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AGROFORESTRY IN THE CONTEXT OF LAND CLEARING AND DEVELOPMENT IN THE TROPICS

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1. INTRODUCTION

The background document for this Workshop has highlighted the importance and urgency of developing scientific approaches to address the critical issues of land clearing. While reviewing and evaluating the current status of methods of land clearing and formulating technological packages for improvements, which are among the specific objectives of the Workshop, it is relevant as well as essential to consider the benefits and potentials of agroforestry and other integrated land use systems.

Land clearing in the tropics whether legitimate (with governmental knowledge and approval) or otherwise, is done either for bringing the land under some pre-determined use other than the existing one or for exploiting the timber and other natural resources.

In government-approved land clearings for alternate land uses, it may be possible to adopt appropriate land management strategies to ensure adequate short-term productivity and longer-term sustainability, provided that the decision-makers and policy-planners are aware of the advantages of such modern approaches and are careful about implementing them. But in common practice, such a satisfactory situation does not exist mainly because of the lack of such modern knowledge. "Non-legitimate" land clearing accounts for a major proportion of the total land clearing taking place today, and the ever-increasing numbers of poor, landless farmers who are always in search of more and more areas to produce food crops,

form a large majority of such land clearers. (Although the illegal traders of timber and others who destroy forest for various products also add to the number of this category, strict enforcement of law rather than any scientific innovation in land-use is the appropriate way to tackle this menace). The defective ways of land clearing, often with disastrous ecological consequences, by the shifting cultivators and other land-hungry people is likely to continue if the people who are circumstantially compelled to do that have no viable alternatives and options to meet their basic demands of food (as well as wood/wood products).

There is also a third category of lands that is important in this context: the areas that are fast becoming unsuitable for sustained agricultural (or other) production. Vast areas of lands developed or managed by unsuitable methods have already been degraded (for example, those that are compacted by heavy machinery, made infertile and unproductive due to continuous use of heavy doses of agrochemicals, turned saline and alkaline consequent to irrigation, and so on). Furthermore, there are also substantial areas of wastelands which are not put under any sort of productive use.

The governments of these developing regions, confronted with mounting economic problems cannot often desist from commercially clearing the land for exploiting land/natural resources to raise money for essential development. They are also not able to effectively prevent the shifting cultivators and settlers from clearing the lands, nor arrest the causes of creation of more and more degraded and waste lands. It is therefore essential to popularize land-use systems in the tropics that would permit both forest land and "marginal lands" (rated unsuitable for profitable production), to be utilized

for the production of food and/or the rearing of animals, and at the same time ensure that the protective cover of forests is maintained and/or restored. Agroforestry is such an approach to land use that enables the land user to produce food and wood products simultaneously as well as conserve the land resources.

2. AGROFORESTRY

2.1. Definition and Concepts

In the recent history of the developments in tropical land use, agroforestry (AF) as a term as well as a concept is unique in terms of the rate, magnitude and extent of the enthusiasm it has generated among all sectors of tropical land use like agriculture, forestry, and animal production. It was not until the publication of the report of Bene *et al* (1977) that the term was coined in the international scene, and since then there has been a veritable explosion in interest and activities relating to agroforestry. Consequent to the increasing recognition of the role and value of trees and other woody perennials in the everyday life of rural communities, and in the wake of the mounting problems of food and fuel shortage, several other terms with forestry endings such as village forestry, farm forestry, social forestry, community forestry, and so on, also have appeared in common usage and in a general sense, most of them denote and are used synonymously for, one or the other form of integration of trees with components of other disciplines relevant to land use and rural development. However, agroforestry has now got established as a sort of generic term for a wide range of integrated land management approaches, systems and practices involving woody perennials to encompass, if not

eliminate, most of the other terms with 'forestry' endings. The word has become so firmly implanted that despite its alleged linguistic inadequacy (Stewart, 1981) and the likelihood of it being erroneously portrayed as a branch of forestry, it would now cause more confusion if another term to encompass the same concept were tried to be introduced and popularised. The concepts and principles of AF have been well elucidated in several publications from the International Council for Research in Agroforestry (ICRAF) as well as other organizations. However, in view of the newness of the topic, some of these aspects need to be recapitulated here even at the risk of repetition.

There has been a surge of enthusiasm in defining AF. Many definitions have been proposed (see Agroforestry Systems 1, 7-12, 1982); some have gone to the extent of exaggerated and presumptuous claims that AF by definition is a superior and more successful approach to land use than others. The definition that is adopted by ICRAF reads as follows:

> Agroforestry is a collective name for land-use systems and technologies where woody perennials (trees, shrubs, palms, bamboos, etc.) are deliberately used on the same land-management units as agricultural crops and/or animals, either on the same form of spatial arrangement or temporal sequence. In agroforestry systems there are both ecological and economical interactions between the different components (Lundgren and Raintree, 1983).

This definition implies that:

(i) agroforestry normally involves two or more species of plants (or plant and animals), at least one of which is a woody perennial;

(ii) an agroforestry system always has two or more outputs;

(iii) the cycle of an agroforestry system is always more than one year; and

(iv) even the most simple agroforestry system is more complex, ecologically (structurally and functionally) and economically, than a monocropping system.

From the point of view of this Workshop, the most important aspect of AF is that it is an interface between forestry and agriculture, offering a viable combination of production and sustainability (Nair, 1982; 1983a). Readers interested to know more about these concepts and principles may obtain additional literature on the topic from the Information/Documentation Services of ICRAF (P.O. Box 30677, Nairobi, Kenya).

2.2. Examples of Agroforestry

In order to increase the understanding about AF, an inventory of such systems and practices existing in different parts of the world, with special emphasis on developing countries, is currently (since 1982) being undertaken by ICRAF. The project aims at collating and synthesizing information on prominent and promising AF and other related land use systems with a view to preparing a state-of-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. Based on the information gathered thus far in the project, an "Agroforestry Systems overview" Table has recently been prepared (Nair, _forthcoming - a), which is presented as Table 1.

TABLE 1 HERE

It is an abstract Table, derived from detailed information gathered and stored at ICRAF. More detailed accounts of some of the prominent examples of such AF systems and practices are also available (for example, see the AF System Descriptions currently being serialised in the journal Agroforestry Systems). Thus, it is no exaggeration to state that AF is wide-spread in the developing countries in almost all ecological regions.

2.3. Types of Agroforestry Systems

An assessment of 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. In order to evaluate the existing systems and develop action plans for their improvement, it is necessary to classify these systems and thus provide a practical and realistic framework. Several criteria can be

used to classify and group AF systems. The most commonly used ones are the system's structure (composition and arrangement of components), its functions, its socio-economic scale and level of management, and its ecological spread, as given in Table 2 (Nair, 1985a).

TABLE 2 HERE

However, since there are only three basic sets of components that are managed by man in all AF systems, viz, woody perennials, herbaceous plants and animals, a logical first and simple step is to classify AF systems based on their component composition.

Thus there are three basic types of AF systems:

- agrisilvicultural (crops -- include tree/shrub crops -- and trees),
- silvopastoral (pasture/animals + trees), and
- agrosilvopastoral (crops + pasture/animals + trees).

Other specialised AF systems such as apiculture with trees, aquaculture in mangrove areas, multipurpose tree lots, and so on, can also be specified. Various subsystems and practices can also be identified under each of these major systems, as indicated in Table 3 (See Nair, 1985a for details).

TABLE 3 HERE

Arrangement of components in AF systems can be in time (temporal) or space (spatial) and several terms are used to denote the various arrangements. Functional basis refers to the main output and role of components, especially the woody ones. These can be productive functions (production of "basic needs") such as food, fodder, fuelwood, other products, etc.) and protective roles (soil conservation, soil fertility improvement, protection offered by windbreaks and shelterbelts, and so on). On an ecological basis, systems can be grouped for any defined agro-ecological zone such as lowland humid tropics, arid and semi-arid tropics, tropical highlands, and so on. These socio-economic scale of production and level of management of the system can be used as the criteria to designate systems as commercial, 'intermediate', or subsistence. Each of these criteria has merits and applicability in special situations, but they have limitations too so that any single classification will depend essentially upon the purpose for which it is intended.

AGROFORESTRY APPROACHES TO CLEARING LAND FOR SUSTAINABLE USE

There are several examples of application of AF principles and practices in the transition from non-cleared lands to managed land-use systems. Some of these are already being adopted widely for example while clearing land for forestry or plantation agriculture, there is a transitory phase of agroforestry resulting in concomitant or cyclic association of herbaceous crops and woody perennials (permanent crops). There are also quite a few agroforestry innovations, which though still mostly in experimental stage, seem to offer good potential for large-scale adoptability both in land clearing for development and in reclamation of degraded lands.

3.1. The Taungya System

Known by different names in different places (Nair, 1984a), taungya refers to a land management system consiting of simultaneous (concomitant) combinations of agricultural crops and forestry species during the early stages of forest plantation establishment. It is reported to have originated in Burma (King, 1968) primarily to promote afforestation on cleared land, and is now widespread throughout the tropics. Most of to-day's forest plantations in the tropics owe their origin to this system.

The taungya system can be considered as a step further in the process of transformation from shifting cultivation to agroforestry. Shifting cultivation is a sequential system of growing woody species and agricultural crops, whereas taungya consists of simultaneous combinations of the two components during the early stage of forest plantation establishment. Although wood production is the ultimate objective in the taungya system, the immediate motivation for practising it, as in shifting cultivation and other subsistence systems, is food production. From the point of view of soil management, both taungya and shifting cultivation systems have a similarity: agricultural crops are planted to make the best use of the improved soil fertility built up by the woody plant components. In shifting cultivation the length of the agricultural cycle can last only as long as the soil sustains reasonable crop yields: in taungya it is primarily dependent on the physical availability of space based on the planting patterns of trees. Taungya has been criticised, however, as a labour-exploitive system. It capitalizes on the poor

forest farmer's demand for food and his willingness to offer labour for plantation establishment free of charge in return for the right to raise the much-needed food crops during only a short span of time.

Reviewing the soil management and productivity aspects of taungya system, Nair (1984a) surmised that eroson hazards, rather than soil fertility posed greater problems of soil management in most taungya systems. The long-term effect of the practice on soil fertility will depend largely on the management practices adopted when clearing the area and re-establishing the second and subsequent rotations. The continuation of the traditional type of taungya system is increasingly becoming difficult primarily because of socio-political reasons; some improvements aimed at overcoming these problems are being tried (example: forest village scheme of Thailand: Boonkird et al., 1984). With modified management techniques such as regulated pruning/thinning regimes and readjustment of espacement of the tree component, the system can be improved biologically, and make a sound approach to managing land that is cleared for plantation establishment.

3.2. Plantation Agriculture

The commercial plantation crop production systems are economically viable enterprises and the soil management in such systems consists of practices that are fairly well established for individual crops based on extensive research. It is an established practice in commercial plantation crop systems, particularly rubber and oil palms, to cultivate fast-growing leguminous cover crops, the

recognized advantages being nitrogen fixation (Broughton, 1977) and soil conservation. Such sound practices are usually adopted carefully and systematically when land is cleared by governmental agencies for commercial establishment of such plantation (example: The Federal Land Development Authority of Malaysia).

In smallholder plantation crop systems, such conventional soil management practices such as cover-crops, soil conservation measures, etc. are not practised so systematically, nor do they appear to be as necessary as in commercial plantations. As pointed out by Nair (1979; 1983c; 1984a) the intimate association of plants in the smallholder integrated systems minimizes erosion hazards and precludes the possibility, and even the necessity, of cover crops. However, application of manures and fertilizers and other soil management packages are important if reasonable yields of the interplanted crops and the main (plantation) crop are to be ensured.

Another widely-practised agroforestry approach to the establishment of plantation crops in the context of land clearing is to grow shade tolerant crops such as coffee and cacao in partially cleared forests and under shade trees. While clearing the forest for establishing such crops, existing vegetation is cleared selectively either leaving tall-growing shade trees, or clearing in strips and planting the commercial crops to be followed up by progressive thinning and clearing as the commercial crops grow.

3.3. Improved Fallow in Shifting Cultivation

Shifting cultivation has often been denigrated as being wasteful and inefficient because of the relatively low crop yields and the potential decline of soil productivity in some areas occasioned by the shortening of the fallow period (FAO/SIDA, 1974). However, the fact remains that shifting cultivation continues to be the mainstay of traditional land-use systems over very large areas in many parts of the tropics. Moreover, the practice is likely to continue until viable and acceptable alternatives are evolved and adopted.

Alternatives to shifting cultivation have attracted the serious attention of land-use experts around the world for quite some time. Agroforestry has recently been suggested as an acceptable alternative (Nair and Fernandes, 1984; Nair, 1985b). The important phenomenon in shifting cultivation that makes AF quite relevant to the context is the restoration of soil fertility during the fallow period through biological processes associated with revegetating the area, especially with woody species. Some alternatives/ improvements to shifting cultivation incorporating this principle are being practised in various parts of the world, including the 'corridor system' in Zaire (Jurion and Henry, 1969) and improved cropping systems in India (Borthakur *et al.*, 1979) and elsewhere (FAO, 1984), the forest village scheme (which essentially is an adaptation of the taungya system) in Thailand (Boonkird *et al.*, 1985), and so on.

In recent years, efforts are being made to exploit the soil-enrichment attributes of the fast-growing woody

perennials, especially legumes and use them as a means of improving the effectiveness of the fallow period. Some past experience with various fallow vegetation species has shown that "artificial fallow" species were no better than the natural forest or bush fallow as far as nutrient immobilization or subsequent crop yields were concerned (Jaiyebo and Moore, 1964; Sanchez, 1976). However, there is now an increasing awareness of the potential role of leguminous woody perennials as efficient fallow species (Brewbaker *et al.*, 1983). As pointed out by Nair *et al.* (1984) the family Leguminosae offers by far the maximum range of choice of woody species for agroforestry in terms of their economic uses as well as ecological adaptability. Compared with other multipurpose woody perennials that are useful in AF, some legumes have the added advantage because of their capability for nitrogen fixation. It is worth pointing out here that legumes are not the only N-fixers (others include, for example, the genera *Alnus* and tropical *Casuarina*), and, moreover all legumes are not necessarily N-fixers; yet, there is a general tendency, albeit errouneously, to equate N-fixation with legumes. Some of the woody perennials (mostly leguminous) that are being used in various agroforestry systems and practices are listed in Table 4.

TABLE 4 HERE

The productive and protective potentials of these woody species can conveniently be exploited through their appropriate integration and judicious management in land-use systems that are being designated for freshly cleared or degraded lands.

The progression from traditional shifting cultivation to intensive agroforestry can be expected to take place gradually but at a steadily increasing labour intensity and landuse intensity factors. Initially, a taungya type of intercropping between rows of trees that are also periodically harvested for firewood will meet the farmers immediate needs for food and wood products. But with an increased population pressure, there will be a hedgerow intercropping cycle with "partial" or shortened rotations of fallow in subdivisions of the farms. Eventually, with still higher population pressure, permanent hedgerow intercropping and subsequently continuous multistorey combinations will follow. Thus the temporal association of crops and trees in sequential cycles (shifting cultivation) can ultimately be replaced by spatial associations and temporal arrangement of crops and trees in vertical dimensions (agroforestry) through a succession of acceptable management practices as indicated in Fig. 1 adapted from Raintree and Warner (1985).

FIG. 1 HERE

3.4. Multispecies Crop Mixes and Home Gardens

The multistorey, multispecies crop mixes around the homesteads form a typical land use system in most parts of thickly- populated regions, especially in Southeast and South Asia. Prominent among these include the homegardens of Java (Indonesia), the 'Kandy gardens' of Sri Lanka (Bavappa and Jacob, 1982), coconut-based systems of India and Sri Lanka (Nair, 1979; 1983c; Liyanage *et al*. 1984), compound farms of

West Africa (Okafor, 1981), the 'Chagga' homegardens of Mt. Kilimanjaro, Tanzania (Fernandes, et al., 1984) and the traditional crop combinations of Latin America (Wilken, 1977). The most well-known and studied system among these is the Javanese "home garden" on which several studies dealing with various aspects have been published (e.g. Anderson, 1980; Wiersum, 1981; 1982; Michon et al., 1983; Soemarwoto and Soemarwoto, 1984).

There are two major types of this system: the homegardens in which there is a home which is usually almost completely concealed by trees, and the multi-species mix of tree garden or compound garden (known as the "talun-kebun" system of Java) in which a house is usually not situated within the garden. Fig. 2 adapted from Soemarwoto and Soemarwoto (1984) describes the evolution of these two types of agroforestry systems in Java.

FIG. 2 HERE

Usually the homegarden has a multistoried canopy structure, composed of a large number of plants ranging from those creeping on the surface (e.g. sweet potato) to tall trees reaching 20 m or more (e.g. coconut palm), with about 2-3 intermediate layers consisting of shrubs like guava (*Psidium guajava*) and climbers (e.g. bitter melon - *Momordica charantia*). The structure and function of the homegardens occurring in various parts of the world are essentially similar. One notable difference is in respect of the

compound farms of Nigeria which are dominated by a large number of indigenous trees which provide food to the local people (Okafor, 1984). Dominant among them are African mango (*Irvingia gabonensis*), African pear, (*Dacroydes edulis*), African star apple (*Chrysophyllum albidum*) and African breadfruit (*Treculia africana*). Besides, the African oil palm (*Elaeis guineensis*) is also a dominant component of the Nigerian compound farms.

Although the different species of a homegarden would appear to be randomly placed, the villagers seem to know from experience where to place each plant to obtain the best results. Because of this multistorey structure and also because plant litter is not removed from most parts of the homegarden, the soil is well protected against erosion and an efficient recycling of nutrients exists within the system. A major share of the products from homegardens is used for home consumption, the harvesting of the products is staggered in such a way that labour- or marketing bottlenecks are seldom experienced.

The tree gardens of Java (*talun-kebun* in Indonesia) consist of a mixture of perennials and annuals, usually outside the village (Widagda *et al.*; 1984). Also known as the annual-perennial rotation, these systems are also dominated by one or a few woody perennial species such as bamboos (*Gigantochloa* spp), *Albizia falcataria* and *A. procera*, jackfruit (*Artocarpus heretophylla*), coconut palm, etc. Some of these tree gardens are of the 'permanent' type where the trees are densely planted with an understorey of shade-tolerant species such as arrowroot (*Canna edulis*), turmeric (*Curcuma longa*), taro (*Colocasia* sp. and *Xanthosoma* sp.). There are also some tree gardens that are sparsely planted, so that more light reaches the floor and food crops

like maize, cassava and sweet potato are also grown. In order to facilitate the cultivation of the annual crops, the tree stands are either thinned or their branches selectively pruned at the beginning of the rainy season. While shifting cultivation is a subsistence system only capable of supporting a low population density, the tree garden system is geared to market economy, yet dependent on family labour and therefore more cost effective.

The significance of the homegarden systems in the context of land clearing is that they represent an ecologically efficient and socio-culturally acceptable land management system. In many extensive, government-involved land clearing efforts such as the transmigration scheme of Kalimantan, each settler is given a piece of land, usually up to 2 ha in area, which, in course of time, will develop into a homegarden agroforestry system.

3.5. Use of Under-exploited, Multipurpose Trees (MPTs) in Land Use Systems

Since the 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. 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 (see Nair, 1984b; forthcoming -b).

Trees used outside forestry except a few ornamental 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 have earned a higher "ranking" and "status" necessitating a distinct identity and definition for this group of plants. The term multi-purpose 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.

MPT, like AF, also has so universally acceptable definition. Several definitions have been proposed (Burley and von Carlowitz, 1984).

Whatever the definition of MPT, the consensus of opinions is that the catch-word is "multipurpose". It is generally agreed that multiple uses of 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. 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 palms of

multiple uses and AF potential in different ecoregions. Similarly Nair (1984b) examined the role of several fruit and nut producing trees and shrubs (collectively called "fruit trees") in various AF Systems. He noted that this group of plants ranging from tall, long-duration perennials (e.g. the Brazil nut tree, Bertholletia excelsa) to relatively short, "non-woody" species, such as papaya (Carica papaya) can be found in association with other woody as well as herbaceous components in traditional AF systems in various parts of the world. Some of them are widely distributed in different geographical regions (e.g. mango, papaya) whereas some others are highly localized and found only in certain geographic regions (e.g. rambutan - Nephelium lappaceum - in Southeast Asia; pejibaye palm - Bactris gassipaes - in South America).

An interesting point to note here is that most of such MPTs found in traditional AF systems have little been 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. Efforts are now under way in different parts of the world to study and exploit the potentials of such lesser-known species. Okigbo (1977) and Okafor (1981) have described the significant role played by various plants that have so far been neglected in the traditional farming systems in the humid lowland tropics of West Africa. The US National Academy of Science publications on underexploited tropical plants (1975) and firewood crops (1980; 1983) and some other publications (e.g. Ritchie 1979) describe several other such

species that could be valuable in AF. Some of the 'non-traditional' genera have already received considerable research attention in the recent years - for example Leucaena (NAS 1977, Leucaena Newsletter) and Prosopis (Simpson, 1977; Felker et al., 1981; Mann and Saxena, 1980). Undoubtedly, there is a great scope to tap the hitherto unexploited potential of this large number of multipurpose trees and shrubs.

4. ROLE OF AGROFORESTRY IN RECLAMATION OF DEGRADED LANDS

The role of agroforestry in reclaiming the vast areas of degraded and otherwise wasted lands stems from the productive and protective attributes, primarily of the woody perennial components, of AF: productive functions make it possible to adopt sustainable land use systems in areas that are "fragile" and subject to rapid deterioration if "ordinary" land management systems are adopted, whereas the protective functions check the causes of land deterioration. It may, however, be pointed out that all AF systems have both these productive and protective roles, and it is only based on the relative dominance of either of these sets of attributes that a system is identified as predominantly productive or protective.

4.1. Productive Role

The productive role of the woody perennials in agroforestry systems includes production of food, fodder, firewood and various other products. One of the most promising technologies of this kind that is applicable in a wide range of situations is the hedgerow intercropping (alley cropping) in crop production fields. Promising results have been

obtained from this type of studies conducted at the International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria (Wilson and Kang, 1981), where the practice is called alley cropping. The most promising system based on those trials is *Leucaena leucocephala*/maize grain yield at a reasonable level even without nitrogen input on a low-fertility sandy Inceptisol, the nitrogen contribution by leucaena mulch on maize grain yield being equivalent to about 100 kg $ha/^{-1}$ for every 10 t ha^{-1} of fresh prunings (Kang *et al.*, 1981). The hedgerow intercropping system offers the advantage of incorporating a woody species with arable farming systems without impairing soil productivity and crop yields. The potential of nutrient (N) contribution by several candidate species of woody legumes mentioned in Table 4 suggests that a wide range of such species could be integrated into crop production systems (Nair *et al.*, 1984).

Integration of trees in crop production fields is an essential part of traditional farming systems in the dry regions also. Two typical examples are the extensive use of *Acacia albida* in the groundnut and millet production areas of sub-Saharan Africa (Felker, 1978) and the dominant role of *Prosopis cineraria* in the arid North-Western parts of India (Mann and Saxena, 1980).

The role of woody perennials on farmlands for producing fuelwood is another example of the productive role of agroforestry. The seriousness of the fuelwood situation has been well recognized all over the world, so that several initiatives and studies on this aspect are currently being undertaken. Several fast-growing firewood crops, most of them legumes, suitable for different environmental

conditions, have been identified (NAS, 1980; Nair, forthcoming -b); most of them combine well with conventional agricultural crops (Nair, 1980).

In the "animal agroforestry" systems, the woody components could be used either as a source of fodder to improve livestock productivity or to obtain another commodity such as fuel, fruit, or timber. Based on this "productivity objective", silvopastoral systems can be either browse grazing or forest/plantation grazing systems as reviewed by Torres (1983).

4.2. Protective Role

The protective role of agroforestry is dependent upon soil improving and soil conserving functions of the woody perennial components. There are variuos avenues through which the leguminous woody perennials could improve and enrich soil conditions; these include fixation of atmospheric nitrogen, addition of organic matter through litterfall and dead and decaying roots, modification of soil porosity and infiltration rates leading to reduced erodibility of soil and improving the efficiency of nutrient cycling within the soil- plant system (Nair, 1984a). However, the main protective function of woody perennials is in physical conservation of the soil.

The long tradition of planting *Leucaena leucocephala* in contour hedges for erosion control and soil improvement in Southeast Asia, especially Indonesia, is a typical example. Indirect terraces are also formed when the washed-off soil is collected behind the hedges. Loppings and prunings from such

hedgerow species could also provide mulch to aid in preventing sheet erosion between trees (Zeuner, 1981; Neumann, 1983). The presence of more plant cover on the soil, either alive or as mulch, also reduces the impact of raindrops on the soil and thus minimizes splash and sheet erosion. Therefore, as pointed out by Lundgren and Nair (1985), the potential role of agroforestry in soil conservation lies not only in woody perennials acting as a physical barrier against erosive forces, but also in providing mulch and/or fodder and fuelwood at the same time.

Other protective functions of woody perennials in agroforestry include their role as live fences, shelterbelts and windbreaks. Use of trees and other woody perennials to protect agricultural fields from trespassing or against the adverse effects of wind is a wide-spread practice in many agricultural systems. For example, a large number of multi-purpose woody perennials are being used as effective live fences at CATIE (Centro Agronomico Tropico de Investigacion ya Ensenanza), Turrialba, Costa Rica (Budowski, 1983). Similarly, very encouraging results on shelterbelts and windbreaks have been obtained at the Pakistan Forestry Research Institute, Peshawar (Sheikh and Chima, 1967; Sheikh and Khalique, 1982).

5. SOIL PRODUCTIVITY AND MANAGEMENT IN AGROFORESTRY

5.1. Soil Productivity

Using existing knowledge derived from land-use systems of relevance to AF, Nair (1984a) undertook an analysis of the likely effects of AF on soil productivity. This involved an

evaluation of soil productivity changes under shifting cultivation, taungya, plantation forestry, integrated systems involving plantation crops and multiple cropping, and an assessment of the role of trees in soil productivity and protection. The main points of interest in the context of land clearing and development that emerged from this analysis are the following:

5.1.1. The inclusion of compatible and desirable species of woody perennials in land-use systems that do not involve such species can result in a marked improvement in soil fertility. There are several possible mechanisms for this, which include:

- increase in the organic matter content of soil through addition of leaf litter and other plant parts;

- an efficient nutrient cycling within the system and consequently more efficient utilization of both native as well as applied (costly) nutrients;

- biological nitrogen fixation (where applicable) and solubilization of relatively unavailable nutrients, for example, phosphate through the activity of mycorrhizae and phosphate-solubilizing bacteria;

- increase in the plant cycling fraction of nutrients and resultant reduction in the loss of nutrients beyond the nutrient absorbing zone of soil;

- complementary interaction between the component species of the system, resulting in more efficient sharing of nutrients among the components;

- additional nutrient economy because of different nutrient absorbing zones of the root systems of the component species;

- moderating effect of soil organic matter on extreme soil reactions and consequent nutrient release/availability patterns.

5.1.2. The improvement in organic matter status of the soil can result in increased activity of the favourable micro-organisms in the root zone. In addition to the nutrient relations mentioned earlier, such micro-organisms may also produce growth-promoting substances through desirable interaction and cause commensalistic effect on the growth of plant species.

5.1.3. Inclusion of trees and woody perennials on farmlands markedly improves the physical conditions of soil in the long run: permeability, water-holding capacity, aggregate stability, and soil temperature regime are all improved, though slowly, so that the soil is made a better medium for plant growth.

5.1.4. The soil-conservating and erosion-reducing role of trees is one of the most widely acclaimed and compelling reasons for including trees on farming systems and farmlands that are prone to erosion hazards. Trees not only protect the farmland directly involved, but also impart stability to the ecosystem and reduce the rate of siltation of dams and reservoirs.

5.1.5. Trees influence hydrological characteristics from the micro-site level up to the farm and regional levels. Although the effect of water use by trees on water availability to crops plants in different climatic conditions is not yet clearly understood, there is evidence that the hydrological characteristics of catchment areas are favourably influenced by the presence of trees, and this is of considerable significance in watershed protection and management.

5.2. Soil Management

These advantages, assuming they are at least partially achieved, as well as other possible but unidentified advantages suggest that the incorporation of soil-improving and compatible woody species on farmlands can considerably retard the soil degradation and decline in productivity that are caused in some of the presently adopted arable farming practices. However, the entire discussion is still only conceptual, indeed speculative, and our understanding of soil conditions in agroforestry is much less than with agriculture and forestry. These conjectures and concepts have to be validated by research before the practice can be recommended with reasonably assured benefits.

Nevertheless, to circumvent the considerable time-lag in generating research data from well-conducted experiments, it seems justifiable to suggest some expedient measures, however *ad hoc* they might appear to be. Alley cropping is one example to show how technically feasible and socially acceptable farming systems involving trees can offer

sustainable production on fragile and easily degradable soils in the lowland humid tropics. Similarly, there is evidence of the soil-improving qualities of some multipurpose tree species, e.g. Acacia albida and Prosopis cineraria, in the dry regions, and their complementarity with the understorey agricultural species. This points out a possibility of using woody perennial species to create or improve soil management systems for other marginal areas and "wasted" lands in different ecological situations.

Some components of low-input soil management systems can therefore be suggested for agroforestry situations.

5.2.1. The Incorporation of trees and other woody perennials can be made on farmlands without significantly changing the conventional agricultural systems. Methods include alley planting, zonal system, and contour strips. Similarly, intercropping of agricultural species can be undertaken in tree stands in a number of ways especially during the early stages of plantation establishment. Several approaches have also been proposed to increase crop production in shifting cultivation systems without substantially changing the structure of such systems: the corridor system, shortening of the length of fallows, planted fallows, and other ways of improving the quality of fallows.

5.2.2. Land clearing/preparation methods are of crucial importance because certain mechanical operations can seriously damage the soil's physical properties and lead to compaction, degradation of soil structure, and erosion of top soil. Similarly, conventional land preparation methods, especially for agricultural species, can aggravate soil

erosion and impair soil physical conditions. The choice of land clearing/preparation methods depends on soil properties, species, and level of management. The efforts needed to control weeds decrease as the proportion of soil surface that is left unprotected by a plant canopy decreases as in agroforestry practices.

5.2.3. When relatively short duration agricultural species are continuously cultivated in sole stands or in combination with perennial species, the fertility status of the soil will change, necessitating frequent external input of nutrients as manures and fertilizers to compensate for the frequent "export" of nutrients from the soil through harvesting. However, in many areas, the cost or availability of fertilizers makes heavy fertilization uneconomical or impracticable. In this context it is important to exploit the soil enriching/restoring characteristics of the perennials to the fullest extent. Biological nitrogen fixation, efficient nutrient cycling, maintenance of higher organic matter status through litter fall and addition of dead biomass, complementary sharing of nutrients, and reduction of leaching loss of nutrients because of more root spread in soil profile are some of the phenomena that could be advantageously manipulated.

5.2.4. A combined stand of plants of different growth habits and phenotype can also be of considerable advantage in soil protection. The presence of more plant cover on the soil, either live or as mulch, reduces the impact of raindrops on the soil and thus minimizes splash and sheet erosion. Moreover, higher organic matter content and more root volume in the soil impart better physical conditions,

causing increased infiltration and decreased runoff. These advantages of species diversity of plants in soil production and protection are little understood and hence overlooked, but is extremely important especially during and immediately after land clearing.

Considering the vast areas and complex situations under which agroforestry could be a desirable land use system, it is inevitable that the soil management considerations outlined above have to be of a general nature. The specific management practices for a given set of conditions will depend upon soil conditions, climate, plant species, level of management and other local conditions. It would therefore appear worthwhile to aim at a soil quality categorization for grouping soils and soil conditions according to the problems they present, and suggest an agroforestry solution to the management of their physical and chemical properties. Thus the different categories could indicate the main soil-related constraints, and the ways of overcoming such constraints by agroforestry technology could be examined. When the necessary data become available, the system would be directly applicable to land evaluation exercises, and serve as a useful tool for analyzing soil constraints in relation to agroforestry.

6. CONCLUSIONS

There are several AF practices and systems of different kinds which function effectively in a wide range of tropical (and subtropical) environments. The range includes the humid (rain forest), subhumid (savanna) and the dry (arid and semi-arid lands) regions, all these in lowlands as well as highlands, and on soils ranging from sandy to clayey and strongly acidic to alkaline.

Although there is practically no area which may not have potential for some kind of AF (other than those where trees/crop/pasture cannot grow), advice on the applicability of AF is often called for with respect to 'marginal' areas and 'fragile' environments. These include areas that are experiencing soil erosion and soil fertility decline, moderately or steeply sloping lands, and those with a degradation of vegetation resources. It could well be that agroforestry functions excellently in these situations where other forms of land use are unlikely to be productive and at the same time sustainable. Moreover, the pressures of other competing land use options are such that bringing food production, or any form of agriculture for that matter, to forest land with the blessing of the forestry departments seems to be an uphill task. At the same time, forests are under severe pressure because of the search for more and more land to produce food. Therefore agroforestry systems that produce multiple outputs of food and wood products and at the same time offer a sustainable approach to the use of soil and other natural resources have an important role in the context of land clearing and development.

Agroforestry options for cleared lands are many. If land is cleared for bringing it under agricultural systems, it will be prudent to opt for agroforestry as a transitory phase between the uncleared land and cultivated, arable system, primarily to minimise the enormous magnitudes of soil loss and other degradation that are likely to occur during and immediately after such clearing. If land is cleared for forestry or other plantations either with or without the involvement of settlers, the agroforestry approach offers an attractive way of achieving food (or other agricultural) production without detriment to

the soil or the long-term productivity of the plantations that are being established. There are also agroforestry options for rehabilitating degraded lands that have become unproductive due to the adoption of defective land management practices.

There is a wide range of agroforestry technologies that can be adopted in each of these situations. A list of various such technologies -- both widely practised and experimental -- has been given earlier. Obviously the choice of technologies will depend on the specific situations. From the stand point of land clearing in humid lowland tropics, the best agroforestry options include:

- alley cropping with various woody species;
- use of fast-growing nitrogen-fixing woody perennials to improve the productivity of fallows in shifting cultivation;
- tree gardens, especially involving fruit and food trees;
- multistoried crop mixes;
- tree integration in agricultural lands;
- intercropping in tree stands;
- improvements to taungya
- integrated farming systems with plantation crops;
- use of multipurpose shade trees for commercial plantations crops;

- woody perennials as soil conservation hedges;

- shelterbelts and windbreaks;

- woody mulch and green manure woodlots;

- agroforestry fuelwood production.

It is strongly recommended that the proposed Soil Management Network (SMN) should undertake some of these technologies for experimentation in various ecoregions. Obviously, such experimentation should give specific attention to monitoring soil changes of soil fertility parameters and possibly also physical properties, under different technologies. The "minimum package" of observations in the Tropical Soil Biology and Fertility programme (Swift 1984) would form a suitable basis for monitoring. ICRAF has the capability and will be interested and willing to be associated with such activites.

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TABLE 1. SOME EXAMPLES OF TRADITIONAL AGROFORESTRY SYSTEMS AND PRACTICES IN THE DEVELOPING COUNTRIES (after NAIR, forthcoming)

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. gun gardens of the Sudan	Acacia barteri, Anthonotha macrophylla, Gliricidia sepium, etc. tried as "Fallow" species	Several forms
	The Taungya System	(e.g. Taro with Cordyline 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	Involving fruit trees	Dominated by fruit trees	In all ecological regions	The Dehesa system; "Parc arboré"			e.g. "Paraíso Mandioc" of Paraguay
	Hedgerow Intercropping (Alley Cropping)		Extensive use of Sesbania grandiflora, Leucaena leucocephala and Calliandra calothyrsus	Several experimental approaches e.g. Conservation Farming in Sri Lanka		The Gberian System of Zaire	Experimental systems on alley cropping with Leucaena and others	
	Multipurpose Tree and Shrubs on Farmlands	Mainly fruit or nut trees (e.g. Canarium, Pometia, Barringtonia, Pandanus, Artocarpus altilis)	Dominated by fruit trees; also Acacia mearnsii - cropping system, Indonesia	Several forms both in lowlands and highlands e.g. Mil farming in Nepal, "Bari" - based system in the dry parts of India	The Oasis system; Crop combinations with the Carob tree; The Dehesa system; Irrigated systems, Olive trees + cereals	Various forms; The Chagga system of Tanzanian highlands; The Nyabisindu system of Rwanda	Acacia albida-based food production systems in dry areas; Butyrospermum + Parkia systems; "Parc arboré"	Various forms in all ecological regions
	Crop Combination with Plantation Crops	Plant. crops and other multipurpose trees; e.g. Gnetum and coffee in the highlands of PNG; also Artocarpus and Leucaena with cacao	Plant. crops + fruit trees; smallholder systems of crop combinations with plantation crops, plantation crops with spice trees	Integrated production systems 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 systems in smallholdings; spice trees
	Af Fuelwood Production	Multipurpose fuelwood trees around settlements	Several examples in different ecological regions	Various forms		Various forms	Common in the dry regions	Several forms in the dry regions
	Shelterbelts, Windbreaks, Soil Conservation Hedges	Casuarina oligodon in the highlands as shelterbelts and soil improver	Terrace stabilization in steep slopes	Use of Casuarina spp. as shelterbelts; several windbreaks	Tree spices for erosion control	The Nyabisindu system of Rwanda	Various forms	Live fences, windbreaks especially in highlands
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		Sesbania, Calliandra, etc. used extensively	Leucaena, Inga spp., Syzigium 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. Gliricidia 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 animals)		Very common, Java Home Gardens often quoted as good examples	Common in all ecological regions	The Oasis system	Various forms (The Chagga homegardens; the Nyabisindu system)	Compound farms of humid lowlands	Very common in the thickly populated areas
OTHER SYSTEMS	Agro-Silvo-Fishery ("Aquasilvicultural")		Silvofishery in mangrove areas, trees on the bunds of fish-breeding ponds					
	Various forms of Shifting Cultivation	Common	e.g. Sesbania farming	Very common, various names		Very common	Very common in the lowlands	Very common in all ecological regions
	Apiculture with Trees	Common	Common		Common	Common	Common	

Table 2

MAJOR APPROACHES IN CLASSIFICATION OF AGROFORESTRY SYSTEMS AND PRACTICES (Nair, 1985 a)

CATEGORIZATION OF SYSTEMS (BASED ON THEIR STRUCTURE AND FUNCTION)			GROUPING OF SYSTEMS (ACCORDING TO THEIR SPREAD AND MANAGEMENT)	
STRUCTURE (Nature and arrangement of components, especially woody ones)		FUNCTION (Role and/or output of components, especially woody ones)	AGRO-ECOLOGICAL/ ENVIRONMENTAL ADAPTABILITY	SOCIO-ECONOMIC AND MANAGEMENT LEVEL
Nature of components	Arrangement of components			
Agrisilviculture (crops and trees incl. shrubs/trees and trees)	In space (Spatial)	Productive Function	Systems in/for	Based on level of technology input
Silvopastoral (pasture/animals and trees)	Mixed dense (e.g. Home garden)	Food	Lowland humid tropics	Low input (Marginal)
Agrosilvopastoral (crops, pasture/ animals, trees)	Mixed sparce (e.g.: Most Systems of trees in pastures)	Fodder	Highland humid tropics (above 1,200 m.a.s.l; e.g.:Andes, India, Malaysia)	Medium input
Others (multipurpose tree lots, apiculture with trees, aquaculture with trees, etc)	Strip (Width of strip to be more than one tree)	Fuelwood	Lowland subhumid tropics (e.g.: savanna zone of Africa, Cerrado of South America)	High input
	Boundary (trees on edges of plots/fields)	Other woods	Highland subhumid tropics (Tropical highlands) (e.g.: in Kenya, Ethiopia)	Based on cost benefit relations
	In time (Temporal)	Other products	Arid Lands (e.g.: North Africa -- the Sudno-Sahelian zone)	Commercial
	Coincident	Protective Function		Intermediate
	Concomitant	Windbreak		Subsistence
	Overlapping	Shelterbelt		
	Sequential (separate)	Soil conservation		
	Interpolated	Moisture conservation		
		Soil improvement		
		Shade (for crop, animal, and man)		

Table 3

COMMON AGROFORESTRY SUB-SYSTEMS AND PRACTICES INDICATING THE ARRANGEMENT OF COMPONENTS

Sub-systems /Practices	Arrangement of Components in space (s) and time (t)	Primary role of woody perennials
I. AGRISILVICULTURAL SYSTEMS		
Improved "Fallow" (in shifting cultivation areas).	Woody species planted and left to grow during the "fallow phase". t: seqential (time-dominant).	Soil productivity improvement; production of wood products.
Hedgerow intercropping (Alley cropping)	Woody species in hedges; agri. species in alleys between hedges. s:zonal (strip); t:concomitant	Protective (soil productivity).
Tree gardens and multistorey crop combinations	Multilayer, multispecies plant associations with no organized planting arrangement. s: mixed, dense; t: coincident.	Productive and protective.
Multipurpose trees and shrubs on farmlands.	Trees scattered haphazardly or according to some systematic patterns. s: mixed, sparse; t: interpolated	Production of various tree products.
Crop combinations with plantation crops:	i) integrated production of plantation crops and other crops in intimate plant associations; s: mixed, dense; t: interpolated.	Productive.
	ii) mixtures of plantation crops; s: mixed t: overlapping	Productive; protective
	iii) shade trees for commercial plantation crops s: mixed, sparse; t: coincident	Protective

Agroforestry for fuelwood production.	Interplanting firewood species on or around agricultural lands s: zonal (strip/boundary); t: coincident.	Productive.
Shelterbelts, windbreaks, soil conservation hedges.	Planting around agricultural fields as windbreaks and shelterbelts; planting along contours for terrace stabilization and soil conservation. s: zonal; t: coincident/interpolated	Productive and protective.
II. SILVOPASTORAL SYSTEMS		
'Protein banks'	Multipurpose fodder trees on or around farmlands (cut-and-carry system) s: zonal; t: coincident/interpolated	Productive.
Living fences	Hedges of fodder trees and shrubs along plot and field boundaries. s: zonal/boundary: t: coincident	Protective and productive.
Trees over pastures	Scattered shade trees over pastures s: mixed sparse; t: coincident/intermittent	Protective
III. AGROSILVOPASTORAL SYSTEMS		
Woody hedgerows for multiple functions	Hedgerows for browse, mulch, green manure, soil conservation, etc. s: mixed or zonal; t: coincident	Productive and protective

Table 4: SOME FIELD EXAMPLES OF THE USE OF MULTIPURPOSE WOODY PERENNIAL SPECIES IN TROPICAL AGROFORESTRY SYSTEMS (1)

SPECIES (2)	REGIONS/ COUNTRIES (1)	AF SYSTEM/PRACTICE (1)	OTHER MAJOR USES (4)
I. HUMID LOWLANDS			
Acacia auriculiformis	Asia-Pacific	AS: Fuelwood lot; trees on farmlands; wind break SP: cattle under trees	PW, Or, SC, Ta NF
Acacia mangium	South and SE Asia	AS: fuelwood lot; soil conservation hedges; reclamation of degraded lands	T, PW, NF,SB
Albizia falcataria	The Pacific and Southeast Asia; also India	AS: tree farms; intercropping ASP: home gardens	FW, PW, T, Ta
Bursera simaruba	Central and South America	AS: trees on farms; live fences; woodlot	T, Or, FW
Calliandra calothyrsus	Southeast Asia (also other regions)	AS: fuelwood lot; trees on farmlandS; fence SP: protein bank (fodder) ASP: woody hedgerows.	B, Or, SC, NF
Casuarina equisetifolia	Coastal areas all over the tropics	AS: shelterbelt; fuel-wood lot; soil conservation	T, PW, Ta, NF

Dalbergia sissoo	Indian sub-continent	SP: protein bank; pasture under trees	FW, T, Fd, SC, Or
Diphysa robinoides	S. America	AS: live fences; shelterbelts.	T, FW
Enterolobium cyclocarpum	A. America	SP: shade/browse tree in pastures	T, NF(?), FW
Gliricidia sepium	All over the tropics	AS: shade for commercial crops; live fences; shelterbelts SP: protein bank (fodder) ASP: hedges; home garden	GM, B, Or, NF FW
Inga edulis	American tropics	AS: shade for comm. crops ASP: home gardens	T, F, FW, B, NF(?)
Leucaena leucocephala	SE Asia; now common throughout the tropics	AS: alley cropping; soil improvement SP: protein bank (fodder, pods) ASP: multipurpose hedges	T, GM, SC, NF, FW
Mimosa scabrella	S. America and West Africa	AS: trees on farms, fuelwood lot	PW, FW, GM, NF
Parkia biglobosa	Central and West Africa	AS: tree gardens	T, Or, SC, F
Parkia Clappertoniana	West Africa	AS: tree gardens	T, Or, SC, FW
Pinus caribaea	Caribbean, Central and South America	SP: pasture under trees	PW, T, FW

Psidium guajava	S. America, India, the Pacific	AS: intercropping; woodlot; tree gardens ASP: home gardens	F, Ta, FW, T, DY
Rhizophora mucronata	Coastal areas	AS: fuelwood lot; shelterbelt, trees on farms	T, Sc, PW, Ta
Samanea saman	S. America, W. Africa	SP: Shade/browse tree in pastures ASP: homegardens	T. Or, FW
Sesbania bispinosa	South Asia	AS: trees on farms: fuelwood lot SP: protein bank (fodder) ASP: multipurpose hedges	G, PW, GM, Fi NF
Sesbania grandiflora	Southeast Asia	AS: live fences; shelter-belts; trees on farms SP: protein bank (fodder) ASP home gardens	F, SC, FW, PW,G GM, NF
Syzygium cuminii	South Asia; also in the American tropics	AS: trees on farms; tree gardens; windbreaks	T, F, FW, Ta, B
Tamarindus indica	South Asia; West Africa	AS: trees on farms; shade for comm. crops; fuelwood lot	F, T

II TROPICAL HIGHLANDS

Acacia decurrens	South and South -east Asia	AS:	fuelwood lot; soil conservation hedges; shelterbelts	T, Ta
Acacia mearnsii	Australia; S.Asia; Southern, Central & E. Africa; Amercian tropics	AS:	fuelwood lot; soil conservation hedges	Ta, GM,PW, NF
Albizia stipulata	S. Asia	SP:	protein bank (cut-and-carry)	T, Sc, NF(?)
Alnus acuminata	Central and South Amercia	AS:	fuelwood lot; soil improvement and watershed protection	T, NF
Alnus nepalensis	South Asia's hilly regions	AS:	fuelwood lot; soil conservation and fertility improvement	T, NF (?)
Casuarina oligodon	Papua New Guinea and other Pacific countries	AS:	shade for coffee and, other commercial crops; fuelwood lot;	T, NF
Erythrina abyssinica	Africa, S. Asia	AS: SP:	live fence; shelterbelts cut-and-carry fodder production	PW, NF, GM, FW
Erythrina poeppigiana	A. America	AS:	Shade for commercial crops	GM, NF, H, SC, FW
Gleditsia tricanthos	South America; also parts of Africa	AS: SP:	erosion control, hedges and live fences protein bank	T, F, Or, FW

Grevillea robusta	Australia; India; East and Central Africa	AS:	shade tree for commercial crops	T, Or, B, FW
		ASP:	home gardens	
Inga vera	American tropics	AS:	shade for commercial crops; fuelwood lot	T, B, F
Lespedeza bicolor	South-east Asia (sub-tropical)	AS:	shrubs on farmlands; fuelwood productions	T, PW, SC NF (?)
		SP:	protein bank (fodder)	
Melia azedarach	South Asia and the Middle East; also other parts of tropics	AS:	trees on farms; soil conservation	T, PC, Or, FW
Trema orientalis	South and South-east Asia	AS:	shade for commercial crops; fuelwood lot	SC, PW, T

III ARID AND SEMI-ARID REGIONS

Acacia albida	West Africa; all other parts of Africa	AS:	intercropping; fuelwood lot	T, F, NF
		SP:	protein bank (leaves and pods)	
		ASP:	home gardens	
Acacia nilotica	Indian sub-continent; Africa	AS:	intercropping; woodlot	T, G, B, Ta
		SP:	protein bank	
Acacia saligna	Australia; Middle East, S. America	AS:	fuelwood lot	SC, G
		SP:	protein bank (fodder)	
Acacia senegal	West and North Africa	AS:	fuelwood lot; erosion control	T, G, F, NF
		SP:	protein bank (leaves + pods); shade in pastures	
		ASP:	multipurpose hedges	
Acacia seyal	Sahelian zone of Africa	AS:	fuelwood lot; erosion control	T, F. NF(?)
		SP:	protein bank (leaves + pods);	
		ASP:	multipurpose hedges	
Acacia tortilis	Indian sub-continent, Africa	AF:	fuelwood lot; sand stabilization	T, SC
		SP:	protein bank;	

Adhatoda vasica	South Asia	AS:	trees on farms; fuelwood lot	M, GM, PC, H
Ailanthus excelsa	India	AS:	trees on farms, shelterbelts.	T, GM, FW
		SP:	protein bank (fodder)	
Albizzia lebbeck	Indian sub-continent; S. America	AS:	shade for comm. crops;	T, B, SC, NF, FW
		SP:	protein bank (fodder)	
Azadirachta Indica	Indian sub-continent; S. America	AS:	windbreak and shade; fuelwood lot; erosion control	T, O, PC, M
Balanites aegyptica	Africa	SP:	trees on pastures; protein bank (browsing)	H, T, F, M, PC, FW
Cajanus cajan	Asia and Africa	AS:	intercropping; soil improvement; erosion control; fences	F, NF
		ASP:	multipurpose hedges	
Cassia siamea	Asia and Africa	AS:	tree gardens; fuel-wood lot	T, SB, SC
		ASP:	home gardens	
Casuarina cunninghamiana	Australia, Africa, S, America	AS:	shelterbelts/wind breaks; fuelwood lot.	T, SC, NF

Cordeauxia edulis	Northeast Africa and the Middle East	AS:	trees on farmlands	F, SC, T, FW
Derris indica	India	AS: SP:	trees on farm protein bank (fodder)	T, PC, SC, Fi, Or, FW
Eucaluptus camaldulensis	Pan-tropical	AS:	shelterbelt; fuelwood lot	T, B, PW
Parkinsonia aculeata	S. America, Middle East, Africa, India	AS: SP:	live hedges; soil conservation protein bank (fodder)	Or, FW
Pithecellobium dulce	S, America, Pacific, India, Africa	AS: SP:	live fences/ shelterbelts; shade/browse on pastures	T, F, O, Or, B
Populus euphratica	Middle East. India, Africa	AS: SP:	live fences; fuelwood lot protein bank (fodder)	PW, T, SB, SC
Prosopis alba	South America	SP:	shade in pastures; protein bank (fodder)	FW, M, T, PW, NF
Prosopis chilensis	South America	SP:	shade/browse in pastures	FW, T, Or, NF

Prosopis cineraria	India sub-continent	AS: SP:	trees on farmlands fuelwood lot protein bank (fodder) shade/browse in pastures	SC, T, NF, FW
Prosopis juliflora	Central and South America, Africa, India	AS: SP:	fuelwood lot shade/browse in pastures	T, B, F, NF
Prosopis pallida	South America	AS: SP:	fuelwood lot protein bank (fodder + pods)	F, SC, NF
Prosopis tamarugo	South America	AS: SP:	fuelwood production shade/browse in pastures	T, NF
Tamarix aphylla	Middle East, North Africa, Mediterranean	AS: SP:	windbreak; erosion control shade over pastures	T, FW
Ziziphus mauritiana	South Asia, Tropical Americana West Africa	AS: SP:	live fence; trees on farmlands protein bank (fodder)	T, F, Ta, FW
Ziziphus spina-christi	West Africa; Mediterranean; Middle East	AS: AP:	live fence; erosion control protein bank (fodder)	T, H, FW

1) Based on the deailed, computerised data bases maintained at ICRAF on Multipurpose Trees (MPTs) and Agroforestry Systems, and adapted from Nair forthcoming -b)

2) See NAS (1980; 1983), and Nair et al. (1984) for details on the growth requirements and characteristics of the trees

3) AS: Agrisilviculture; SP: Silvopastoral: ASP: Agrosilvopastoral

4) B - Bee forage; Dy - Dye; F - Food; Fi - Fibre; FW - Fire Wood; G - Gum; GM - Green manure; H - Hedges; M - Medicine; NF - Nitrogen fixing; O - Oil; Or - Ornamental; PC - Pest control; PW - Pulpwood; SB - Shelterbelts; SC - Soil conservation; T - Timber; Ta - Tannin.

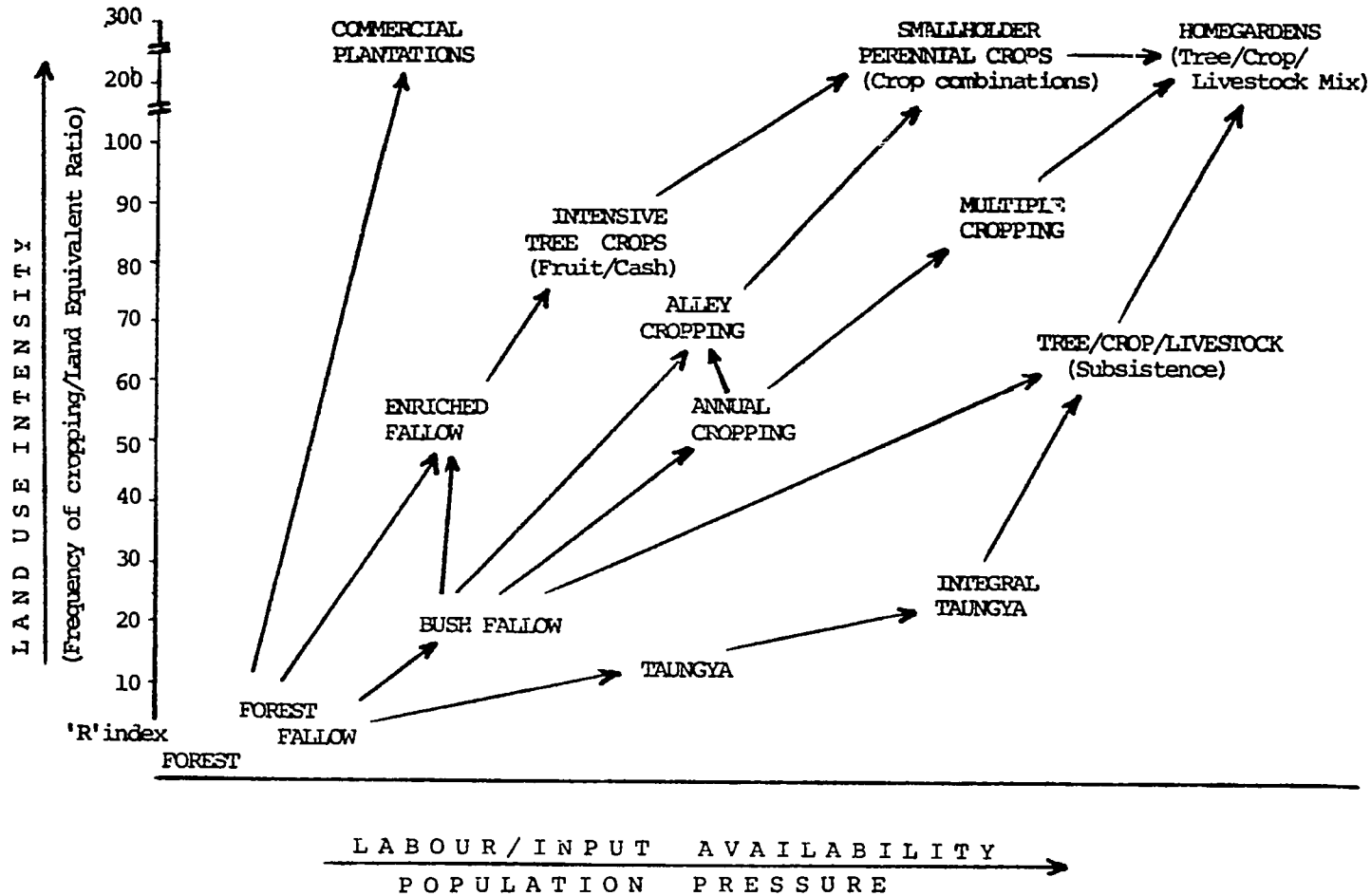

Fig. 1. Agroforestry approaches to agricultural intensification consequent to land clearing in the tropics especially in the humid and sub-humid zones (c f: Raintree and Warner, 1985)

The 'R' index refers to land use intensity in shifting cultivation (i.e. the length of cropping season expressed as a percentage of the total of cropping and fallow periods), and is equivalent to the frequency of cropping in multiple cropping. It can also be equated to land equivalent ratio (LER) in intensive multispecies crop mixes involving trees (Nair, 1979).

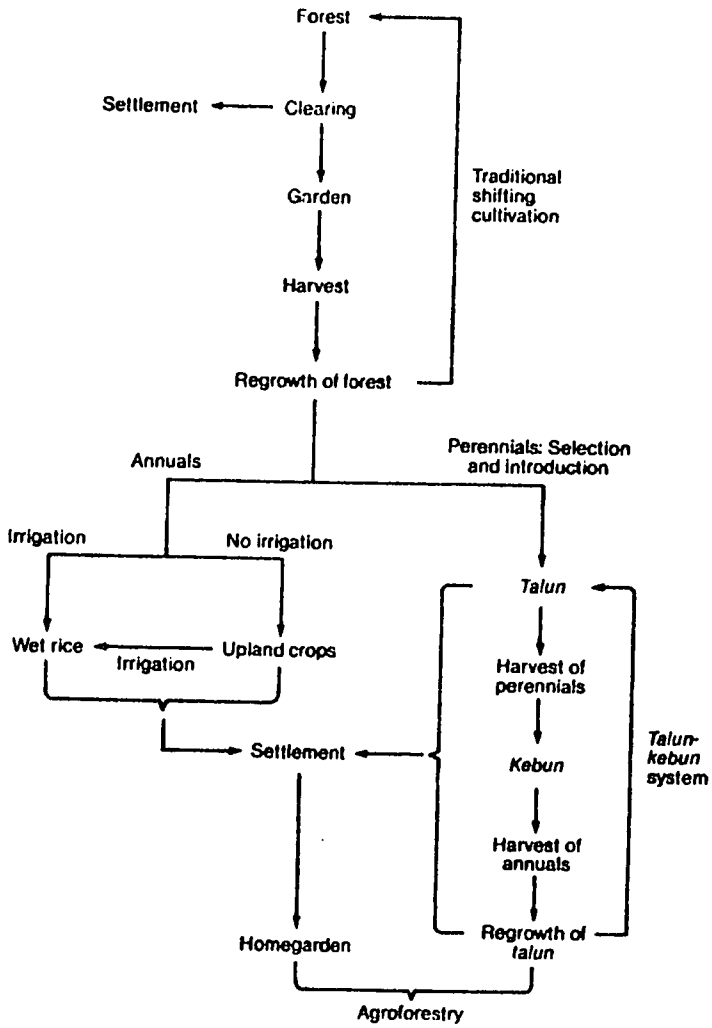

Fig. 2. The evolution of agroforestry systems in Java (Soemarwoto and Soemarwoto, 1984).

The homegardens are around houses whereas the Talun-kebun systems (perennial-annual rotation or tree gardens) are away from houses, usually outside the village.