Agroforestry for Sustainable Agricultural Systems and Environmental Conservation*

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Introduction

Millions of smallholders in the tropics are farming under rainfed conditions in diverse and risk prone environments. A wide range of different farming and land use systems have evolved, each adapted to local ecological conditions and culture. These practices include among other the cultivation of trees and agricultural crops in intimate combination with one another. Practiced for generations they have one thing in common, farmers have used elements of conservation farming to sustain the continuity of their subsistence farming efforts.These are dynamic systems that change with time and external pressures. Rapid changes in economic, technological and demographic conditions during the last few decades, have led or forced the small holder farmers to seek short-term profits from their crops more than to maintain the long-term gains of their traditional conservation farming practices. Increasing cropping intensity in no-input subsistence agriculture often leads to increased mining of soil fertility, soil degradation and low yields. To assist farmers in meeting these changing conditions, there is an urgent need for appropiate technologies that can enhance productivity and yet will not deplete the resource base upon which they depend. This can be done by combining conservation farming practices with judicious application of organic and inorganic inputs.

Results of a recent study on "Global Assessment of Soil Degradation", indicated a rapid decline in quality and productivity of land resources during the past half century as the world population doubled from 2.5 billion in 1950 to 5.3 billion in 1990 (Oldeman *et al.*, 1990a). This pressure will further increase in the future. World population is projected to increase to 8.5 billion in the year 2025, with the largest increased taking place in the developing countries in the tropics. It is estimated that over the past four decades, 750 million ha of soils in the world have been lightly degraded, 910 million ha have been moderately degraded, 330 million ha have been severly degraded and 9 million ha have been extremely degraded (Oldeman *et al*, 1990b). Of the total degraded land of 1.96 billion ha, Asia (747 million ha) and Africa (494 million ha) show the largest area of degraded land. Most soil degradation is attributed to water and wind erosion resulting from agricultural activities (28 %), overgrazing (34 %) and deforestation (29 %). Although soil degradation is associated with all of the major agroecosystems, in southeast Asia the sloping lands are geographically the most threatened (Garrity, 1993), because of the high

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population density and enchroachment of farming on marginal lands.. Although techniques are available to restore slightly degraded land using chemical inputs combined with conservation farming practices, it is better if it can be avoided at the onset. Of more concern is the amelioration of soils that are moderately, severely and extremely degraded. This will require costly investments to rehabilitate their productivity. Although it is well known that all farming endeavours entail some degree of soil degradation, the concept of sustainable agriculture seek to minimize the anthropogenic or human induced soil degradation.
This paper will first discuss how agroforestry systems provide a major contribution to the sustainability of agriculture in the tropics. Their role and limitations in protecting and improving soil resources will be emphasized. Next, we will discuss how smallholder farmers adopt and adapt agroforestry ystems to increase their livehood. We elucidate the variety of pathways available, and how particular systems are selected depending upon the household's circumstances and the land resources of the farm. This leads to a discusssion of current efforts to protect the fast -diminishing biodiversity resources of the tropics, and how agroforestry systems are uniquely suited for buffer zone management on the boundaries of protected forests land ecosystems. Finally, we review a major global effort to develop better ways to evolve sustainable agriculture and natural resource management (SANREM), and the role that agroforestry is playing in this effort.

Agroforestry and Sustainability

The deliberate growing of woody perennials with agricultural crops on the same unit of land in some form of spatial mixture or sequence have been practiced for many generations by traditional farmers in the tropics. The intricacy and purposes for establishing the systems vary tremendously, depending on ecological and socio-economic conditions (Nair, 1989). Farmers practice agroforestry to maximize exploitation of growth factors and limited nutrient supply to sustain modest levels of agricultural production, minized risk of crop failure, obtain multiple products and maintain soil fertility and minimize soil erosion. In most of these practices, farmers have incorporated woody perennials that have multipurpose functions or uses for nutrient recycling, weed suppression and as sources of timber, fodder, food and other auxilliary products for their own use or the market. Agroforestry thus involves old practices. The concept of agroforestry as a new science was introduced only in the sixties by King (1968). It was defined as " a collective name of land-use systems and tehnologies where woody perennials are deliberated used on the same land-management units as agricultural crops and/or animals, in some form of spatial arrangement or temporal sequence " (Lundgren and Raintree, 1982).

The current view of agroforestry has, however, led many people to see it merely as a set of distinct prescriptions for land use. Agroforestry is much more than this, and as such, it still often falls short of its ultimate potential as a way to mitigate deforestation and land depletion. When we see agroforestry as the increasing integration of trees in land-use systems we perceive the passage toward a more mature agro-ecosystem of increasing ecological integrity. Leakey (1996) has proposed that agroforestry be considered as a " dynamic, ecologically based natural resource management systems that, through the integration of trees in farm and range land, diversifies and sustains smallholder production for increased social, economic, and environmental benefits ". This definition is currently being refined by the International Centre for Research in Agroforestry (ICRAF) as a more holistic conceptualization of agroforestry. It evokes the process of integrating the variety of current agroforestry practices into productive and sustainable land-use systems. The land uses become progressively more complex, biodiverse, and ecologically and economically resilient.

The concept of agricultural sustainability has received much attenttion during the last few decades due to environmental concerns in relation to agricultural production. However, the scope of sustainability means different things to different people. Agricultural sustainability and productivity have been the main goal of various international agricultural research centres and development programmes . Since agricultural sustainability , is a dynamic concept, the Consultative Group on International Agricultural Research (CGIAR, 1990) has defind sustainable agriculture as: "The succesful management of resources for agriculture to satisfy changing human needs, while maintaining or enhancing the quality of the environment and conserving natural resources". A comprehensive definition proposed by the American Society of Agronomy (Anon., 1989) describes sustainable agriculture as one: " that over the long term enhances environmental quality and the resource base on which agriculture depends; provides for basic human food and fiber, is economically viable, and enhances the quality of life of farmers and society as a whole". In the simplest sense, sustainability is the ability of a production system to produce a stable yield of a desired crop(s) over a long period of time while minimizing soil degradation (Kang *et al.*, 1991). This restricted definition is useful, as it sets recognizable goal (stable yield of diverse high quality crop over a long term), and a boundary (e.g. production system) for examining the quality and maintenance of renewable and non-renewable resources and a measure of effects on externalities.

Contribution to Soil Conservation/Protection and the Environment

There is a widely held belief that agroforestry systems reduce erosion and water runoff. (Young, 1989). This is true for some agroforestry systems (Nair *et al.*, 1995). Multistory systems or home gardens that mimic forest conditions, do protect the soils because of their multilayer canopies and litter layer. However, other systems such as shifting cultivation can be detrimental with extended cropping and inadequate fallow periods. Frequent cycles of vegetation clearing, and repeated burning of plant litter can result in the degeneration of vegetation cover and increased exposure of the soil surface to erosion. There are several ways in which the presence of woody species in agroforestry systems can effect soil erosion.

1. Canopy cover is inadequate to fully control impact of raindrop on soil particles and subsequent soil erosion. Intercropping of woody species with crops can increase and give a multilayer canopy cover that is more effective for reducing the impact of erosive rainfall,

2. Presence of living and dead mulches from crop residues, tree litter and prunings, and perennial woody cover, is more effective in reducing raindrop impact and water runoff. This soil surface

cover approach contributes the most towards soil erosion protection in agroforestry systems,

3. The planting of hedgerows of leguminous trees along contours on sloping land for soil conservation have been practiced for some time in eastern Indonesia and the Philippines. The presence of woody hedgerows such as in an alley cropping system, can significantly reduce water runoff , soil erosion and nutrient loss (Paningbatan, 1990; Kang and Ghuman, 1991). The effectiviness of the barrier effect of hedgerows and other agroforestry practices in soil erosion control was also confirmed by the results of recent investigations conducted at various locations on sloping lands in Asia and southeast Asia by the International Board for

Table 1. Cumulative soil loss (1990-1993) as affected by different soil conservation practices (Sajjapongse and Meyers, 1995).

Site	Slope (%)	Treatments	Soil loss (t/ha)
China	30-46	Farmers' practice	237.2
		Alley cropping	77.4
Indonesia	8-18	Farmers' practice	536.7
		Alley cropping	81.7
Malaysia	10-15	Farmers' practice	61.5
		Rubber/corn/peanut	72.2
		Rubber/pineapple	91.5
		Rubber/corn/peanut/ Pineappple	21.5
Philippines (Mabini)	15-25	Farmers' practice	230.8
		Alley cropping (low input)	2.2
		Alley cropping (high input)	1.1
		Banana hedgerow (High input)	2.1
Thailand Chiang Rai)	20-50	Famers' practice	496.6
		Alley cropping	149.9
		Hillside ditches	31.2
Vietnam (Bavi)	5-7	Farmers' practice	8.0
		Alley cropping (low input)	3.7
		Alley cropping (high input)	3.7

Soil Research and Management (IBSRAM) (Table 1). The cumulative soil losses vary considerably due to site differences in slope, rainfall and soil type. Despite the variation, soil losses are reduced with agroforestry and conservation farming practices, in some cases dramatically. The highest soil losses were observed in Indonesia and Thailand, with cumulative losses over 4 years period exceeding 500 t/ha with farmers' practices. Soil losses were low in the Philippines and Vietnam when alley cropping was practiced. The effectiveness of barrier hedges in alley croping for reducing soil erosion and water runoff on sloping land can be attributed to the following factors:

(a) a physical barrier effect. This depends on the hedgerow species and intra-row plant density. The denser hedgerows of *Leucaena leucocephala* for example, provides a better barrier effect than that of *Gliricidia sepium,* and

(b) the presence of high amount of plant litter combine with the shading effect beneath the hedgerows provides a favorable niche for the greater activity of soil fauna, such as earthworm (Hauser and Kang, 1993). The increased soil faunal activities results in better soil physical conditions, lower soil bulk density and increase soil porosity and water infiltration rate beneath the hedgerows. Kiepe (1995), attributed the barrier effect of hedgerows in water runoff and erosion control in an alley croping system, to the increase in water infiltration rate beneath the hedgerows, which is 3 - 8 higher than in the alleys. Depth of water infiltration was also observed to be higher beneath the hedgerows than in the alleys or in contol plot without hedgerows.

4. One of the most often cited advantage of contour planting woody or other vegetational hedgerows on sloping lands, is the creation of natural terraces through a soil deposition process. The use of vegetative barriers is also known as the most cost effective way for the creation of terraces. The rate of terrace formation depends on soil type, rainfall intensity and especially on the frequency and intensity of tillage in the alleys. Although terrace formation can greatly lessen soil erosion, it is however, not always good for the crops (Garrity, 1995) Particularly on shallow soils or soils with very acid subsoil layer. Upper alley scouring, and displacement of the soil to the lower part of the alley results in lower soil productivity in the uppert part of the alley. This problem can be avoided or alleviated by reduced frequency of tillage, combined with the greater application of organic matter, plant residues, and fertilizers on the upper part of the alley.

5. Crop production systems are known to be very leaky with regards to nutrient leaching from the system. Crops have a shallow rooting depth compared to forest systems. The presence of deep rooting trees and shrubs in an agroforestry system contribute to better nutrient cycling from deeper soil layers. The roots of the woody species can serve as a safety net, capturing and recycling back to the surface nutrients that have leached to deeper soil layers., They thereby reduce nutrient leaching losses and prevent water pollution.

6. Windbreaks and shelterbelts are important agroforestry practices for soil erosion control in areas where wind is a major cause of erosion. Windbreaks consisting of narrow strips of trees and shrubs planted in lines, or around fields and compounds have been traditionally used for crop and soil protection from wind in the semiarid tropics. These windbreaks may also provide a wide range of useful household and economic products such as timber, poles, fruit, fodder, fiber, gums and others.

7. Deforestation and vegetation burning in subsistence farming is blamed as one of the main factors that contributes to increase emission of CO_2 and global warming. One way of reducing this problem, is sequestration of the excess atmospheric CO_2 . Presence of woody species in agroforestry systems such as alley cropping can for example increase carbon absorption and storage per unit land area as compared to pure annual cropping system. Recent investigation by Kang (1994) showed that total amount of biomass production in alley cropping of *Leucaena* with food crops was about 21 t/ha/year as compare to only about 3.7 t/ha/year for the no tree crop production system. We are curently looking at different types of agroforestry systems which has large accumulations of biomass that can serve as "permanent" sinks of carbon. One of the most promising solutions to transforming slash-and burn systems , is the development of "complex agroforest". These are farmer-evolved forests that contain a mixture of tree species in multi-story systems. Agroforests and many types of home gardens often resemble natural secondary forest systems in structure and ecology. The trees provide food, fuel, and cash income. The agroforest accumulates and sequesters carbon. There are many examples of agroforests in the humid tropics. An outstanding example are the rubber agroforests of Indonesia that occupy over 2.5 million hectares. In these systems, rubber trees are the main component, but many others species of fruit and timber trees are combined with rubber, either intentionally or through natural regenaration. In Torquebiau's (1992) review of the sustainability indicators of tropical home gardens, he found many indirect sources of evidence that soil fertility levels were maintained over long periods, and that soil organic matter levels increase.

Contribution to Soil Fertility and Crop Production

The incorporation of trees and shrubs in an agroforestry system may increase utilization of limited amount of nutrients in the system. However, presence of trees or shrubs in the system may not always benefit the associated food crops. They might also compete for growth resources factors such as light, nutrients and water with the food crops. In a succesful agroforestry system the contribution of the woody species needs to be optimized and tree-crop competition minimized. This can be achieved in several ways.

1. Incorporation of suitable trees and shrubs in the production system. Deep rooting trees and shrubs can contribute in nutrient recycling and compete less with the shallow rooting crops. Use of legumes that can biologically fixed atmospheric nitrogen can contribute nitrogen to the production system. In an alley cropping system of food crops with *Leucaena* and *Gliricidia* on a high base status soil, the woody species can contribute about 40 kgN/ha to the maize crop in one season (Kang et al., 1990). One factor that may effect N fixation is phosphorus, if the soil is low

in this nutrient it has to be added.

2. Planting the trees and shrubs in hedgerows allows separation of the woody species from the associated crops to provide more flexibility in managing the woody species to reduce competition with the crops. To reduce shading to the adjacent crops during the cropping period the hedgerows can be periodically pruned. Since, soil organic matter plays a vital role for maintaining the productivity of upland soils in the tropics. These prunings serve a as valuable source of mulch, green manure and soil organic matter. The contribution to soil organic matter varies with the quality and amount of pruning biomass added.

3. On poor and acid soils, trees and shrubs tend to have shallow roots and compete strongly with the crops for the limited amount of nutrients available. However, with use of suitable species and husbandry practices and the application of fertilizer and lime the woody species can increase the productivity and sustainability of the system .

4. In home gardens and multistory systems. Where the trees and associated crops occupy complementary nutrient uptake zones in the soil. In some areas farmers intensify the system by planting more revenue-producing fruit tree species, crops and undergrowth and compensate nutrient losses with the use of inputs. The perennial crop/shade-tree systems, especially of cacao and coffee and leguminous shade trees, are other good examples of potentially sustainable agroforestry systems (Nair et al., 1995). However, population pressure and increased product removal may make these system less sustainable in some areas of tropical Africa and Asia.

5. Sustainability of food crop agroforestry production systems are more problematic than systems with perennials and trees. In traditional agriculture in many areas of the tropics intensification of production enhance depletion of nutrient reserves, as the majority of farmers have no access to viable levels of inputs. During the 1970's the alley cropping system concept was promoted as an alternative low input system for the humid tropics. This technique based on intercropping of N_2 fixing woody legumes such as *Leucaena* and *Gliricidia* with food crops was shown to have high potential for sustaining maize production on high base status soils using low input (Kang et al., 1990). As shown in Figure 1, maize yield can be sustained at reasonable level with no N application and at higher level with low N appplication in alley cropping with *Leucaena leucocephala.* Alley cropping with non legume woody species such as *Dactyladenia barteri,* however, requires higher N application to sustain maize production. However, the system cannot recycle sufficient amount of phosphorus to meet crop growth needs and amount removed with crop harvest in a continuous production system. A low level of phosphorus application is needed for longterm sustainability. The alley cropping concept can be used in a no input system, but requires a period of fallow every so often. Although the concept can be applied to various agroecological zones, the technique has limitations for dry areas and acid and poor soils. Production packages need therefore to be adjusted to local site constraints and input requirements, and prevailing socio-economic needs and conditions.