been presented in Table 2. This Table, which by no means is exhaustive, indicates that the woody perennials used in AF systems include a multitude of species in terms of their growth habits, forms, economic products, other biological characteristics, management etc. Thus firewood crops, fodder trees, timber species, palms, fruit trees, vines, bamboos, shrubs, and so on can be found in different AF systems in various ecological regions.

Based on the experience gained from intercropping and other forms of crop combinations with tree crops, Nair (1980b) evaluated the "AF suitability" of a number of conventional agricultural species. He observed that with the knowledge of the ecophysiological requirements of different groups of plants in general, and of the individual species or cultivars in particular, some predictions could be made with a reasonble degree of accuracy about the conditions that are optimum for their best growth. Thus it is possible to list a large number of physiological and agronomical characters that decide the compatibility of the species in admixture and the ability of the species to produce a reasonable yield under conditions of reduced supply of growth factors such as light and nutrients where it is grown as an understory species. Furthermore from the practical viewpoint, the ease of management of the species, its ability to withstand adverse climatic and managerial conditions, its adaptability to low-input systems and marginal areas, marketability, local use of its produce, and so on, are important considerations. All these apply to the woody perennials as well.

Based on these considerations, it will be possible to assess the "AF potential" of the species as well as the characteristics that contribute to make a candidate species potentially useful for AF. The manifestation of the potential will, however, depend upon environmental conditions, and in AF situation, these conditions vary from farm to farm. Besides, the socio-economic aspects and food habits of the local population are extremely important factors in deciding the adoptability of any species in a particular place. Above all, within a given set of soil and climatic conditions, some of the important aspects of AF significance such as plant form, canopy density and even rooting pattern will depend upon and can be altered by management.

Thus a number of steps have to be followed in logical sequence while selecting plant species - both herbaceous and woody perennial - in AF. One factor that makes this process particularly important in the case of woody perennials is their relatively long spans of the juvenile phase as well as total life so that the effect of any of the initial management (such as, say, planting pattern) will not be manifested until after a long time, and any modification of such management operation will have long-term effects. These logical sequence of steps to be followed in choosing the AF species is:

- o evaluate the ecophysiological requirements for optimum growth of the species;
- o examine the growth habits of the species under the usual cultivated conditions;
- o assess the specific AF possibilities including the socio-cultural aspects of including the species under a given situation;

- o look for any successful examples of similar systems in other conditions.

It was according to this sequence that Nair (1980b) examined the AF potential of the commonly cultivated agricultural species including several fruit trees. Additionally, Huxley (1983a) prepared an aide-memoire of characters of trees for those looking at the role of trees in AF.

2.2. Multipurpose Trees

With the recent understanding (by the scientists and other experts) of the values of age-old, integrated land management systems involving woody perennials and the consequent awareness about and acceptability of the concept as a sound and viable land-use option, several terms such as village forestry, social forestry, farm forestry, forest village, community forestry, and so on have appeared in common usage among the community of experts. Depending on the priority of objectives and, to some extent, according to the personal opinions and biases, the definitions and interpretations of the terms vary; but in common parlance most of these terms have often been used synonymously, and sometimes even out of context. But strictly speaking, each of the terms has distinct connotations; some are land-use systems (e.g. farm forestry); others are land (forest) management approaches (e.g. community forestry); See Kirchhofer and Mercer (1984) for a discussion. In a general sense, all these terms denote one or the other form of integration of trees with components of other disciplines relevant to land use and rural development. Although the trees so used are usually neither the conventional

forestry species nor are they managed as in a forestry community (natural or planted), all these terms have, unfortunately, a semantic emphasis on forestry as though they are specific branches of forestry. Agroforestry, which has now got established as an all-embracing generic term for a wide range of integrated land management approaches and systems involving woody perennials to encompass, if not eliminate, most of the earlier-mentioned terms with 'forestry' endings, also causes such a confusion about its identity vis-à-vis forestry. However, not only the species and types, but also the uses, role, arrangement and management of woody perennials in AF are different from those of trees in forestry. Trees used outside forestry except a few ornamentals and fruit and nut trees had hitherto been relegated to a status of lower economic significance and importance. But, with the recognition of the importance of AF, such trees and other woody perennials used in traditional mixed AF systems and other species of AF potential have earned a higher "ranking" and "status" necessitating a distinct identity and definition for this group of plants. The term multipurpose tree (MPT) thus emerged and acquired wide acceptance in a rather short time to encompass all such trees and woody perennials of AF significance/potential. It has even been opined that the term" multipurpose tree" is better and more appropriate than "agroforestry" in terms of expressing and conveying the respective meanings and concepts of the two different terms (von Carlowitz, 1984a). This should not, however, lead to the impression that AF and MPT are synonymous.

MPT, like AF, also has no universally acceptable definition. Several definitions have been proposed. Some are simple ones, for example:

> A multipurpose tree in an AF context is one that provides multiple outputs of economic use from the tree itself and at the same time is able to combine well, both ecologically and economically, with the other components(s) of that particular AF system (Nair, cited by von Carlowitz, 1984b).

After evaluating the various ideas and definitions put forward by a number of experts who assembled at an International Workshop on MPT Germplasm in Washington, D.C., June 1983, von Carlowitz proposed the following:

> An MPT is a tree which clearly constitutes an essential component of an AF system or of other multipurpose land use system. Regardless of the number of its potential uses, an MPT has to have the capacity to provide in its specific function(s) in the system a substantial and recognizable contribution to the sustainability of yields, to the increase of outputs and/or to the reduction of inputs, and to the ecological stability of that system. Only a tree which is kept and maintained or introduced into an AF system specifically for one or more of these purposes qualifies as an MPT.

Whatever the definition of MPT, the consensus of opinions is that the catch-word is "multipurpose". Although "virtually every species of trees or shrubs can be used for more than one purpose" (Burley, 1983), it is generally agreed that multiple uses or multiple outputs are considered important attributes of any definition of MPT, and the term should be used to cover species that may be grown for different purposes on different sites. An explanation of this latter point is provided by, say, Grevillea robusta, an accepted timber tree, which if grown in plantations for predominantly timber production, does not form an MPT whereas it becomes an MPT when grown in another situation not only for timber, but also for shade, mulch, honey etc. For example, Johnson (1984) assessed the multipurpose nature and AF

potential of palms and observed that in addition to the four improved, cultivated palms (Areca catechu - areca or betel palm, Cocos nucifera - coconut palm, Elaeis guineensis - oil palm, and Phoenix dactylifera - date palm) there are 18 unimproved cultivated or managed palms and 29 semi-wild or wild palms of multiple uses and AF potential in different ecoregions. An interesting point to note here is that most of such MPTs found in traditional AF systems have been little studied in the past so that they do not fall under the category of conventional forestry/agricultural/horticultural species. Yet they make significant contributions in various ways to the livelihood of a large number of people, and more research efforts on these species can lead to the exploitation of their potential to a much larger extent. Undoubtedly one of the greatest advantages in AF lies in making the best use of the vast potential offered by these MPTs of little-known values.

2.3. Fruit Trees in Agroforestry

Table 2 indicates that the woody perennial components of some of the AF systems in tropics and subtropics are the fruit and nut producing trees and shrubs, some of which are conventionally called "horticultural species". In traditional AF systems, these species can often be found in association with other woody components. Subject to their ecological adaptability, some of these fruit species are widely distributed in different geographical regions (e.g. mango, papaya) whereas some others are highly localized and found only in certain specific geographic regions (e.g. rambutan - Nephelium lappaceum - in Southeast Asia; pejibaye palm - Bactris gassipaes - in South America).

Table 3 shows a summary account of the occurrence of some of the fruit trees in AF systems in different parts of the world and their condensed crop profiles. The species listed here range from tall long duration perennials (e.g. the Brazil nut tree) to relatively short, "non-woody" species such as papaya. In this paper all these species are hereafter collectively referred to as "fruit trees".

Table 3 indicates that among the various types of AF systems and practices (Tables 1 and 2 - for details, see Nair 1984b), the fruit trees are found only in some of them. The major AF subsystems of Table 1 in which fruit trees are only sparingly found include:

- o the taungya system
- o alley cropping (where the woody species is mainly for mulch production)
- o AF fuelwood production
- o protein bank (cut-and-carry fodder production)
- o woody hedge for browse, fodder and green manure
- o Agro-silvo-fishery (Aquaforestry)

Obviously, the main reason for this "exclusion", or rather, "limited inclusion" of the fruit trees in these subsystems is that the fruit-tree products are primarily for human consumption, whereas the primary roles of the woody perennials in the subsystems mentioned above are production of other basic needs such as fuel and fodder and/or protection and improvement of soil. However, the fruit trees, by their very nature (woody perennial) not only perform some of the essential functions of all woody perennials in integrated AF production systems, but also produce nutritive as well as economically valuable outputs (which some other AF woody perennials do not). Thus,

Table 3. Condensed Crop Profiles of Some Fruit and Nut Trees in Existing/Potential Agroforestry Systems in the Tropics

SPECIES			ECOLOGY							
Common (English) and Scientific Name	Family	Plant type/ Growth form	Range/ Distribution	Climate	Soil	Tolerances	Management	Functions/ Uses	Common agro-forestry systems/ practices involving the species	Other Remarks
Areca palm or betel palm *Areca catechu* L.	Palmae (Arecaceae)	Slender, erect tropical palm to 25 m; ringed stem; apical crown of leaves; about 2.5 m diameter.	Up to 900 m mainly in S. Asia; tropical rainforest zones preferred	Mean temp. 16-35°C; 1000-3000 mm well-distributed rainfall	well-drained laterite or reddish soil, fertile clay loams and alluvial loams	Does not tolerate poor drainage and very infertile soils.	Propagation by planting one year-old seedlings; 2.7 m square planting; also in hedges; about 1300 plants/ha; bearing in 5 yrs, up to 60 yrs; responds well to manuring	Used as a masticatory; edible heart; leaves for thatch in some places; Leaf sheath for hats, containers; trunk for wood; seeds also used in veterinary medicine	Cultivated as sole crop or with other crops; usually mixed with cocoa and other shade-tolerant perennials; also in home gardens and tree gardens	The crop is not suitable for marginal areas and places with long dry spells
Avocado *Persea americana* Mill.	Lauraceae	Spreading tree of 10-15 m; thick evergreen foliage; broad leaves.	Native to mesoamerica (Mexico); sub distribution esp. tropical highlands	Up to 2000 m in tropics 15-25°C temp; rainfall up to 1500 mm	Deep well-drained soils; pH 5.0-6.5; fertile soils preferred	Can tolerate drought, but not flood and frost	Propagated by stem cuttings; epiphs or hedge system of planting; about 400 trees/ha; starts bearing 1-5 yrs; usually no pruning	Fruit weighing up to 250 g is edible; mainly eaten raw; edible pulp is buttery with 25-30% oil; known as "poor man's butter" foliage is a good mulch	Commonly grown mixed with other fruit trees in tree gardens/ homestead	Thick canopy allows little light penetration to ground so undercrop possible only in hedge planting
Breadfruit *Artocarpus altilis* (Parkin) Fosberg	Moraceae	Monoecious tree up to 20 m; evergreen in over-wet areas; deciduous in monsoon areas; profuse foliage.	Native to Polynesia; grown all over hot humid tropics, especially in Asia and the Pacific	Tree of hot humid lowlands; 750-250 cm rainfall; 20-30°C.	Rich range of soils; prefers deep, well-drained soils	Does not grow in shallow or water-logged soils	Propagated vegetatively by root cuttings; usually on seed cuttings planted 8-10 m apart; grows rapidly; bears in 3-5 yrs; needs little care	Mainly grown for edible fruits produced all the year round, 700 fruits/ tree/yr; fruits very starchy; vegetable or snacks; biomass also used; timber useful for farm uses	Usually grown mixed with a large number of other spp. in homestead; vine usually trailed on trees; offers shade for livestock and crops like taro	Sometimes a staple food in the Pacific islands and the Seychelles
Brazil nut *Bertholletia excelsa* Humb. et Bonp.	Lecythidaceae	A tall large tree up to 45 m; straight trunk, short-stalked large leaves; long-lived	Grows mostly in the wild form in Amazon forestry; not popular in other areas	not but tropical forest of Amazon (attempts to introduce to C. Indies, SE Asia not successful)	In the native habitat, the soil is acid, fertile forest soils.	Not known	Seed-propagated; begins fruiting when 10-15 years old. Fruits fall off naturally and then collected. Edible portion is the nutlet (kernel) inside a thick, hard, woody shell.	Fruits (nutlet kernel) edible; an important nut of commerce in the Amazonia region. Timber very valuable.	Can grow in association with several other species. Can be a good overstory species for coffee, cacao etc.	No research data, but potentially very promising for agroforestry as a fruit, shade and timber species.

NAMES			ECOLOGY								
Common (English) and Scientific Name	Family	Plant type/ Growth form	Remarks/ Distribution	Climate	Soil	Tolerances	Management	Functions/ Uses	Common agro-forestry systems/ practices involving the species	Other Remarks
Carob *Ceratonia siliqua* L.	Leguminosae (Fabaceae)	A dioecious tree of medium height 10-20 m	Cultivated mainly in the Mediterranean area	Cool dry mediterranean climate; 10-30°C; low rainfall	Deep, fertile loams; pH above 7.5	Can withstand drought, can tolerate salinity	Propagation by seed; transplanted; first bearing in about 12 years; produces about 12 t/ha/yr.	Pods rich in sugar and protein; flesh of fruit edible; used in confectionery; valuable forage for animals; produces useful gum; low forage	Used widely in silvo-pastoral systems; as an over-story shade tree; in soil-erosion bedges; windbreaks.	Known also as St. John's bread
Cashew *Anacardium occidentale* L.	Anacardiaceae	Spreading evergreen tropical tree up to 12 m; old tree canopies up to 30 m dia.	widely distributed in tropics; Brazil, India, East Africa	up to 1200 m; 500-1500 mm rainfall p.a.; dry weather needed for flowering and fruiting	wide range of soils; grows in infertile and rocky areas; pH 5.5-6.5	Tolerate poor soils and areas with dry spells; does not tolerate floods	Seed-propagation; seeds sown at stake; also vegetative prop. by layering or grafting; about 10 m spacing; usually very little aftercare; bearing in 7-10 years, up to 50 yrs	Highly-prized kernels used in confectionery and desserts; shell-oil has several industrial uses; cashew apple is juicy and edible, and used for wine-making; firewood	Cattle grazing under cashew in plantations; tree gardens in small-holdings; also in home-gardens; used as windbreak and shelterbelt.	A very drought-resistant tree; non-synchronised flowering and difficulty in collecting nuts are main problems
Coconut palm *Cocos nucifera* L.	Palmae (Arecaceae)	Tree to 30 m; stout, unbranched stem; crown of long leaves with slender leaflets; apical growth.	Coastal areas of the tropics; Philippines, India, Sri Lanka, Malaysia, etc.	Mean temp. 27°C ± 7°C; well-distributed rainfall > 2000 mm p.a.	well-drained soils of 1 m depth; pH 5.5-8.0; very common in coastal sands and loams.	Tolerates salinity; does not tolerate prolonged water logging.	Propagation by transplanting one year-old seedlings; about 175 palms/ha; square or triangular planting; full bearing from about 8 years and continues up to 75 yrs; responds well to manuring	Edible oil from copra (dried endosperm); fruits; drinks; leaves for thatch and weaving; trunk for wood; many other products; nicknamed as "Tree of heaven"	Many types of crop combinations in small holdings; intercropping and multistorey cropping; also grazing under coconuts in the Pacific Islands very common.	Most widely cultivated palm also is with annual or perennial crops; numerous types (dwarf and tall) and cultivars
Custard apple (Bullock's or sugar apple) *Annona squamosa* L.	Annonaceae	Woody shrub or small tree of 3-6 m height	Native to tropical America, but now grown throughout the tropics, especially Southeast Asia	Humid tropics of low to medium altitudes; 20-30°C	Deep fertile well-drained soil of pH 5.5-6.5	Can tolerate drought	Seed-propagated. Fruiting starts in 3-4 years; fruit-set can be enhanced by hand pollination; fruits 7-10 cm in diameter. Fruit very perishable.	The custard-like granular pulp in which the seeds are embedded is edible. Bark produces tannin. Pulverised seed has insecticidal properties. Offers light shade for subsistence agriculture. About 10 tonnes t/ha/yr.	Usually a plant of the backyard where grown along with a large number of other spp.	A very similar fruit, *Annona reticulata*, known as Bullock's heart, is also sometimes referred to as custard apple

SPECIES: Common (English) and Scientific Name	Family	Plant type/ Growth form	ECOLOGY: Extension/ Distribution	Climate	Soil	Tolerances	Management	Functions/ Uses	Common agro-forestry systems/ practices involving the species	Other Remarks
Date palm *Phoenix dactylifera* L.	Palmae (Arecaceae)	Tall palm, up to 36 m; unbranched stem covered with leaf remains; dioecious habit.	Grown mainly in the Arab countries, India, N. Africa, Mexico.	Requires high temp. (28-45°C), low humidity, typical of the Middle East vegetation.	Loam and sand of pH above 6.8, alkaline; responds to P application.	Tolerant to drought and salt in root zone.	Vegetative propagation by basal axillary shoot (suckers); many named cultivars based on fruit quality. Female flowers are artificially pollinated.	Edible fruit (20-100 kg/ tree/yr); sap for wine; leaves for thatch, roofing; trunk for wood, many minor products; stalk/petiole and for wood dust flotation.	Grown as an overstorey species in oasis and other arid regions; large number of crops grown underneath.	It is said to have about 800 different uses.
Dwarf palm *Hyphaene thebaica* L.	Palmae (Arecaceae)	Tall palm, up to 15 m; branched fan palm.	Mainly in semi-Deserts and Deserts in Africa.	Semi-arid to arid, hot dry climate; up to 800 m altitude.	Sandy sand or loam, pH above 6.5; also grown on alluvial beds.	Tolerant to drought and salinity.	Seed-propagated; germination very poor; transplanted; bearing in about 10 years.	Fruits are edible; edible heart; sap for wine; fruit for medicinal use; leaves for weaving.	Grown in association with vegetables and other crops, mainly as an overstorey species.	Also known as gingerbread palm.
Iron stick (Arrowstick tree) *Bulbine frutescens* Lam.	Malvaceae	Small, branching tree, up to 8 m; spiny canopy; small leaves.	Lowland humid tropics of Asia and SE Asia and the Pacific Islands.	Hot humid lowlands (28-35°C), 1500 mm well-distributed rain; p.a.; up to 600 m.	Well drained, deep, fertile soils; pH 5.5-7.8; loams and sands; also stony silt; rocky patches.	Does not tolerate water logging; tolerates dry spells of up to 4 months.	Propagated by seed and stem-cutting; bearing long (up to 60 cm) slender (1.5 cm dia) fruits when 3 years old; stems weak; strong winds can cause serious damage.	Tender fruits are cooked as a vegetable; tender leaves used as a spinach; leaves have medicinal value in local medicines.	Grown along with other species in home gardens; used as a hedge plant/ border plant and for light shade.	A useful species about which only very little is known.
Durian *Durio zibethinus* Murr.	Bombacaceae	Medium to large tree up to 30 m; fairly thick foliage; fruit is a large ovoid-to-spherical capsule, up to 30 cm long, 15 cm diameter.	Lowlands of south-east Asia; attempts to grow it in other places of similar climate not successful.	Humid tropical, lowlands below 350 m (sea p.a.); 25-40°C, up to 800 m.	Deep, well-drained, acid fertile soils; loam or sands; pH < 5.5; rocky soils also suitable.	Tolerates drought to some extent; does not tolerate water stagnation.	Propagated by stem cutting or grafting, also by seeds but seeds lose viability soon; bearing starts in 7 yrs; needs very little care and management attention. Fruit does not mature well if falls from the tree.	Fruit is famous, but also of nutritional and flavor; provides imported revenue to villagers; a useful tree of the backyard.	Usually a smallholder, homegarden crop, grown along with a large number of other plants.	Durian is a famous fruit, but is disliked by some; it is liked very much by wild animals also.

SPECIES: Common (English) and Scientific Name	Family	Plant type/ Growth form	ECOLOGY: Remarks/ Distribution	Climate	Soil	Tolerances	Management	Products/ Uses	Common agro-forestry systems/ practices involving the species	Other Remarks
Guarana *Paullinia cupana* L.	Sapindaceae	Perennial woody vine, but the cultivated form is a thick-foliaged shrub	Native to Amazon basin; not grown in other areas	Warm humid climates; up to 800 m; well-distributed rainfall	Grows in poor acid laterite with a thick layer of organic matter	Little tolerance to long dry periods as well as floods	Propagation by seeds, but seeds have very short viability. Also propagated by stem cuttings; usually 5 x 5 m spacing; young plants trelled on to trellises. Pruning done regularly to produce fruiting branches. Flowering in first year.	Seeds contain 4-6% caffeine; guarana is a preferred drink of Brazil; dried powdered seeds mixed with cassava flour used for making pastries and cakes.	Usually grown as an agro-forestry species under the shade of large trees; common with cacao and coffee in agro-forestry systems in Brazil.	Guarana has some medicinal properties. Research is now being undertaken by Brazilian institutions
Guava *Psidium guajava* L.	Myrtaceae	Shallow-rooted large shrub or small spreading tree, 3-10 m; low-branching	Widely distributed in the tropics from sea level to 1500 m	15-35°C; low humidity; 500-1500 mm rain p.a.	Uniform, deep loam preferred; pH 5.5-7.5; grows in a variety of soils	Tolerates drought and floods, but salinity	Propagated by stem cutting, rooting or seeds; regular pruning to shape the trees and remove watershoots and suckers; fruiting in 2 years; up to 30 years	Guava fruits are eaten raw or preserved; fruits vary in size and flavor; rich in vitamin C. Average yield about 100 kg/tree p.a.; but up to 2500 kg	Grown mixed with a large number of other spp. in the homegarden and tree gardens; forms a shade layer canopy in multistoreyed cropping	In some places (e.g. Fiji), it has been declared as a weed
Jackfruit *Artocarpus heterophyllus* Lam.	Moraceae	A handsome monoecious evergreen tree up to 20 m; one of the largest cultivated fruits; up to 30 kg/fruit	Native to tropical India; grown in India, Sri Lanka, but also in SE Asia and the Pacific	Hot humid tropical lowlands up to 800 m; rainfall above 150 cm p.a.	Deep, fairly fertile loam or sandy loam; pH 5.5-7.0	Tolerates drought and floods to some extent	Seed propagated, but also by layering and grafting; fruiting in about 8 years, lasts up to 60 years; needs very little care	Fruit used as a dessert; unripe fruit is a vegetable; leaves are eaten by goats; timber is very valuable for furniture and house construction; branches used for firewood	Grown mixed with other species in the homegarden; used for feeding cattle underneath; good for border planting; vines are trelled on the tree	Thick foliage does not allow much light to understorey spp.
Kola nut (Cola nut) *Cola nitida* (Vent.) Schott & Endl.	Sterculiaceae	Several species of kola trees; *C. nitida* is 10-15 m high, unbranched in lower part; large leaves	Mostly in humid west Africa; also in West Indies, India, Brazil	Warm humid tropical climates with > 150 cm rain p.a.; pronounced wet and dry seasons; up to 800 m	Light, well-drained, fertile soils; loam or loamy clay; pH 5.0-7.0	Tolerates drought and floods, but not salinity	Propagated by seeds; germination in 3-12 weeks; growth is in flushes; fruiting in 7 years; fruiting up to 80 years; fruits harvested by using hooks at the tip of long poles	Seeds used as stimulants and beverages; average yield 250 kg/tree; but much higher yields reported. Seeds contain 2% caffeine and some essential oils	Intercropped with fruit trees in the young stage and with other tree species in the adult stage	Fruit is erroneously called "nut"

SPECIES		ECOLOGY								
Common (English) and Scientific Names	Family	Plant type/ Growth form	Range/ Distribution	Climate	Soil	Tolerance	Management	Functions/ Uses	Common agro-forestry systems, practices involving the species	Other Remarks
Litchi Litchi chinensis Sonn. or Nephelium litchi Cav.	Sapindaceae	Small to medium tree, 10-20 m high; dense canopy; evergreen	Sub-tropical to tropical China, northern India; 1000-2000 m	Moderate climate; 15-35°C; cool dry season for fruiting; high altitudes	Deep, well-drained loams; pH 5.0-7.5	Tolerates drought and occasional floods; fails to fruit in lowland tropics	Propagated vegetatively, mainly by air-layering; trees come into bearing in 4-6 years	The fruit is a nut; the edible part is the aril which surrounds the nut; the aril is juicy; eaten raw or preserved. In China, the aril is also dried to produce "litchi nuts"	Useful as a windbreak, low forage; also grown mixed with other fruit trees	Also an ornamental plant
Longan Euphoria longana Lam. Dimocarpus longan Lour.	Sapindaceae	Small to medium tree, 10-30 m high	Mainly in semi humid parts of Southeast Asia	Humid, lowland tropics; well-distributed rainy 20-35°C; up to 1000 m	Deep, well-drained, fertile loam or clay loam; pH 5.5-7.0	Does not tolerate drought or salinity; can withstand some flooding	Propagated by rooting or stem cutting; comes to fruiting in 6-8 years	Fruit is very juicy	Grown mixed with other fruit trees and also vegetables; common in homegardens	Not known outside SE Asia
Macadamia nut Macadamia integrifolia Maiden et Betche	Proteaceae	Small to medium tree, 10-15 m	Native to Australia but mainly cultivated in Hawaii	Semi-moderate climate 15-30°C; occasional rains with dry periods in between	Deep, well-drained loam; pH 5.5-7.5	Tolerates drought and occasional floods	Propagated by stem cutting or grafting	Fruits are the macadamia nuts of commerce; rich in protein and fat; also produce oils and lanolin	Can be grown with other fruit trees and coffee; good for low forage; also for bee keeping	Also known as Queensland nuts or Australian hazel nuts
Mango Mangifera indica L.	Anacardiaceae	Medium to large evergreen tree 15-30 m height	Native to India; very popular in India, but also in SE Asia, Africa and tropical America	Wide range of climate from lowlands to highlands; semi, dry to wet humid	Deep fertile loam to infertile well-drained sandy, pH 5.0 - 8.0	Tolerates drought and occasional floods	Propagated by seed or layering and grafting; pruning for shape and induce flowering branches; full bearing in about 8 years; bearing continues up to 50 years and more; several cultivars and hybrids	Fruits very delicious dessert; immature fruits in chutneys and pickles; also ripe fruits as preserves; branches for food construction; timber as a firewood; seed is dye	Grown in association with other fruit trees in the backyard; good as a border/windbreak species; cattle grazing in the shade; animal feed or forage	Several forms and types are popular; used extensively on the backyard in India, East Africa

SPECIES: Common (English) and Scientific Name	Family	Plant type/ Growth form	ECOLOGY: Range/ Distribution	Climate	Soil	Tolerance	Management	Position/ Uses	Common agro-forestry systems/ practices involving the species	Other Remarks
Mangosteen *Garcinia mangostana* L.	Guttiferae	Slow-growing pistacious, evergreen medium tree to 12 m; compact conical shape	Rainforest Asia; attempts to introduce to other countries unsuccessful	Hot, humid lowland climate with a well-distributed rainfall	Well-drained fertile deep soil, pH below 6.8	Can withstand dry spells	Seed-propagated; seeds have low germination and poor viability; veg. prop. not successful. Requires shade when young. Bearing in 10-15 years; up to 50 years. 500-600 fruits per tree per year	A prefered, delicious fruit; fruits eaten fresh. The shell of fruits is rich in tannins, used for leather tanning and medicinal purposes	Usually grown mixed with other fruit trees and in homegardens	Tendency to bear only in alternate years; difficulty to propagate; long juvenile phase
Metalite *Prunus persica* (L.) Batsch (syn. *Amygdalus persica*)	Rosaceae	Low to medium sized tree very similar to the peach tree, but having pubescence	Grown in tropical highlands and sub-tropics	Tropical, adjusted to sub-tropical climate; 15-35°C; low rainfall	Well-drained deep sandy or loamy soil over clay; pH 5.5-7.5	Can withstand drought, wind and shade	Seedlings either from a seed or bud of the peach, as a matching propagation by grafting or root stock; starts bearing in 2-3 years after planting; pruning required	Fruit is delicious, eaten raw, yields about 20 t/ha/yr; used as a shade tree and for border planting	Grown mixed with other fruit trees; used as a shade tree and for border planting	Not very popular in the tropics
Nipa palm *Nipa fruticans* Wurmb.	Palmae (Arecaceae)	Suckering monocious feathery palm over 10 m height	South and SE Asia and N Australia, tropical rainforests	Tropical rainforests, lowlands; high rainfall; no clear dry season	Lowland, marshy, brackish areas; pH above 7	Can withstand salinity and waterlogging	Sometimes planted; seed-propagated; very little care and management	Edible fruit; sap for sugar; 3 t sugar/ha/yr; leaves for thatch and weaving; shelterbelts; wood for firewood	Used for anti-erosion effects and shelterbelts	Very little studied
Orange *Citrus* spp.	Rutaceae	Low growing tree with a spacious canopy; various species and cultivars having different types of flowers and fruits	Very widely cultivated all over the tropics, especially in sub-arid areas	Prefers warm dry climate with mild temperature (20-30°C) and low rainfall; also adaptability	Deep, fertile loamy soils of almost neutral pH	Can withstand drought and, to some extent, wind, but not floods	Propagated by stem cutting for budding or grafting; pruning is a regular management; seedling bearing in about 5 years after planting	Edible fruits; juices, preserves, marmalades, etc.	Usually grown in commercial mixed stands, but also in mixed plant stands of homegardens; good for hedge planting and as windbreak	Very well studied and commercially cultivated, several varieties

SPECIES: Common (English and Scientific) Name	Family	Plant type/ Growth form	ECOLOGY: Range/ Distribution	Climate	Soil	Tolerances	Management	Functions/ Uses	Common agro-forestry systems/ practices involving the species	Other Remarks
Papaya, Papaw *Carica papaya* L.	Caricaceae	A short-lived perennial, 2-10 m; unbranched stem, soft-wooded, hollow stem with leaves at the apex	All over the tropics. South Asia, S. Africa, Hawaii are major producers	Wide range of climate; up to 2000 m altitude; 20-40°C; low altitude for papaya prod.	Well-drained deep, fertile soil; pH 5.8-7.8; loamy texture	Does not tolerate flood or waterlogging and salinity	Seed propagated; transplanted; plants usually dioecious, so usually planted in one numbers and later thinned; flowering in 4-6 months; responds well to fertilizer and management	Preferred delicious fruit. Leaves and long petioles sometimes used for mulch or compost	Can be found in almost all subsistence agricultural systems in association with various crops; good for hedge/ border planting	Commercial production usually as sole crop
Mulberry pale (French pale)	Moraceae (Alternative)	Monoecious fast-growing pale; slender stem; up to 15 m; numerous profusely	All over Central and S. American lowlands up to 1200 m altitude	Hot humid lowlands, 200 cm rain p.a.	Deep, well-drained clays of medium fertility, pH neutrality	Can tolerate dry spells, but not flood or	Propagated by seed or cuttings; seed-propagated plants mature in 6-7 years; last for up to 30 years	Edible fruit (1 t dry fruit/ha/yr); edible heart; tried for wood; animal feed; shade over coffee, cacao, etc.	Often grown along with other fruit trees or over coffee, cacao, pastures, etc. Also good as windbreak and for border planting	Also known as Pejibaye; widely cultivated in agriforestry along all over S. America
Rambutan *Nephelium lappaceum* L.	Sapindaceae	An evergreen leafy tree up to 15 m tall; fruits hairy, in pendent clusters	Very common in the lowland humid tropics of SE Asia	Hot, humid, lowlands; 200 cm evenly-distributed rain p.a.	Deep, fertile loams; pH below 5.5	Can tolerate dry spells and floods, but not salinity	Seed-propagated, but veg. propagation by cuttings and budding possible; seedlings fruit in 5-6 years; 200-400 fruits per tree/yr; tree lasts up to 60 years	Edible fruit, eaten fresh; also a low forage and ornamental (bright red, hairy fruit and broad crown); timber useful	Often grown along with other fruit trees in the homestead; good for border planting and as a windbreak	Unknown in regions outside SE Asia

Species: Common (English) and Scientific Name	Family	Plant type/ Growth form	Ecology: Range/ Distribution	Climate	Soil	Tolerance	Management	Functions/ Uses	Common agro-forestry systems practices involving the species	Other benefits
Sago palm Metroxylon sagu Rottb.	Palmae (Arecaceae)	A flowering feathery palm growing in thick stands, 15-20 m tall; stout erect trunk	Reinforest swamps of SE Asia and the Pacific	Hot, humid, high rainfall, swampy areas of tropical rain forests	Swamps; deep loams and clays	Tolerant to flooding and salinity but not drought	Propagated by suckers or tillers; transplanted; flowering in 10-15 years, after which the palm dies. Starch extraction from split trunks just before flowering	Starch from trunk (300 kg/tree); leaves for thatch	Good for swampy areas and for silvipasture	Few cultivated and managed stands; starch exported
Sapota, Sapodilla Manilkara zapota (L.) van Royen syn. A. achras, A. sapota, A. zapotilla Achras zapota	Sapotaceae	Evergreen bushy tree up to 20 m	Native to Mexico and C. America; now widely grown in Southeast Asia also	Hot tropical lowlands of varying rainfall	Fertile, deep, uniform loams; pH below 7.5; wide variability	Tolerates drought, and, to some extent flooded and salinity	Usually propagated by seeds; but also stem cuttings and grafting; fruiting in 3-4 years; 2500-4000 fruits/tree/yr. Latex can be obtained by tapping trunk once every 2-3 years	Edible dessert fruit, eaten raw when ripe; latex from the stem contains 20-40% gum, which is raw material for chewing gum; wood is durable and good as construction timber	Usually grown along with other fruit trees and crops in the homestead; can be used for light shade and border planting	Very popular fruit in Asia and tropical America
Shea butter tree Butyrospermum parkii (Gaertn.f) var. parkii	Sapotaceae	A small-to-medium-sized tree, 7-15 m; deciduous	Abundant in Central and east African savannas	Dry, but equatorial savannas; low altitudes	Dry lateritic slopes; pH above 6.5	Tolerant to drought, but not flooded	Usually propagated by seeds transplanting difficult; about 8 m spacing; starts bearing in 12-15 years; fruit falls naturally and then is collected	Shea butter extracted from the seed is used as a cooking fat, illuminant, medicinal ointment; stem oil from the nuts is used in soaps, candles, cosmetics	Grown in mixed stands with other species in the drier margins of savannas with pronounced dry seasons	Its cultivation is not labor-intensive
Tamarind Tamarindus indica L.	Leguminosae (Fabaceae)	A large tree over 20 m tall with light canopy and thick stem	Native to dry parts of Africa; now popular all over Africa, India	Wide adaptability; grows well in dry and wet climates, mainly in low altitudes	Wide adaptability; pH about neutral; deep, infertile soils preferred	Withstands drought very well	Propagated by seeds seeds very little care; starts bearing in about 10 years; lasts for several decades; fruits are collected from tree or allowed to fall	Fleshy mesocarp is eaten fresh or preserved in syrup; seeds eaten as nuts; used as a condiment and flavoring; also produces gum and tannins; firewood; timber good for furniture; foliage and seeds are animal feed	Grown as an overstorey species in many agricultural lands; light canopy and nitrogen fixation are advantageous	Grows widely in drier savannas of Africa and all over India

from an economic and to some extent biological (with implied significance on plant management) points of view, a distinction can be drawn between fruit trees and other woody species used in AF.

Keeping in view the afore-mentioned aspects on the characteristics to be looked for in the selection of woody perennials in AF, let us examine the special attributes of fruit trees, which may, on the one hand, enhance their value or, on the other, diminish their suitability for any particular system. It is important to note in this context that the two main distinct attributes of AF are production and sustainability (protection), and the woody perennials are expected to play a major role in both, especially the latter, i.e., imparting sustainability to the system. All the important factors related to this sustainability aspect can be considered under "environmental" whereas the production aspects have to be linked with the socio-economic setting.

3. ENVIRONMENTAL ASPECTS OF FRUIT TREES IN AGROFORESTRY

The major environmental aspects of fruit trees (and other woody perennials) in AF (and, in fact, in any land use system) can be grouped under two groups: soil and climate, with various processes involved in each. Of these, soil-related aspects are better documented. While examining the soil productivity aspects of AF, Nair (1984a) stresed that both micro-site enrichment (soil fertility and productivity) and macro-site improvement (soil conservation and ecosystem stability) by trees are net effects of several factors. He grouped these factors broadly under soil fertility and soil physical

conditions, with rooting patterns of trees as central to both groups of factors.

3.1. Rooting Pattern

There is a general belief that trees have deep and spreading roots and are, therefore, capable of exploiting more soil volume and taking up nutrients and water from layers that are usually not contacted by herbaceous crops. This process of taking up nutrients from deeper profiles of the soil and eventually depositing at least a part of them on the surface layers though litter fall and other mechanisms is refered to, albeit erroneously, as "nutrient pumping" by trees. However, there is a considerable difference between the situations found in a forest, or a plantation, and that of an individual tree (as, sometimes, in agroforestry) with regard to both rooting patterns and root system functions, including the so-called nutrient pumping effect. It is well known that, within the limits of genetic restrictions, the root development of plants will depend on a number of site characters and environmental conditions. In agroforestry systems the woody species often do not exist in such close proximity as in monospecific forest plantations. Therefore it is to be expected that the root development pattern of woody species, and consequently the extent of their root interaction with other species, will be of a different order of magnitude compared to the situation in forests or plantations.

The difficulty in predicting the rooting pattern and root interaction of fruit trees in AF is further compounded by the fact that the root systems of most such species mentioned in Table 3 have

little been investigated. Some of the reviews that are available on the rooting patterns of trees in general indicate that for many woody species, the largest number of roots and the majority of fine roots are located in the uppermost fertile portion of the soil profile. Some species of trees are consistently shallow-rooted while others exploit the soil to a considerable depth. Apart from these genetically induced variations, environmental conditions including soil type and quality can also influence the root spread and therefore rooting pattern, which, in turn, can affect the physical form of the plant. A typical example is Acacia tortilis, an African native found throughout the semi-arid regions. Usually it is a medium-sized (4 to 15 m tall) tree, but under conditions of extreme aridity and shallowness of soil, it becomes a low shrub. In a study of the rooting pattern of coconut palms, Kushwah et al. (1973) observed that in a deep sandy loam soil at Kasaragod in Kerala, India, nearly 75% of the roots of coconut palms under "normal" plantation management were confined to a circular area of about 2 m radius from the bole of the palm (Figure 1). According to usual planting practices, coconuts are planted in a 7.5 m square pattern, in order to accommodate the large-sized canopy of the growing palms. Nelliat et al. (1974) and Nair (1979) analyzed the implications of this in the context of intercropping in coconut plantations, and postulated that excepting the area of active root zone of the coconuts, the entire interspace of coconuts in a mature plantation would be available for intercropping without much overlappings of root systems of the associated crops. In quantitative terms, this amounts to a total area of 7.5 m x 7.5 m = 56.25 sq. m per palm, less πr^2; r = 2m; 12.7 sq. m per palm of active

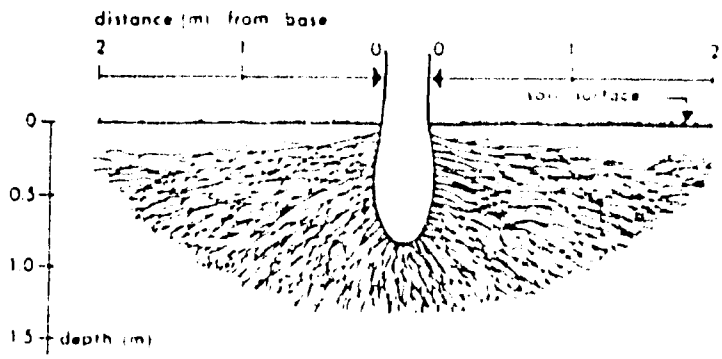
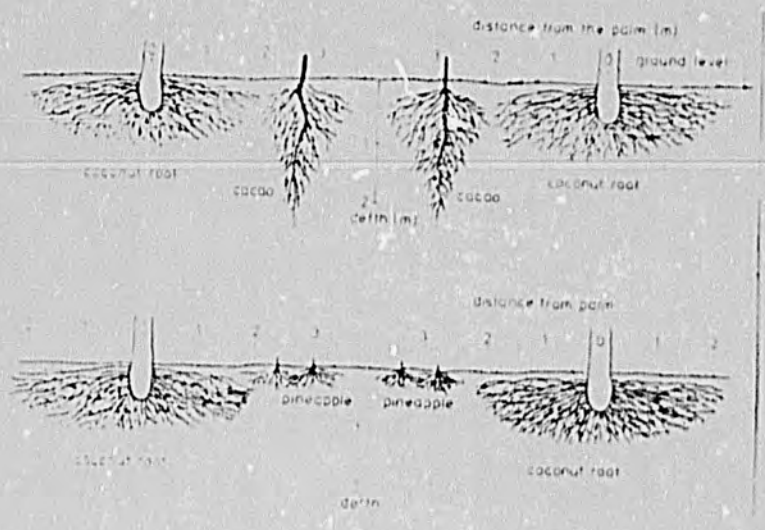


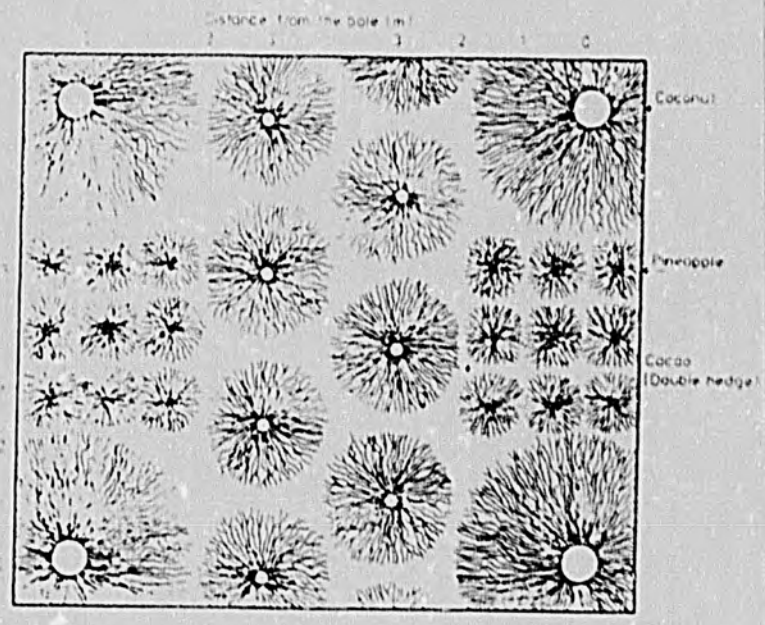
Figure 1. Schematic presentation of the rooting pattern of an adult coconut palm (Nair, 1979, from Kushwah et al., 1973).

root zone of coconuts, so that the area available for intercropping would be 43.55 sq. m per palm, or about 75% of the total land area per palm in a monoculture (sole stand) coconut plantation. The authors also examined the rooting patterns of various intercrops grown between or under coconuts, and found that even in a systematically planted multistoreyed crop combination of coconut + cacao (Theobroma cacao) + black pepper (Piper nigrum) + pineapple, the rooting configurations of the various component species could be such that there would be restricted localizations of the various root systems with minimal overlapping of the root zones, as shown in Figure 2. The roots of black pepper are not shown in the diagram because of the difficulty of depicting them in the diagram. But it has been observed that black pepper, a climber, has most of its roots very near the soil surface and close to the coconut trunk. Note that this area near the soil surface is usually devoid of coconut roots (Figure 1).

Aside from these genetically controlled and environmentally induced variations in the rooting patterns of (fruit) trees, one of the most important factors of relevance in AF is the extent to which the root system of such trees can be manipulated by appropriate management techniques. Haynes (1980) reviewed the influence of soil management on orchard agro-ecosystem and noted that the root growth of a fruit tree may be modified by soil management practice by the absence of cultivation allowing tree roots to grow into the surface soil or by direct competition of the grass undergrowth (and other understorey species in an AF system) for nutrients and water. It has been observed that the roots of many tropical fruit trees such as cacao (Alvim, 1977) and coconut (Nair, 1979) tend to accumulate on the



A. VERTICAL DISTRIBUTION



B. HORIZONTAL DISTRIBUTION

Figure 2. Schematic presentation of the distribution of roots in a multistoried crop combination of coconut, cacao and pineapple (Nair, 1979, from Nelliat, Bavappa and Nair, 1974).

soil surface if the plantation floor is left uncultivated and thus undisturbed as is usually done in sole crop cacao plantations, but the roots can also be 'trained' to be confined to a certain pattern by proper management and cultural operations. Thus in an AF situation, the constant cultural operations necessitated by the cultivation of associated herbaceous species can help restrict the root zone of the fruit trees to specified zones. Moreover, such operations can also cause root pruning, which is a common practice in orchard management of some tropical fruit trees (Alvim and Kozlowski, 1977) to induce fruiting. This could well be one of the most significant differences between the fruit trees and other woody perennials as components of sustainable AF systems in so much as that the indirect effect of cultural operations done for the associated crops can cause a beneficial interaction effect for the fruit trees growing with the herbaceous crops. As noted earlier, these aspects pertaining to the commonly used fruit trees in tropical AF systems (Table 3) have not been investigated in detail.

Obviously, there is a great deal more that can be conjectured and hypothesized about the rooting characteristics of fruit trees in AF. In fact, that by itself, could be the topic for a separate review. The organic matter relations and nutrient cycling aspects of roots will be considered in subsequent sections dealing with those aspects.

3.2. Soil Fertility and Nutrient Relations

In a recently published comprehensive review of soil productivity aspects of AF, Nair (1984a) postulated that the important mechanisms

by which compatible and desirable species of woody perennials in AF systems can contribute to the improvement in soil fertility include:

- an increase in organic matter content of the soil through addition of leaf litter and other plant parts;
- more efficient nutrient cycling within the system, including an increase in the plant-cycling fraction of nutrients, and consequently more efficient utilization of nutrients that are either inherently present in the soil or externally applied;
- biological di-nitrogen fixation, solubilization of difficultly available nutrients, for example, phosphate, through the activity of mycorrhizas and phosphate-solubilizing bacteria;
- complementary interactions between the component species of the system, including an enhanced nutrient economy because of different nutrient-absorbing zones of the root systems, resulting in a more efficient sharing of nutrient resources among the components;
- a moderating effect of additional soil organic matter on extreme soil reactions and, consequently, improved nutrient release/availability patterns.

These factors can broadly be grouped under two categories: organic matter relations and nutrient cycling. Readers are invited to refer to Nair (1984a) for detailed discussions on each of these factors. In this paper, the discussion will only be confined to the relative advantages of fruit trees as the woody perennials in such AF systems with respect to these postulated mechanisms.

3.2.1. Organic matter

The major recognized avenue for addition of organic matter (and, hence, of nutrients) to the soil from the trees standing on it is through litter fall, that is, through dead and falling leaves, twigs,

fruits and so on, and several studies on and estimates of the amounts so added have been reported. Fruit trees are not likely to be of any special advantage or merit in this respect. Most fruit trees mentioned in Table 3 are not deciduous; their leaves are not the best sources of readily decomposable organic material; moreover, the removal of the foliage of some of them may cause setbacks to fruit production. Other woody perennials, especially those grown primarily for mulch and green manure will be of much greater significance in this context.

However, the fruit trees can be equally efficient as other woody perennials in the constant addition of organic matter to the soil through dead and decaying roots (Nye and Greenland, 1960) as well as "rhizodeposition", that is, the steady release of carbohydrate-rich organic material from actively growing roots (Sauerbeck and Johnen, 1977) thereby supporting a substantial microbial population.

3.2.2. Nutrient cycling and nutrient economy

Nutrient cycling processes that take place to varying degrees in all land-use systems (Golley et al., 1975; Frissel, 1977; Rosewall, 1980) are particularly relevant in the AF context because of the likely effect of trees on such processes. "Closed" nutrient cycles are known to operate in mixed evergreen natural forest (see Golley et al., 1975; Sanchez, 1976; Ulrich et al., 1977; Nair, 1979; 1984a).

From the point of view of soil fertility maintenance and sustainability of production, the major processes in nutrient cycling that are usually accounted are nutrient inputs into and outputs from the soil-plant system. Besides these important processes that can be

quantified, there is also a process of "plant cycling" of nutrients. It represents that part of the total uptake of nutrients which is again leached out from the vegetative parts through crown washout, occurring as canopy drip and stem flow. Although this phenomenon is usually not recognized in nutrient cycling studies, its magnitude is of importance, especially in deciduous trees. The presence of this fraction, which is circulated within the ecosystem, is a sort of "necessary waste" (Nair, 1979), and it indicates the amount of "losses" of nutrients that must be accounted for while calculating nutrient budgets of plant communities. The total amount involved in this cycling depends on the nutrient content of leaves, the intensity and frequency of rain, the age and arrangement of leaves, and so on (Ulrich et al., 1977).

From a unique study on a coconut-based system in India, it has been brought out that the presence of more plant cover on the plantation floor increases plant cycling fraction of nutrients (Nair, 1979; Khanna and Nair, 1980). Khanna and Nair (1980) estimated that out of a total annual potassium input of 353 kg/ha to the soil-plant system in a pure stand of regularly fertilized and well managed coconut palms in the west coast of India, 150 kg was returned to the soil after being taken up by the plant through cycling within the plant system (unavoidable "loss"). In a crop combination system of coconuts plus cacao under similar environmental conditions, this plant cycling fraction was increased to 237 kg and the direct loss by percolation beyond the root-absorbing zone was 55 kg/ha as compared with 114 kg/ha/yr in a sole crop coconut system. These plant cycling fluxes represented 33 and 35 percent of the total fertilizer addition

from the sole and mixed (with cacao) plantings of coconuts under the climatic conditions prevailing in the study area (Tables 4 and 5).

The increase in the proportion of the plant-cycling fraction of nutrients as a consequence of increased plant cover on the ground facilitates not only a reduction in the direct loss of nutrients, but also enables the plants to meet the demand for highly mobile nutrients, like potassium, when the plants' metabolic needs are not fully met through external inputs, as, for example, in seasons of continued heavy rains (Nair and Khanna, 1978). One of the means through which this phenomenon operates in a mixed community of plants is a larger rooting volume. Since the transport of nutrients below the rooting zone is a major avenue for the direct loss of nutrients in monoculture agriculture, the rate of that process can be considerably reduced in mixed plant community systems where the total soil volume of root exploitation will be larger as discussed, and consequently the amounts of nutrient loss less.

There is also evidence of complementarity in the interactions between compatible plant species, resulting in the build-up of soil fertility under a mixed crop community as compared to the sole crop (Nair and Khanna, 1978; Nair, 1979; Khanna, 1981). One of the reasons that contribute to this complementarity could be the increased activity of beneficial microorganisms, such as the free living di-nitrogen-fixing bacteria, Beijerinckia sp.; phosphate-solubilizers, such as Aspergillus niger, Pseudomonas sp.; and others producing growth promoters, such as glycerine-like substances (GLS) and indole acetic acid (IAA), in the rhizosphere of the crop combination, as discussed by Nair and Rao (1977).

Table 4. Annual Fluxes of Nutrients in Pure Coconut System (kg/ha) (Khanna and Nair, 1980)

No.	Nutrient fluxes	N	P	K
	Input			
1.	Precipitation	2.3	4.8	5.0
2.	Fertilization	175.0	49.0	348.0
3.	Total (1+2)	177.3	53.8	353.0
	Output			
4.	Nuts	120.0	7.7	71.3
5.	Leaves	33.1	3.8	13.4
6.	Spathes and rachis	0.4	0.1	0.3
7.	Percolation (3-4-5-6-11)	20.5	-	265.0
8.	Total (4+5+6+7)	174.0	11.6	350.0
	Increments			
9.	Stem	2.3	0.3	2.0
10.	Roots	1.2	0.2	1.0
11.	Total (9+10)	3.5	0.5	3.0
12.	Plant cycling fraction	0.0	0.0	151.2
13.	Total uptake (4+5+6+11+12)	157.0	12.1	239.2
14.	Δ soil store (3-8-11)	0.0	41.7	0.0

Table 5. Biomass and Nutrient Fluxes in a 30 Year-Old Coconut Plantation With 5 Year-Old Cacao (350 trees/ha) as Mixed Crop (Khanna and Nair, 1980)

Biomass (t/ha) of cacao

Plant parts	Stores	Annual productivity (net assimilates)
Beans	1.35	1.35
Leaves	3.20	1.60
Stems	4.32	1.60
Roots	1.75	0.65
Total	10.62	5.20

Fluxes of nutrients ($kg \cdot ha^{-1} \cdot yr^{-1}$)

	Nutrient fluxes	N	P	K
	Input			
1.	Col. 3 of Table 4	177.3	53.8	353.0
2.	Fertilizer for cacao	35.0	6.1	40.7
3.	Total (1+2)	212.3	59.9	393.7
	Output			
4.	Coconut parts (4+5+6 of Tab. 4)	153.5	11.6	85.0
5.	Cacao beans	9.0	2.0	4.7
6.	Percolation (3-4-5-10-13)	8.9	0.0	274.7
7.	Total (4+5+6)	171.4	13.6	364.4
	Increments			
8.	Coconut (Col. 11 of Tab. 4)	3.5	0.5	3.0
9.	Cacao (stem and roots)	9.0	1.8	9.0
10.	Total (8+9)	12.5	2.3	12.0
	Plant cycling fraction			
11.	Coconut-washout	0.0	0.0	151.0
12.	Cacao-washout	0.0	0.0	69.2
13.	Cacao-fallen leaves	28.4	2.7	17.3
14.	Total (11+12+13)	28.4	2.7	237.5
15.	Total uptake (4+5+10+14)	203.4	18.6	339.2
16.	$\triangle$ soil stores (3-7-10)	28.4	44.0	17.3

The beneficial interaction effects of plant associations involving some woody perennials (primarily through nitrogen fixation) in several AF situations have been reported in quantitative terms. Examples include Acacia albida in the millet and peanut production areas of West African Sahel (Felker, 1978), Prosopis juliflora in crop production fields in the arid and semi-arid Western parts of India (Mann and Saxena, 1980), Casuarina oligodon in coffee production systems of the highlands of Papua New Guinea (Thiagalingam, 1983; Bourke, 1984) etc.

Although such quantitative figures of complementary interactions are not available from fruit tree-based AF systems, the existence of several such very productive and sustainable systems (e.g., in the homegardens of Southeast Asia: Vergara, 1981; Wiersum, 1982; Widagdo, et al., 1984) is a good indication that such phenomena of efficient nutrient cycling and complimentary interactions are operative in such systems.

The major avenue of output from the total system is "export" through harvested produce. Such exports are generally more for agricultural crops in terms of the total quantity removed per unit area and unit time. But because even repeated harvests do not amount to destructive harvesting in woody perennials, the rates of their "export" out of the soil-plant system are relatively low compared to those of agricultural crops. Therefore the nutrients that are removed out of the system too are relatively low. Alvim (1981) pointed out that the products harvested from tropical plantation crops (rubber, vegetable oils, fibers and starchy foods) are basically composed of carbon, hydrogen and oxygen with only a small fraction of mineral

elements extracted from the soil. In other words, these crops "export" from the field mainly elements extracted from air (carbon and oxygen) and water (hydrogen), leaving only very little stress on the mineral elements in the soil. The situation is more or less the same in the case of fruit trees also. This is a major difference between the fruit trees and other woody perennials that are frequently harvested for their products for off-farm use such as fodder and firewood.

Moreover, in AF systems consisting of commercial crops like coffee and cacao under tall-growing shade trees, the net harvest output of nutrients from the commerical crops is amply compensated for by nutrient input by the shade tree leaf litter alone. For example, Arangiren et al. (1982) studied the distribution of fluxes of nitrogen in some parts of coffee and cacao plantations under shade at a typical highland location in Venezuela (1380 m above sea level). The N flow associated with litter fall in the coffee system was dominated by the shade tree (Erythrina sp. and Inga sp.) fraction amounting to a transfer of 86 kg/ha/yr of the total of 189 kg/ha/yr. The N output (export) from the system by harvest (17 kg/ha/yr) was thus much less than the contribution (input) by the shade trees. The average litter decomposition constant (k) of the shade tree leaves, expressed in terms of N, was estimated to be 4.5, equivalent to a half-life of approximately 2 months. The cacao system consisted of 302 kg N/ha in the plants, of which woody above-ground parts made up 50 percent; fine roots and leaves contained about 60 kg N/ha. Litter on the soil surface, sampled quarterly, was found to contain an annual average of 37 kg N/ha, with shade tree leaves making up 61 percent of the total.

Out of a litterfall rate of 2,900 kg dry matter/ha/yr, the shade tree leaves accounted for 50 percent. The rate of N transfer by litter fall was 321 kg N/ha/yr, decomposition constants (k) for shade tree leaves and cacao leaves being 7.7 and 9.5 respectively. Nitrogen output by harvest was about 45 kg/ha/yr, with about 20 kg N being returned annually to the field with cacao pod shells after processing. It is of considerable significance that besides the nutrient compensation of the harvested produce by the shade tree leaf litter, much of the shade tree leaf litter nutrients could be from soil horizons deeper than those exploited by coffee or cacao and possibly from biological di-nitrogen fixation by the shade trees. The situation can be identical in the case of low-canopied fruit trees such as guava, rambutan, sapote, papaya, and so on, grown under tall, dense-canopied shade trees.

In summary, plant nutrients are involved in a constant and somewhat close cycling within the soil and plant compartments of tree-based ecosystems, with minimal output (loss) from the system. The extent to which the system is "closed" or "open" will depend upon various factors, the decisive one being the tree-crop proportion. Even in agroforestry systems with a high proportion of woody perennials, the frequency and method of harvesting their produce, the structure and density of the root system, the type and magnitude of disturbance (including management) to the system, and the spatial and temporal arrangement of species are among the important factors that contribute to the effectiveness of the nutrient cycling processes in soil productivity. In fruit tree-based AF systems, the general tendency is to maintain an increased volume of tree canopy (because of

minimal pruning), which could be a plus point not only for leaf litter production but also for increasing the amount of plant cycling fraction of nutrients thus leading to a higher nutrient cycling efficiency in the soil-plant system.

3.3. Soil Conservation

The establishment of a vegetative cover is one of the most effective ways of soil and water conservation. When the protective cover of vegetation on the soil is removed, the structurally unstable tropical soils are exposed to the beating action of rains. Losses due to erosion immediately after land clearing are normally alarmingly large. Experiments at the International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria indicate a soil loss of up to 120 t/ha in the first year after land clearing (Lal, 1974). As is well known, the magnitude of loss depends upon several factors, such as erodibility of the soil, erosivity of rain, slope, vegetation types, management practices, and so on.

The potential role of trees in reducing runoff and erosion losses is well appreciated and understood. The litter and the humic layers on the soil surface act as a cushion against erosion. The presence of more organic matter on the soil surface increases soil's infiltration capacity and enhances its capacity to absorb as well as retain water. The physiognomy of natural forest communities is such that it provides a multi-layer defence against the impact of raindrops. The different strata of the canopy progressively reduce the force of rain, thereby reducing the adverse effect of the impact on the soil below.

The soil conservation benefit of woody perennials can conveniently be made use of in AF in various situations, especially in areas with steep slopes and rolling topography. Wiersum (1984) reviewed the quantitative data on surface erosion in various forest and tree crop systems and evaluated the effect of trees grown in combination with agricultural crops on rainfall erosivity, soil erodibility and soil surface protection. Using the data from various places, he concluded ... it in AF there exists the possibility that coalesced raindrops falling from high canopy species may cause more damage, than the rain itself, to the soil. On the other hand, tree canopies may also slightly decrease the amount of water reaching the soil and thus decrease the hazard for runoff and rill erosion. Obviously several canopy characteristics such as crown architecture, extent of ground cover, tree (canopy) height and size and position of leaves will influence the net balance of these two contrasting effects of trees on rainfall erosivity. Moreover, the tree/crop ratio and management practices are the key factors in this regard too.

An increase in the susceptibility of soil to erosion (soil erodibility) has been reported from a few AF systems (compared with forest ecosystem) such as the Taungya system in Kerala, India (Alexander et al, 1980), Leucaena leucocephala system in the Philippines (Baconguis and Rondilla, 1979), Tanzania (Lundgren, 1978). However, not much research information is available to judge if soils under AF may develop lower erodibility as compared with soils under agricultural cropping. Predictions are that it is very likely (Lundgren and Nair, 1984; Nair, 1984a).

The data put together by Wiersum (1984) and presented in Table 6, indicate that the erosion rates in any tree stand, whatever its nature, tend to be within the same range as long as a good direct soil surface cover is ensured. In AF systems where leaf litter production by trees is limited as a result of leaf harvesting or wide espacement of trees, there will be a reduction of such plant cover on soil at various times depending on the management of the crop and the tree. But in AF systems involving fruit trees, where trees are not harvested periodically for their leaves, there is always some plant cover on the soil. However, the extent to which this can be effective in soil protection depends on a large number of factors as discussed. There are also management possibilities for exploiting such permanent canopy cover for soil protection in systems involving fruit trees; these will be discussed in the later section dealing with tree management. The important role of trees in slope stability also needs to be realized and exploited.

In summary, it can be said that while fruit trees too can be expected to have the beneficial effects attributed to all trees in general with respect to soil conservation, the extent to which these effects can be exploited and realized in field situations depends on a large number of management considerations and site factors.

3.4. Ecosystems Stability

Arising from the realization of the protective action of a community of trees in imparting stability to the broad ecosystem or watershed where they exist, and alarmed at the ill-effects of forest denudation in the water catchment areas on the reservoirs and

Table 6. Some Data on the Extent of Soil Erosion in Land-Use Systems Involving Trees
(after Wiersum, 1984)

A. Erosion in various tropical moist forest and tree crop systems (ton/ha/year)

	Minimal	Median	Maximal
Multistoried, tree gardens (4/4)[1]	0.01	0.06	0.14
Natural forests (18/27)	0.03	0.30	6.16
Shifting cultivation, fallow period (6/14)	0.05	0.15	7.40
Forest plantations, undisturbed (14/20)	0.02	0.58	6.20
Tree crops with cover, crop/mulch (9/17)	0.10	0.75	5.60
Shifting cultivation, cropping period (7/22)	0.40	2.78	70.05
Taungya cultivation (2/6)	0.63	5.23	17.37
Tree crops, clean-weeded (10/17)	1.20	47.60	182.9
Forest plantations, burned/litter removed (7/7)	5.92	53.40	104.8

[1](x/y) x = no locations
y = no. treatments/observations

B. Throughfall and erosive power under tree canopies on Java

	Tree height (m)	Canopy cover (pct)	Throughfall (pct incident rainfall)	Erosive power[1] (pct incident rainfall)
Tree plantations				
Acacia auriculiformis	13	80	81	119
Albizzia falcataria	20	40	80	102
Anthocephalus chinensis	10	80	80	147
Bamboo sp.			80	180
Agroforestry systems				
Homegarden			79	202
Mixed garden			81	196

[1]Erosive power measured by splashcups

Source: Lembaga Ekologi, 1980.

farmlands served by such catchment areas, a lot of speculative and often exaggerated thinking has gone into the likely effects of trees on farmlands and other AF systems. However, there is very little direct research information on these asepcts. As Hamilton (1983) puts it, it seems to be assumed that when trees are introduced into a cropping or grazing system, nothing but beneficial results will accrue to the watershed parameters.

The beneficial effects of trees on watershed protection can be realized to any discernible extent in only a large community of trees. Usually any such large-scale afforestation or tree planting activities on watersheds are planned and implemented by or at the advice of the forest officials who have a tendency to select conventional forestry species for the purpose. The logistical aspects of more attentive management and more frequent harvesting needed for the fruit trees may also preclude them from the list of candidate species for such activities. However, the possibility exists for using fruit trees for slope stability and ecosystem protection. But the extent to which watershed protection on a large-scale can be achieved by fruit tree-based AF system depends on a large number of these factors.

Two other aspects of ecosystem stability and environmental protection of fruit trees in AF which can be of significance at the micro-site and farm level are the microclimate modification and windbreak/shelterbelt effects of trees. Nair (1979) has discussed the effect of crop combination with coconuts on the microclimate effects. Nair and Balakrishnan (1976) reported that the evaporation during the dry months in the microclimate (mean values from measuring sites at ground level and 1 m and 2 m from the ground) of a multistoreyed crop

combination of coconut, cacao, black pepper and pineapple was only about 30 percent of that from the open area whereas it was 60 percent under a sole stand of adult coconut palms. Similarly, there was also a considerable difference in the temperature regimes within the crop mix and the sole crop stands. The air temperature on the plantation floor in a sole stand of coconuts (as well as in the open area) was about 3°C higher than at 1 m above the floor, which caused movement of air from the heated soil surface to upper layers by convection. There was no such temperature difference, and hence no air movement, in the crop combination. Moreover, the presence of crop canopies at various vertical distances from the ground in a crop mix offered greater aerodynamic roughness and a buffer action against any drastic microclimatic changes. This could have considerable effects on the various biological processes occurring in the environment (including soil) of the crop community and on the multiplication of plant parasites. Coconuts with their tall unbranched stems probably present an extreme situation in this regard. Nevertheless, similar effects though of reduced magnitudes are likely to occur in crop associations involving other fruit trees too.

Fruit trees may have a special role in offering shelterbelt/windbreak effects in AF systems. As pointed out by Darnhofer (1982), the choice of woody perennials as windbreaks is dependant upon a number of factors such as their phenology, growth habit, complementarity and compatibility with other species, and so on. But the possibility of arranging the fruit trees in rows resembling hedges on farm and plot boundaries makes them particularly suitable for AF systems. There are also other environmental issues

such as pest and disease management in agroforestry mixtures, the effects of such mixtures on avian population etc. But there are no experimental evidence on such issues.

Thus it is clear that there are several environmental advantages of including fruit trees in AF systems. Some of them are common to all trees, but some are specific only to fruit trees. The degree of success and the extent to which the benefits can be realized depend on the location, the species involved and their management.

4. SOCIO-ECONOMIC ASPECTS OF FRUIT TREES IN AGROFORESTRY

4.1. Fruit Trees Agroforestry and the Small Farm

Agroforestry systems involving fruit trees are most commonly found in the small farm holdings in most parts of Asia-Pacific and other parts of the world, and invariably much of the land-use practices adopted by these home gardeners are one or the other forms of fruit tree integration with other types of plants and/or animals. The word "small farm" need not necessarily refer to the size of the farm unit. In agro-economic parlance, size of a small farm can vary from a fraction of a hectare mixed home garden unit to hundreds of hectares of arid zone grazing land, so that a more appropriate concept of a small farm is that of one where the resources available to the operator severely limit his opportunities for improvement. Size is usually at or near the minimum required for maintenance of a subsistence-type operation under existing conditions. However, in the home gardens of Asia-Pacific where fruit tree-based agroforestry systems predominate, the size of the holding is usually only a

fraction of a hectare. Green revolution technologies dominated by high-yielding varieties of crops for monoculture stands and concomitant requirements for expensive inputs have not permeated to these small farm agroforesters. As pointed out by King (1979), for these resource-poor farmers who yield no recognizable social or political power, agroforestry is the only appropriate approach to land management whereby both food and wood products can be produced from the same piece of land at the same time without causing deterioration of the ecosystem. In addition to this possibility of producing multiple outputs, the other socio-economic advantages attributed to integrated agroforestry production systems include generation of additional employment to the farmer, favorable cost/benefit relations, risk minimization in farming, staggered production of subsidiary farm produce, economic complementarity in the use of inputs, improved nutritive value of diet, and so on. Some of these benefits cannot be expressed realistically in quantitative terms. Nevertheless, they shall be considered here briefly from the point of fruit tree-based agroforestry systems.

4.2. Production Aspects

Various reports are available on the production of different species of plants grown together in plant associations of various types in diverse situations. For example, yield of annual field crops under coconuts in the Philippines was reported by Famer (1975); intercropping results under coconuts in India by Nair (1979), Nelliat and Bhat (1979), Varghese et al. (1980) and Nair and Varghese (1980); coconut intercropping results in Sri Lanka by Liyanage et al. (1984);

observations from hill farming systems of Nepal by Fonzen and Oberholzer (1984), reports on highland agroforestry systems in Papua New Guinea by Bourke (1984) and so on. Apart from giving some broad indications on the general productivity levels, these results are neither comparable nor quite extrapolable to other areas because of the lack of uniformity in the conditions from which the results are reported. In addition to the usual variations in such results caused by differences in climate, soil, etc., the results are also influenced by a host of factors related to the type and management of the woody perennial component in such mixtures. The species, its planting pattern and density, management regime, cultural operations to the understorey species, etc., will have marked influence on the results. Moreover, in most of the reports, results are reported for gardens or parcels of plots of undefined area.

One of the very rare sets of research results on this aspect was reported from the Central Plantation Crops Research Institute (CPCRI), Kasaragod, Kerala, India (Nair, 1979; Nelliat and Bhat, 1979; Varghese et al., 1978) a part of which is presented in Table 7 for comparative purposes. Other reports from CPCRI indicate that when the overstorey species (coconut) and the understorey species were separately fertilized and managed according to the recommended package of practices for the individual species, intercropping did not have any adverse effect either temporarily or over a longer period of time, on the productivity of the overstorey species (Varghese et al., 1978). Although not substantiated by research results, it can be surmised that such a situation can be anticipated in the case of crop combinations involving other fruit trees also, wherety the yield of

Table 7. Cultivation Details and Yield of Some Rainfed Intercrops Under Coconuts in India (After Nair, 1979; Nelliat and Bhat, 1979; and Varghese et al., 1978)[a]

Intercrop	Method of Planting	Per Hectare of Coconut Area: Net area of intercrop (%)	Fertilizers for intercrop N (kg)	P_2O_5 (kg)	K_2O (kg)	Yield	Net monetary return per unit cost of cultivation
Cassava *Manihot esculenta*	Pits; 1.0 x 1.0 m spacing	75	75	75	75	14.82	1.52
Elephant foot yam *Amorphophallus campanulatus*	Pits; 1.0 x 1.0 m spacing	70	75	75	75	13.46	1.37
Sweet potato *Ipomoea batatas*	Ridges and furrows; 1.0 m between ridges	70	52	35	52	8.38	0.93
Greater yam *Dioscorea esculenta*	Pits in paired rows; 1.0 m between pair of rows; 0.75 m between rows in a pair and plants in a row	70	75	75	75	13.61	1.64
Lesser yam *Dioscorea esculenta*		70	75	75	75	9.26	1.38
Chinese potato *Coleus parviflorus*		70	80	60	80	7.32	1.71
Ginger *Zingiber officinale*	Beds; 0.25 x 0.25 m between plants; 1.0 m between beds	70	80	60	80	8.61	1.92
Turmeric *Curcuma longa*		70	80	60	80	10.94	0.36[b]
Taro *Colocasia esculenta*	Pits; 1.0 x 1.0 m spacing	70	75	75	75	9.2	1.23

[a]Data are average for four seasons' trials (1973-74 to 1976-77)
[a]All yields were 60 to 75 percent of the open area yield of the same species on unit area basis.
[b]During the period, turmeric had very low market value.

the fruit tree *per se* may not be adversely affected by growing other species between or under them, provided that the fruit tree and the companion species are managed reasonably well.

4.3. Productivity Comparisons

Although there is no general pattern that emerges from all such reports, it is not unlikely that in some situations the yield of a particular understorey species, which normally can be or is grown as a sole crop, is slightly less when grown in an agroforestry combination, as compared to its sole crop yield. There are two aspects to any such yield reduction. First, the yield reduction on a per plant basis and secondly, on an area basis. The latter is only apparent because the net area occupied by an understorey species in a crop combination, say, one hectare, will be less than one hectare. Therefore, intercrop yields can be adjusted on the basis of the net area occupied by the species in the total crop mix. The yield reduction that might occur on a per plant basis is a net effect of a large number of factors, mainly competition for growth factors such as light, nutrients and water. These interaction effects of herbaceous plant mixtures have been discussed in detail by Trenbath (1976) and of perennial plant mixtures by Nair (1980a). Such yield reduction possibilities in mixtures have often been advanced and articulated by critics of crop combination despite the fact that the yield of the overstorey species is unlikely to be adversely affected and the total yield from unit area will be higher.

This leads to the question of yield and productivity comparisons in polycultures. The crux of the problem is that the usual tendency

is to compare the yield of a particular species grown in crop association to that of the same species in monoculture. But the appropriate comparison should be based on the total productivity of all species grown in a unit of area in the short run, and the sustainability of such productivity in the long run. Obviously, since the yields of different crops in a crop association are not additive, other comparable values should be ascribed to such yields. Money is one such practical unit that can be applied to all products, is easily understandable and acceptable to all, and is capable of reflecting the quality differences among the products. However, the relevance of monetary figures also depends upon the time, the country or the locality, the socio-cultural values, etc. Moreover, there are also several non-monetary benefits of a social and cultural nature that can be accrued which will be difficult to quantify precisely.

The concept of land equivalent ratio (LER) that has been developed to deal with agricultural intercropping (International Rice Research Institute, 1975; Trenbath, 1976; Willey, 1979) has been applied to tree-based intercropping systems as well (Nair, 1979). Assuming equivalent levels of management, LER refers to the relative land area under sole crops that is required to produce the yields achieved by intercropping (Willey, 1979). The practice of intercropping is assumed to be beneficial when LER is more than 1, and detrimental to yield when LER is less than 1. Similar to LER, income equivalent ratio (IER) has also been proposed to assess the relative performance of a crop combination compared to sole crops of the component species. Thus, IER is the ratio of the area needed under sole cropping to produce the same total net income as obtained from a

unit area (hectare) under crop combination of the same management level.

In agroforestry systems, there is likely to be complementary use of resources because the components of the system exploit the environmental supplies of growth factors in differing ways as discussed in a previous section, and therefore, the LER (and IER) values can exceed unity. When the yield of the fruit tree component is not adversely affected, agroforestry practice will result in an LER (IER) of 1 + x, where x corresponds to the extra yield (income) obtained from additional component(s). This would also mean that land units equivalent to produce x extra units of yield (income) would have been necessary to produce yields which contribute to the increase in LER (IER) over unity by x. The optimum density of the additional component to obtain a maximum value of x can be calculated. Raintree (1983) discussed some of these bioeconomic considerations of agroforestry in some detail and postulated that certain highly promising agroforestry complementarities are significant only under low input production conditions.

4.4. Social Benefits of Fruit Trees in Agroforestry

4.4.1. Employment potential

Intensification of land-use by increasing the number of crops/enterprises per unit area at any given time will understandably increase the on-farm employment potential too. Nair (1979) reported that the annual labour requirement for managing one hectare of adult coconut plantation in Kerala, India increased from 150 man-days for

monocrop of coconut to 350 man-days for high intensity crop combinations. In the agro-silvo-pastoral system (of raising 2-3 milk cows per hectare of coconut area and stall-feeding them with the fodder grasses that are grown along with other intercrops under coconuts), the annual labour requirement was as high as 1000 man-days per hectare. There was also a corresponding increase in total income per unit area. Such improvements in employment generation and income by coconut intercropping has been reported from Sri Lanka also (Etherington and Karunaratne, 1981). In most small farm holdings where fruit tree-based agroforestry systems are most feasible, most, if not all, of the labour needs for the farm are provided by the owner/occupier and his family. Crop intensification will, therefore, provide additional on-farm employment to the farmer and his family and thus alleviate, at least to some extent, the feeling of inertia and inactivity caused by unemployment and underemployment during some parts of the year on the part of monoculturists. This is particularly true in the case of fruit-tree agroforesters because fruit-trees normally demand higher labour throughout or most parts of the year for their management and harvesting, as compared to the management of most other woody perennials in agroforestry systems.

4.4.2. Risk minimization

Most home gardeners grow a variety of crops together not only to meet their domestic needs, but also as an insurance against the risks of monoculture cropping. This would apply equally to monoculture herbaceous crops and to fruit tree growers. In spite of the general belief that fruit trees are low-risk crops in comparison with most of

the arable crops, their monocultures pose some element of risk. For example, a glut in the market, and transport bottlenecks, especially for perishable products, can cause serious problems. Moreover, the incidence of pests and diseases that affect growing meristems can have disastrous consequences particularly for species having single (apical) growing buds (e.g., palms). Crop diversification and agroforestry offer some sort of insurance against such calamities, and this is particularly important in tree crop husbandry where it is not possible to change the crop after one or even a few years.

4.4.3. Staggered production and subsidiary products

The possibilities for staggering the farm operations to some extent exist in the management of some fruit trees that are aseasonal in growth and production. This is advantageous to the farmer so that cultivation expenses and labor use can be distributed as desired by him. Planting of intercrops can be timed in such a way that a steady supply of subsidiary food materials can be ensured during lean periods of availability of staple foods.

4.4.4. Nutritive improvement of rural diet

Perhaps the most significant attribute of fruit trees that make them eminently suitable for rural agroforestry is the nutritive value of their products. In many village societies all over the world, legendary tales exist linking some species of trees to the prosperity of the village. Sommers (1978) evaluated the nutritive value of various indigenous species in the homegardens of the Philippines and found that such species contributed substantially to the diet of the

people. Table 8 gives nutritive values of some of the fruit trees for indicative purposes. Sustainable agroforestry practices involving such fruit trees is an excellent way of supplementing and enriching the diet of rural people in many developing countries.

There are also several other social values attached to fruit trees. For example, it is still customary in many rural societies to exchange or make other use of tree products in social ceremonies and religious rituals and celebrations, and many such trees exist in compatible association with other cultivated plants. Intensification of land use with systems involving such trees will not pose any problem of social acceptance and adoptability of such technologies by farmers. On the other hand, many of the fast-growing, multipurpose trees with agroforestry potential may have this problem of social acceptance by farmers when they are tried to be introduced for the first time in a locality.

5. MANAGEMENT CONSIDERATIONS OF FRUIT TREES IN AGROFORESTRY

It is a truism that the success or failure of any innovation in farming systems depends on the skill of its management. It is one thing to elucidate the scientific merits and advantages of a new and innovative technology; to make it acceptable and adoptable by the farming community is yet another. The matter is more complex in AF situations because the extent to which the suggested advantages and postulated benefits can be realized in actual field situations will depend enormously on the level of management especially of the woody component. The term management is used here in a broad sense to encompass all aspects of species selection, planting density and

Table 8. Average Nutritive Value of the Edible Parts of Some of the Fruit Trees in Comparison to Some Other Common Foods of Plant Origin (Values per 100 g Material) (after Bourke, 1975)

Product	Water	Proteins	Fats	Carbohydrates	Vitamins (Vitamin A in International units, others in mg)				
	%	%	%	%	A	Thiamine	Riboflavin	Niacin	C
Fruits and nuts									
Brazil nut, dry	4.6	14.3	66.9	10.9	tr	0.96	0.12	1.6	-
Cashew nut, roasted	5.2	17.2	45.7	29.3	100	0.43	0.25	1.8	-
Coconut (meat)									
fresh	50.9	3.5	35.3	9.4	0	0.05	0.02	0.5	3
dry	3.5	7.2	64.9	23.0	0	0.06	0.04	0.6	0
Custard Apple, raw	71.5	1.7	0.6	25.2	tr	0.08	0.10	0.5	2
Date, dry	22.5	2.2	0.5	72.9	50	0.09	0.10	2.2	0
Guava, entire, raw	83.0	0.8	0.6	15.0	280	0.05	0.05	1.2	242
Litchi, raw	81.9	0.9	0.3	16.4	-	-	0.05	-	42
Macadamia, dry	3.0	7.8	71.6	15.4	0	0.34	0.21	1.3	0
Mango, raw	81.7	0.7	0.4	16.8	4800	0.05	0.05	1.1	35
Nectarine, raw	81.8	0.6	tr	17.1	1650	-	-	-	13
Orange, peeled, raw	86.0	1.0	0.2	12.2	200	0.10	0.04	0.4	50
Papaya, raw	88.7	0.6	0.1	10.0	1750	0.04	0.04	0.3	56
Sapota, raw	76.1	0.5	1.1	21.8	60	tr	0.02	0.2	14

(cont'd)

Table 8. cont'd.

Product	Water	Proteins	Fats	Carbohydrates	Vitamins (Vitamin A in international units, others in mg)				
	%	%	%	%	A	Thiamine	Riboflavin	Niacin	C
Other common foods (of plant origin)									
Apple, raw	84.8	0.2	0.6	14.5	90	0.03	0.02	0.1	7
Banana, raw	75.7	1.1	0.2	22.2	190	0.05	0.06	0.7	10
Cassava, tubers, raw	62.0	0.7	0.2	37.0	-	0.07	0.03	0.7	30
Maize (flour)	12.0	7.8	2.6	76.8	340	0.2	0.6	1.4	0
Mung bean, ripe dry seeds	10.7	24.2	1.3	60.3	80	0.38	0.21	2.6	-
Potato, raw	79.8	2.1	0.1	17.1	tr	0.10	0.04	1.5	20
Rice (whole grain)	12.0	7.5	1.9	77.4	0	0.34	0.5	4.7	0
Soybean immature pods, raw	69.2	10.9	5.1	13.2	690	0.44	0.16	1.4	29
ripe dry seeds	10.0	37.1	17.7	33.5	86	1.10	0.31	2.2	-
Sweet potato tubers, raw	70.6	1.7	0.4	26.3	8800	0.10	0.06	0.6	21
Wheat (whole grain)	12.5	12.3	1.8	71.4	0	0.52	0.12	4.3	0
Yam, raw	73.5	2.1	0.2	23.3	tr	0.10	0.04	0.5	9

tr = trace

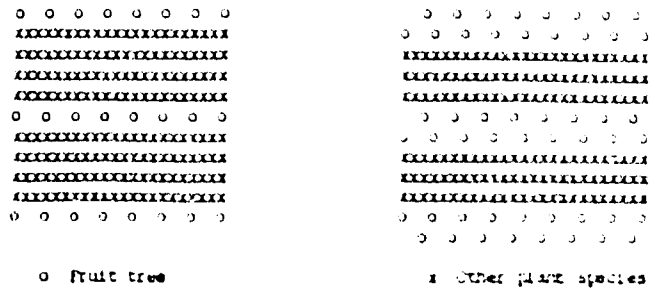
pattern, pruning, thinning and other plant manipulations to regulate and alter its architecture, its care and maintenance including usage of fertilizer and other agrochemicals, and so on.

It is also to be kept in mind that the productive and protective values of fruit trees elucidated earlier in this paper would apply only in a community of plants where such trees form a discernible component of the system. In other words, individual and scattered trees cannot be expected to have such noticeable beneficial effects; in any case, such scattered sprinkling of trees on the farmland or other landscapes may not offer any significant ecological or economical interaction with major production components of that land-use system and therefore may not merit identification with or inclusion under the generic term of agroforestry.

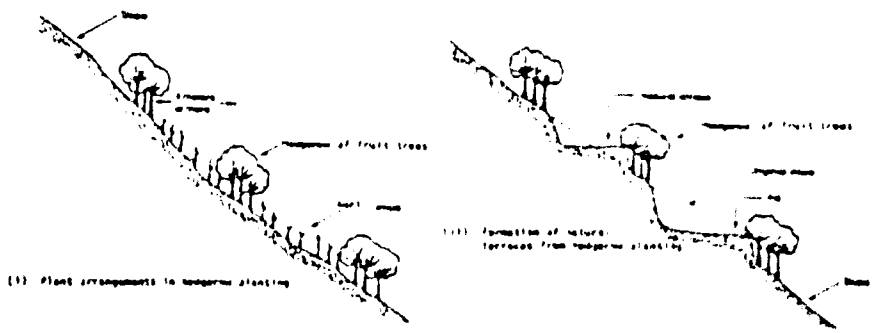
Some of these management considerations to be taken into account while introducing fruit trees in AF systems are discussed here.

5.1. Planting Pattern

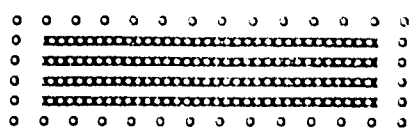
The admixture pattern of species will depend upon the species themselves, climatic conditions and the level of management. There can be a substantial body of knowledge on these aspects concerning certain species whereas that on others, such as the underexploited species, may be meager. The most commonly adopted planting pattern of fruit trees in existing AF systems can be grouped into five as indicated in Figure 3. These are, however, rather broad categories and many variations within each of these schemes are common.



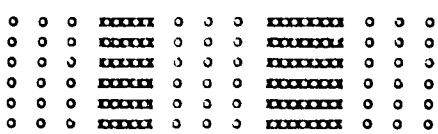
A. HEDGEROW PLANTING OF FRUIT TREES IN SINGLE HEDGE (LEFT) OR DOUBLE HEDGE (RIGHT) WITH OTHER CROPS IN THE INTER-ROW SPACES



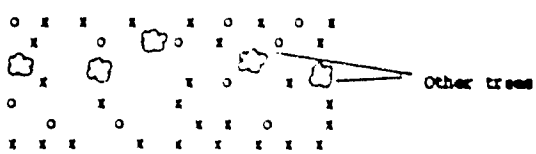
B. HEDGEROW PLANTING FOR SOIL CONSERVATION



C. BORDER PLANTING



D. ZONAL PLANTING



E. MULTISPECIES RANDOM MIX

Figure 1. Some spatial arrangements of plants in agroforestry systems involving fruit trees (Nair, 1980; Vergara, 1982).

A. Hedgerow planting. The fruit trees are planted in rows at spacings much closer within the rows than between the rows, so that the rows appear like hedges. Depending on the canopy configurations of the species, the rows can consist of single, double or even more lines. The interspaces between the rows can be used for agricultural species, so that the lay-out resembles that of an alley cropping system (Kang et al., 1981; Wilson and Kang, 1981) except that in alley cropping system, the woody perennial is periodically pruned and kept to a low height. This is a systematic planting pattern where intensive management is possible and is well-suited for thin-canopied fruit tree species like guava, palms, etc.

B. Contour Hedges. In areas with sloping land, selected tree species can be planted in hedge rows across the slope along contour, in different arrangements (single, double or alternate rows); inter-row distances vary depending on species and the degree of slope; soil binding perennial grasses can be established between the rows along the contours. Well-suited for slopping lands and rolling terrains as in the highlands.

C. Border planting. Close planting of fruit trees in rows all around the plots and along the boundaries of agricultural fields. The trees will form live fences and windbreakers and sheltertelts. The scheme is particularly suitable for large-canopied trees like jackfruit, mango, cashew, etc.

D. Zonal planting. Fruit trees and other components of the AF system are planted in defined zones or stips the width of which will usually be narrow so that there will be some interaction between adjacent zones over a significant proportion (i.e. more than 50%) of the area involved. For example the other component of such a system can be a mulch-and-fuelwood producing nitrogen-fixing tree or shrub, rather than an agricultural species. The scheme is particulary suitable for semi-arid areas where it may be advantageous to avoid overcrowding of the species in order to minimize competition for water and yet be able to get the beneficial interactive effect.

E. Home garden mix. This is the most commonly found planting pattern involving fruit trees in AF. The trees are integrated very intimately with other herbaceous and woody species to form a multilayer canopy configuration with no definite planting arrangement.

All the above mentioned patterns can also be adopted for situations where the fruit trees form the lower or middle layer of canopies, with other taller-growing species forming the overstorey. In such cases, schemes A,B and C can be adopted for the tallest-growing species, with the fruit trees coming in between the tall-tree rows.

5.2. Plant Density

This is again another highly location-specific management variable so that a general scheme is difficult to be recommended. Once the species and planting pattern have been decided, then plant

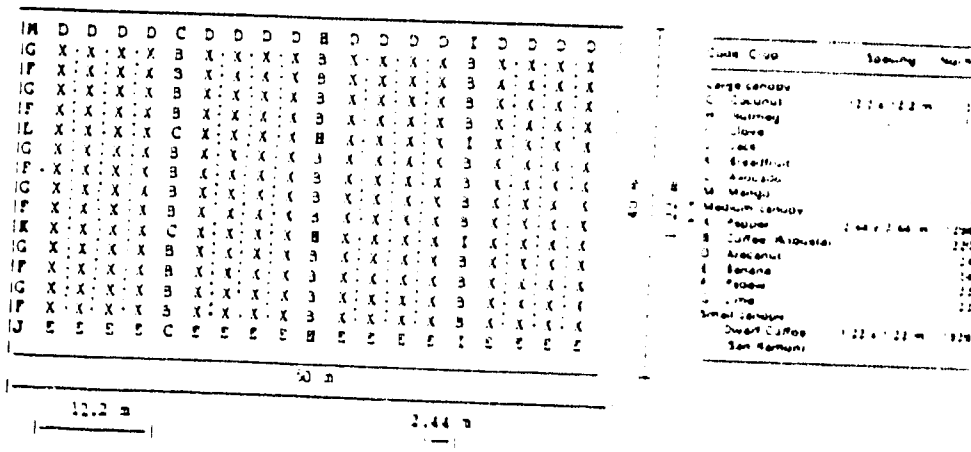
density will depend mainly upon the degree of managerial ability of the farmer as well as prevailing climatic conditions. Bavappa and Jacob (1982) tried various models of crop associations with perennials in Kandy, Sri Lanka. Two such models, one for high intensity multi-species cropping, and the other for homestead gardening by paddy farmers, are given in Figure 4.

Schematic diagrams of canopy configurations of such high-intensity multi-species combinations have been presented by various workers (Bavappa and Jacob, 1982 from Sri Lanka; Fernandes et al., 1984 from Tanzania; Widagda et al., 1984 from Indonesia; and so on). A common feature of all such diagrams is the localization of the various canopies so that they fit very well vertically and horizontally within the available space and thus minimize overlapping and interference effects with the canopies of the co-habiting species.

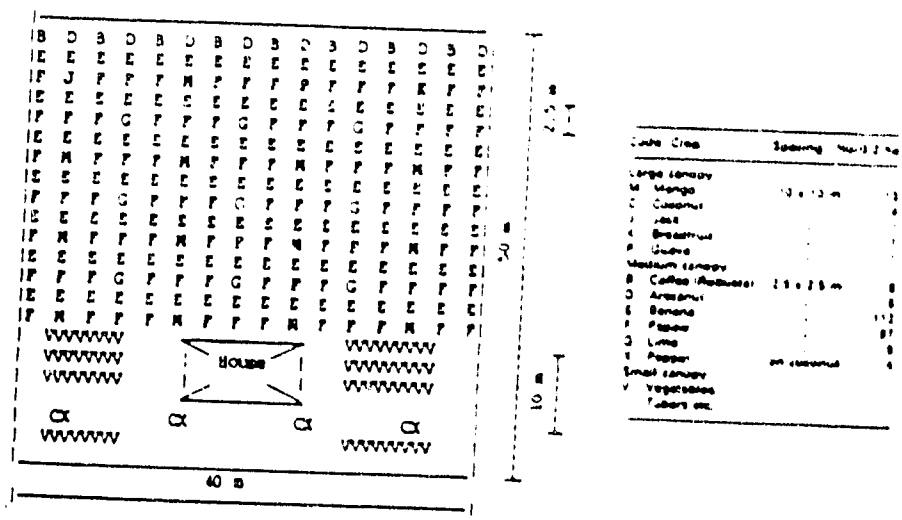
5.3. Admixture Sequence

Depending on the existing land-use practice on a site, fruit tree-based AF can be initiated by either introducing them into existing systems, or by incorporating other species into fruit tree gardens. The former can be accomplished in agricultural lands according to the planting patterns described earlier. In forested lands varying degrees of strip thinning can be done according to the nature of the forest (primary, secondary or plantation) and the fruit trees introduced.

The strategy for introducing other crops in existing fruit tree gardens involves intensification of land use at various growth stages of the fruit trees without altering their planting pattern or density.



A. MODEL FOR HIGH INTENSITY CROPPING



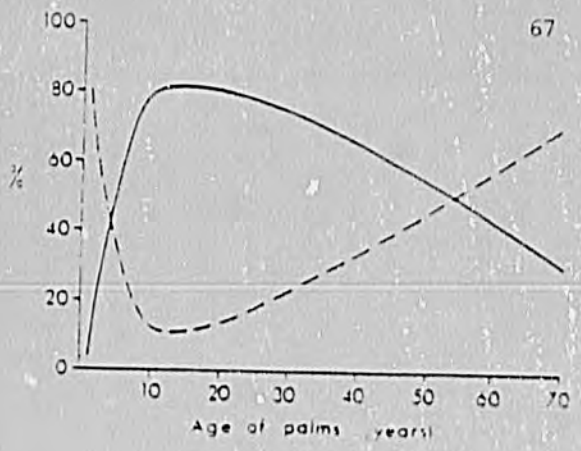
B. MODEL FOR HOMESTEAD FARMING BY PADDY RICE FARMERS

Figure 4. Planting patterns for multilayer perennial crop combinations in the smallholdings of Sri Lanka (Bavappa and Jacob, 1982).

This practice usually does not adversely affect the fruit tree's short term as well as sustained productivity. Before undertaking such species admixtures, the growth form and shade tolerance of the fruit tree, the light transmission characteristics of its canopy etc. have to be evaluated. Figure 5 shows such an evaluation of the growth phases of coconut indicating possibilities for crop combinations. A third possibility that can be visualized is that of new plantings of fruit tree-based AF enterprises. In such a situation, the planting patterns of the fruit trees and other perennials can be adjusted well in advance keeping in view the requirements of the associated species. Generally speaking, in such plantings, agricultural species can be cultivated during the intial 2-3 years when the fruit trees and other perennials are in the early stages of the development, similar to the Taungya system of forest plantation establishment (King, 1968). Canopy development over the years of the various components of such a three-storeyed crop combination (consisting of lower, middle and upper layers) is presented in Figure 6. Assuming appropriate plant densities to provide a compatible mix of species, the total canopy coverage of the ground by such a combination will be more or less constant right from the early stage of establishment and thus the protective actions of the canopy on soil as discussed in an earlier section can be ensured.

5.4. Plant Manipulation

The challenge of management of fruit trees in AF does not end with decisions on species selection and planting arrangements. Equally important is plant manipulation such as pruning, training,



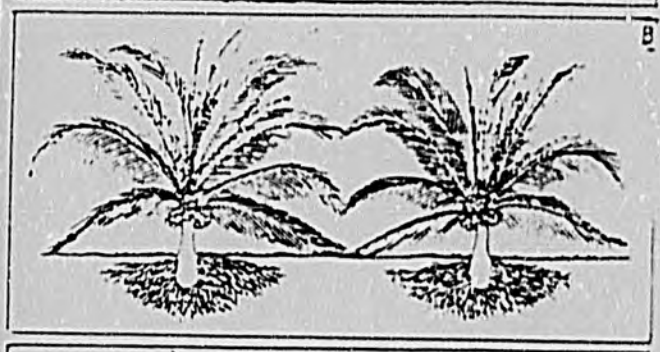
Light penetration and ground coverage pattern by coconut palms of different age groups planted at 7.5 x 7.5 m spacing. (Nelliat, Bavappa and Nair, 1974)

——— Apparent coverage of the ground

- - - - Light transmission through the canopy

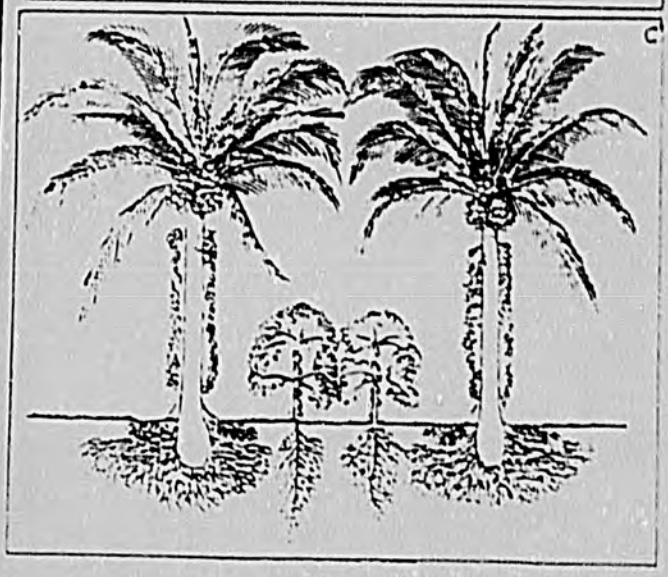
A. Early phase (up to about 8 years after planting):

Canopy of the palm develops gradually; much scope for intercropping.



B. Middle phase (about 8-25 years):

Greater coverage of the ground by coconut canopy; very limited scope for intercropping.



C. Third (Fully mature) phase (after about 25 years):

Coverage of the ground by coconut canopy is reduced; possibilities for introducing other perennials; a multistoried combination of coconut, cacao, black pepper and pineapple is depicted.

Figure 5. Light penetration pattern and crop combination possibilities during different growth stages of coconut palms (Nair, 1979).

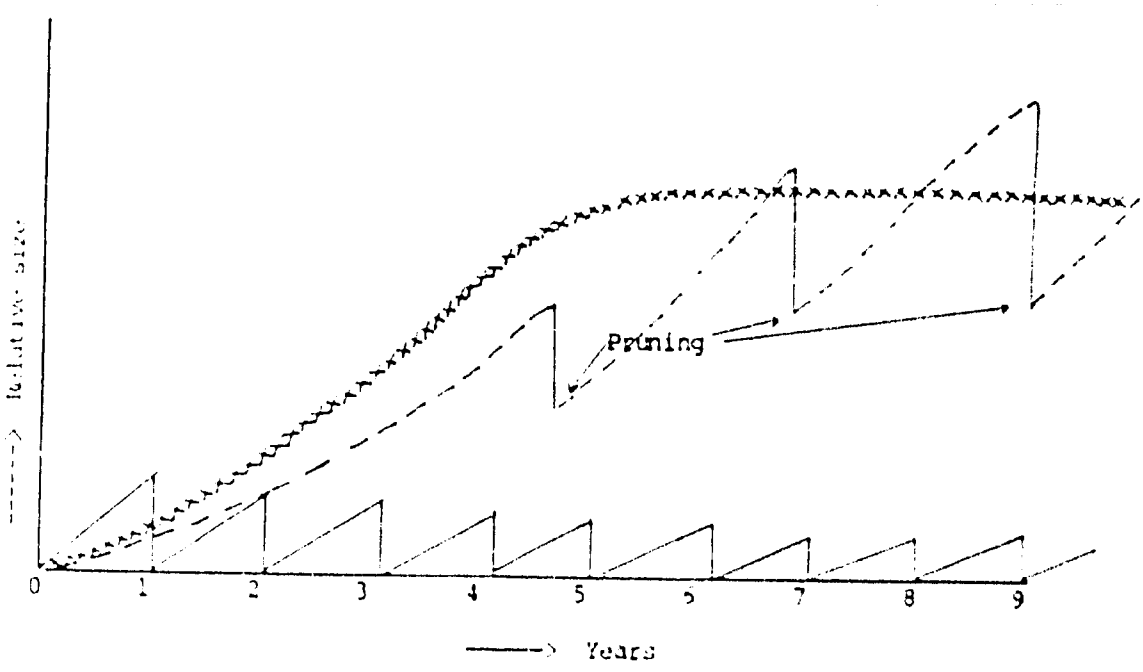


Figure 6. Schematic presentation of canopy development over the years of an agroforestry plant combination of annual agricultural species, fruit tree and an overstory dense-canopied tree.

thinning, etc. These operations have to be carried out on a continuing basis for ensuring the best results from the fruit tree and for providing the optimum conditions for other species. Manipulation requirement for different species vary considerably. In general terms, propagation (nursery), transplanting, juvenile phase and mature phase are the growth phases during which manipulations are possible.

One obvious difference between fruit trees and other woody perennials in AF with respect to plant manipulation is that the vegetative mass of most other woody perennials will be harvested periodically depending on the main purpose for which they are grown (fodder, fuel, poles, green manure, etc.). On the other hand, the removal of vegetative mass of the fruit trees will normally be for inducing fruiting or promoting growth of other desirable parts than for any economic produce. However, in AF situations, such prunings will also be necessary for creating more congenial environment for the growth of other species, or sometimes for pest and disease management.

6. SOME COMMENTS ON FIELD TRIALS WITH FRUIT TREES IN AGROFORESTRY

We have seen that the problems associated with fruit trees in AF are many. Though the practice is old, it has not attracted much scientific attention so far, so that intensification of such land uses based on the modern scientific concepts in order to increase the productivity and sustainability of the system has little or never been attempted. Research methods to tackle such complex systems have also not been developed. However, potential gains from systematic improvement of such hitherto neglected species and systems have recently been strongly emphasized by several research and development

agencies (NAS, 1975; World Bank, 1981). Thus it would appear that there exists an unlimited scope for innovative and imaginative AF technology packages, as well as the enthusiasm and support of many development agencies. But there are several problems of varying nature and magnitude to be circumvented to get effective and efficient research effort on ground.

6.1. Institutional Niche of Agroforestry

All of those who are involved in AF research and development often find that one of the strongest impediments to AF research is the lack of understanding of the disciplinary nature of AF. As pointed out by Lundgren and Raintree (1983), rigid boundaries exist at government and administrative levels among separate departments dealing with different aspects of land use; these departments compete severely for the same developmental resources; the professionals in the different departments trained in traditional disciplines like forestry, agriculture, animal husbandry and so on are confined to their own discipline-oriented branches and sub-branches with very little interaction. To complicate the matter further, in many national institutions and international agencies, AF is often considered as a branch of forestry so that the resources for its promotion and development have to come from forestry's. And in all developing countries, agriculture gets the lion's share of resources for land use activities. Even in institutions where integrated research programs and crop diversification activities are undertaken, they are, understandably, strongly biased toward the basic discipline/commodity of the institute concerned. Thus any

horticultural institution that might be interested in doing some work on the fruit trees of potential value in AF would do so with the focus on the fruit tree per se with practically very little attention on the other components of the system or on the system as a whole. Thus, the dilemma is that AF is institutionally considered a sub-division of forestry, but the major initiative and potential for it have to come from agriculturalists (including live stock production experts), who are professionally not trained and seldom interested in AF, nor are their institutions mandated to deal with it. Then there is the important aspect of integrating sociological aspects in any AF research. So, the problem is really complex and that is the challenge of AF research.

6.2. Priorities for Field Research

There is not much point in formulating a list of research priorities in isolation. Apart from technical issues, it will depend on institutional capabilities and other physical factors. It has already been pointed out that a large number of issues—biological, environmental and socio-economic—need to be attended to, and all would seem to deserve equal priority rating. However, it seems to this author (biased, as usual, by disciplinary interest!) that in terms of the practical value of the nature of results and feasibility of undertaking field trials, the efforts should first be focussed on management of a few selected fruit tree species and their performance evaluation in AF. This could involve selection of germplasm, simple trials on their propagation, cultural aspects and plant manipulation under AF combination, and the evaluation of the species per se as well

as the system over a period of time. The advantage of this approach is that such trials could be initiated at various levels of technology and infrastructure; even institutions with limited facilities or no formal research resources can undertake some such trials and gather the basic data; institutions with greater capability can go deeper into conducting research on the varous aspects such as soil fertility, environmental protection, and so on, as described earlier. Such trials need not be limited to experiment stations (on-station); they can also be undertaken according to a general format on cultivators' fields (on-farm) so that the trials will have more socio-economic similarities to the real farmers' situations.

6.3. Experimental Methods and Procedures

The approach in such research endeavors has to combine scientific values and ecological awareness, and adopt a framework that makes optimum use of available resources. The procedure should be aimed at farmers' requirements and adoptability of new packages rather than to supply scientific data of academic value. In order to accomplish that, the research methodologies that have been developed for a single crop or organism, and the conventional research procedures will have to be modified. As has already been pointed out, the scientists involved in such studies have to shed their commodity- and discipline orientation and focus attention on the multidisciplinary demands made on them by implicitly considering the needs and conditions of the low-input and integrated production systems. In many cases, the experimental framework should be kept highly flexible to take advantage of all new information as soon as it is available even if it

disturbs the norms of statistical accuracy developed for conventional monocrop field experiments. For example, the traditional procedures stipulate to have several years of experimentation with a fixed set of variables to gather "valid" conclusion and recommendations on the feasibility of an agronomic practice. Such luxuries cannot be afforded in AF research at this stage.

Some AF methodology designers have even gone to the extent of totally ruling out the applicability of conventional experiment station research in AF. For example, Raintree (1983) argues that production conditions enjoyed by research stations and a select group of "high access" farmers are such that the more limiting production factors are routinely topped up to optimal levels by inputs from outside the system, and, therefore, such conditions are not representative of the world outside the agricultural laboratory. While it is likely that some of the synergistic intercropping potential and complementary interactions of AF are better manifested under low-input conditions, it should not be forgotten that experiment station researchers do not always confine their trials to high-input conditions only. Moreover some of the basic aspects of component behavior which are so essential for understanding component interactions and system dynamics cannot be properly understood if they are not investigated in rather controlled situations as in research stations. Therefore, what is pragmatic and desirable is to modify the conventional experimental procedures to the special needs and demands of AF.

ICRAF and other organizations involved in AF research have made some efforts to develop methodologies for AF research in accordance

with the above considerations. A diagnostic and design (D&D) approach has been developed by input from a multidisciplinary team (ICRAF, 1983), which describes the step-wise procedure in initiating an AF study. Methodologies are also being formulated for specific experimental needs. For example Huxley (1984) and co-workers have assembled information on the methodologies for evaluating mulipurpose nitrogen-fixing trees in AF; procedures for land evaluation and build-up of environmental data bases have been outlined by Young (1983) and Darnhofer (1984).

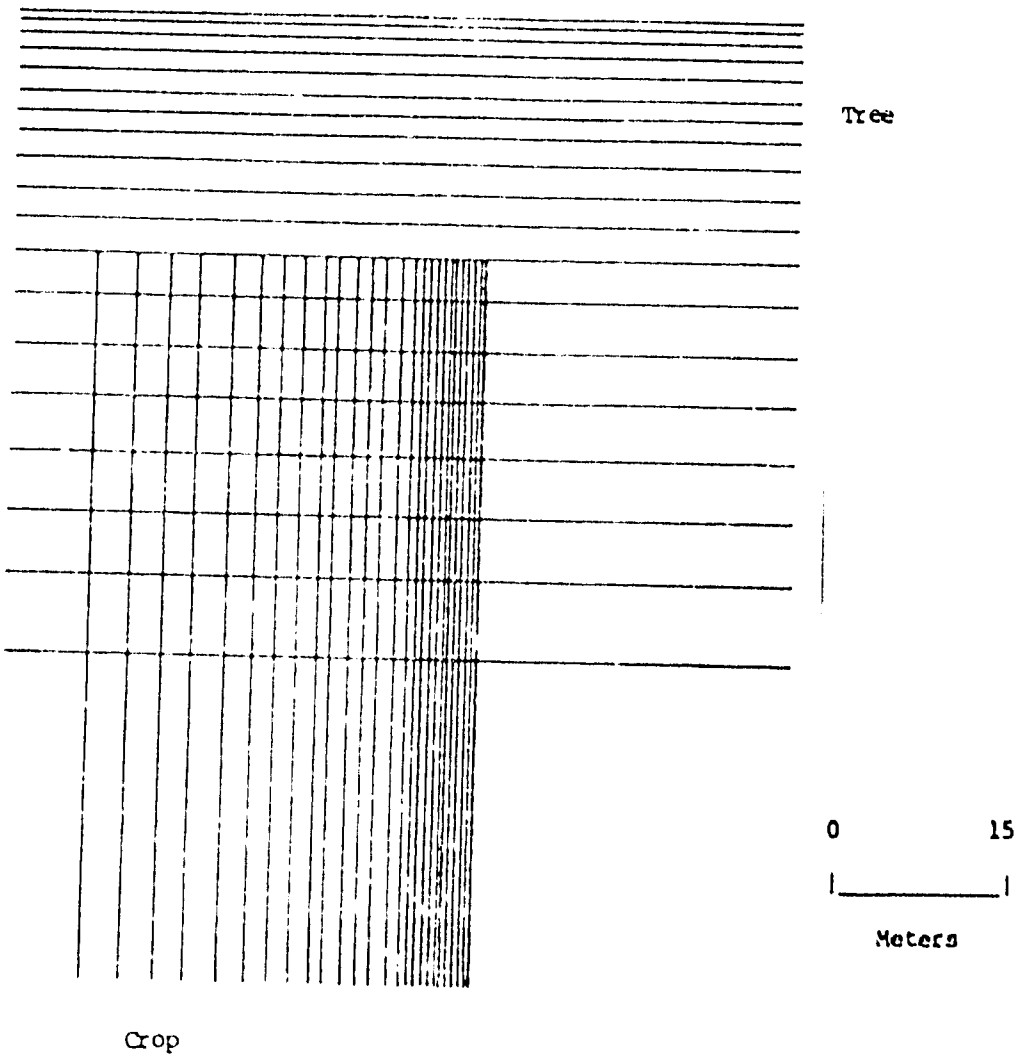
Huxley (1983a) proposes the use of systematic and geometric designs for field experiments in AF, which are used usually for initial screening of a large number of species. Brewbaker (1984) advocates the use of augmented designs for trials with fast growing tree species. That design too has some limitations in AF applications. This author has recommended a more conventional Split-Plot Design for a detailed field experiment in AF (Research project proposal for hedgerow intercropping in Machakos, Kenya: C. Soekabembe, 1984; unpublished). In AF trials with fruit trees, any or all of these designs can be adopted depending on the main objective. If the idea is to test the feasibility of a number of agricultural species as understorey crops with a few fruit tree species, the systematic design will be advantageous. Augmented design will be appropriate if the objective is to evaluate a few little-studied fruit trees and compare them with better known species of more or less similar growth, and at the same time collect more detailed information on the better known species. A Split Plot experiment is more suitable if more management (agronomic) variables are being investigated in a

selected tree-crop mixtures. Figure 7 outlines these three schemes. The underlying principle in all the experimental procedures in AF should be to strike a balance between accepted scientific (disciplinary) norms on the one hand and optimum use of the scarce research resources on the other.

6.4. Interpretation and Extrapolation of Research Results

The socio-economic considerations involved in AF systems with fruit trees have been discussed in a previous section. Similar to the modifications needed for applying research procedures of conventional disiplines to AF, a change in the traditional thinking on economic analysis is necessary to evaluate the labour intensive, resource efficient, sustainable AF systems of the small holdings. Some approaches in this direction have been proposed (Etherington and Matthews 1983; Hoekstra, 1983; Raintree 1983; Arnold, 1984). One immediate consequence of the multiproduct nature of AF production systems is that their productivity cannot be assessed by conventional measures of yields per unit area of separate components taken individually, but some modifications of these productivity measurements which take account of their net value to the producer. Thus interpretation of research results in AF has to take into account the social value also, and therefore it becomes more difficult and location-specific than in the case of conventional disciplinary experiments.

The same applies to extrapolation of research results too. A particular AF practice may cause substitution of some scarce resource or some other form of economic complementarity in the sharing of



1. SYSTEMATIC DESIGN: Two superimposed parallel row designs for testing the effects of simultaneously changing plant density in both a tree and a crop species. If the tree parallel row is extended a second crop layout could be fitted in (Huxley, 1983b).

(Figure 1 continues on next page)

	Treatments				
	Replicated			Unreplicated	
Rep. I	C	A	B	D	E
Rep. II	B	C	A	F	G
Rep. III	A	B	C	H	I

2. AUGMENTED DESIGN: Lay-out of an augmented design consisting of 15 plots, 3 replications, 3 replicated treatments and 6 unreplicated treatments (Brewbaker, 1984).

Block I	a	b	c	d	e	f												

A B C

A, B, C = Main plots (fruit trees), randomized

a, b—>f = Sub plots (agric. species), randomized

3. SPLIT-PLOT DESIGN: Lay-out of one block (replication) a split-plot experiment consisting of 3 main plot treatments and 6 sub-plot treatments; other blocks of similar type; both main plot and sub-plot treatments to be randomized throughout.

Figure 7. Some experimental designs for field testing of agroforestry schemes involving fruit trees.

resources. In another situation with similar biophysical environment, but with dissimilar socio-economic condition, the practice could be equally productive biologically, but less attractive in socio-economic terms. This is especially true in the case of fruit trees because of different food habits and varying degrees of substitution of staple foods, by products of fruit trees. Moreover, in remote areas with severe transport bottlenecks, where farmers are forced to produce all basic needs (food, fodder, fuel, cash) locally to the extent possible, such fruit trees will have added social value.

The point that gets strengthened from all these discussions is that formulation of research plans as well as interpretation of their results has to be very location-specific in all AF trials, especially those involving fruit trees. In other words, there cannot be a set of uniform proposals for all situations. Even within a locality, a "cafeteria approach" (Nair, 1979) has to be developed so that the operators/recipients will have an array of choices from which to select based on their resources, input requirements and output possibilities. The additional information concerning the various aspects of each of these options can be stored in a data bank so as to advise the users on the merits, requirements, drawbacks, etc. and help them in the decision making process.

7. CONCLUSIONS

There are innumerable examples of traditional AF systems and practices in the tropics involving a large number of fruit trees. Although a considerable amount of research has been done on some tropical fruit trees albeit with the conventional monocultural

perspective, the fruit tree-based AF systems have not received research attention to any substantial extent as is the case with all low-input traditional AF systems. The foregoing brief and sketchy evaluation of the potential role of fruit trees in AF system reveals that there are some distinct environmental and socio-economic advantages in choosing fruit trees, as compared with other woody species, as the perennial plant components of AF systems.

While selecting the woody perennial component of AF systems, the emphasis is on multipurpose species, i.e., species that produces multiple outputs and/or performs multiple roles in increasing the productivity and/or sustainability of the system of which it will form a component. Most of the fruit and nut producing trees and shrubs have the added value of producing various products of immense nutritive value in addition to their environmental protection role, and are therefore eminently suitable for AF. However, since they are usually not harvested for their vegetative mass such as fodder, fuelwood or green manure, fruit trees are not to be the preferred species in those AF systems in which the primary production function of the woody perennial is to produce such non-edible vegetative parts.

An evaluation of the environmental aspects of fruit trees in AF reveals that there can be significant advantages of soil improvement, microclimatic amelioration and environmental protection in fruit tree-based AF systems. The maintenance of an increased volume of tree canopy by fruit trees (because of minimal pruning) can be advantageous not only in leaf litter production but also for increasing the amount of plant cycling fraction of nutrients. Thus there are strong indications of better organic matter relations (and all the

consequential benefits) and improved nutrient cycling (and therefore a better nutrient economy) the soil-plant system in fruit tree-based AF systems. Morever, through appropriate planting arrangement and other management schedules, fruit trees can also be used for soil conservation and as shelterbelts and windbreaks.

In socio-economic terms the fruit trees have a special significance in the context of small holder farming systems. By virtue of their various products and by-products, they can be an important contributor to the cash economy of the small farmer. The possibility of staggering the production from fruit trees that have aseasonal production habits offers a means of regulated supply of minor food stuffs in lean periods of staple food availability, as well as provides cash flow to the farmer on a continuing basis. Generation of increased labor potential and minimization of the risk of monocultural farming are strong factors that can alleviate the inertia caused by underemployment and instability that are characteristics of the resource-poor smallholder farming systems.

These suggested advantages and attributes of fruit tree-based AF are only conceptual. They need to be validated by extensive field trials. Research information on these aspects are very rudimentary if not non-existent. The extent to which these potentials can be exploited depends on a large number of environmental factors and management considerations. Choice of appropriate species, the pattern and density of their planting, their management schedules, and so on, have to be carefully determined to suit specific requirements of each site. Because of the extreme location-specificity of all practices and their strong links with prevailing socio-cultural conditions of

the study area, it is difficult to come up with specific recommendations on these management aspects.

Conventional methods and procedures of field experimentation also need to be modified in AF research. The approach should be to strike a balance between the accepted norms and procedures of disciplinary research on the one hand and deriving the maximum information with limited resources in as short a time as possible on the other. Interpretation of research results will also be different from the conventional procedures in monocultural systems where one is dealing with a single commodity often with no regard to social factors. The value of the products and benefits from integrated AF systems, especially those involving fruit trees, cannot always be realistically assessed and explicitly expressed in quantitative terms, and this has to be taken note of while extrapolating such research results to other areas.

Integrated AF systems involving fruit trees as an approach to land use is eminently suitable to the small holder farming systems of the Asia Pacific region and other thickly populated areas of the world. In order to realize its potential fully and to make the practices and systems widely adoptable, concentrated efforts in research and development are needed at various levels. The present institutional arrangement of clear-cut demarcations among the mandates as well as activities of various land-use disciplines such as agriculture, forestry, and livestock production is an impediment to successful implementation of such integrated programs. But the potential is so bright that these problems that are not-so-insurmountable should not be allowed to hinder the ways to realize the benefits. AGROFORESTRY CANNOT WAIT.

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