Place for Alley Cropping in Sustainable Agriculture in the Humid Tropics

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Abstract

Successful integration of useful trees and perennials into food crop production system is a key to developing sustainable agriculture in the humid tropics. Alley cropping or interplanting multipurpose tree legumes with annual food crops provides an ecologically sound basis for new farming system development.

This paper reviews progress of alley cropping research and development and assesses its place in sustainable agriculture in the humid tropics.

On high-base status soils (i.e. Alfisols in West Africa and Andisols in Central America and Southeast Asia), alley cropping systems using tree legumes, such as Leucaena Leucocephala and Gliricidia sepium, have been shown to sustain crop yields and maintain soil fertility. The established leguminous trees provide nitrogen-rich green manure, recycle subsoil mineral nutrients, prevent soil erosion on sloping land and provide fodder to livestock and fuel wood to the farm household. Because subsoil infertility, the establishment of tree legumes in alley cropping on the strongly leached acidic soils (i.e. Ultisols and Oxisols in the high rainfall tropics) would require external inputs of phosphorus and prerequisite for effective recycling of nutrients in alley cropping systems on strongly leached acid soils. Successful dissemination of alley cropping technologies from research station to the farmer's fields, depends upon the land tenure system and public awareness of land degradation by the indigenous community.

Introduction

More than a decade ago, an experiment of interplanting *Leucaena Leucocephala*, a tree legume, with maize was established at the International Institute of Tropical Agriculture (IITA) in Nigeria with a major purpose of developing an alternative soil management system that retains certain features of shifting cultivation while allowing continuous cultivation. The subsequent publication of a technical bulletin on alley cropping (Kang et al 1984) has led to numerous studies dealing with a wider range of soil, crop and climatic conditions. As an agroforestry system, alley cropping has received increasing attention by researchers throughout the tropics. However, few efforts have been made so far to extend this technology to the farmer's field. This paper reviews the state-of-the-art of alley cropping research and extension and assesses its place in sustainable agriculture in the humid and subhumid tropics.

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The Alley Cropping System

Alley cropping is an agroforestry or soil management system in which fast-growing and deep-rooted leguminous or non-leguminous trees are interplanted with annual crops in an arrangement that minimizes competition for light, nutrients and water while sustaining crop yields and soil productivity. The first alley cropping experiment was established in 1976 on a sandy, high base-status Entisol (Apomu Series) at IITA in Nigeria with a major purpose of providing nitrogen from prunings of *Leucaena leucocephala* to the maize crop. The typical alley cropping system involves planting Leucaena hedgerows in alleys 2 or 4 meters apart. The hedgerows are allowed to establish for a period of two years before cropping. The hedgerows are then pruned at the beginning of the rainy season or before the food crop is planted. Leaves and twigs are returned to the soil as green manure for the food crop; the woody parts may be saved for fuelwood, or for staking of yams and beans in the home gardens. The hedgerows are further pruned during the cropping season to minimize shading and to provide additional green manure and mulch (Kang et al 1984). A schematic diagram of the alley cropping system is presented in Figure 1.

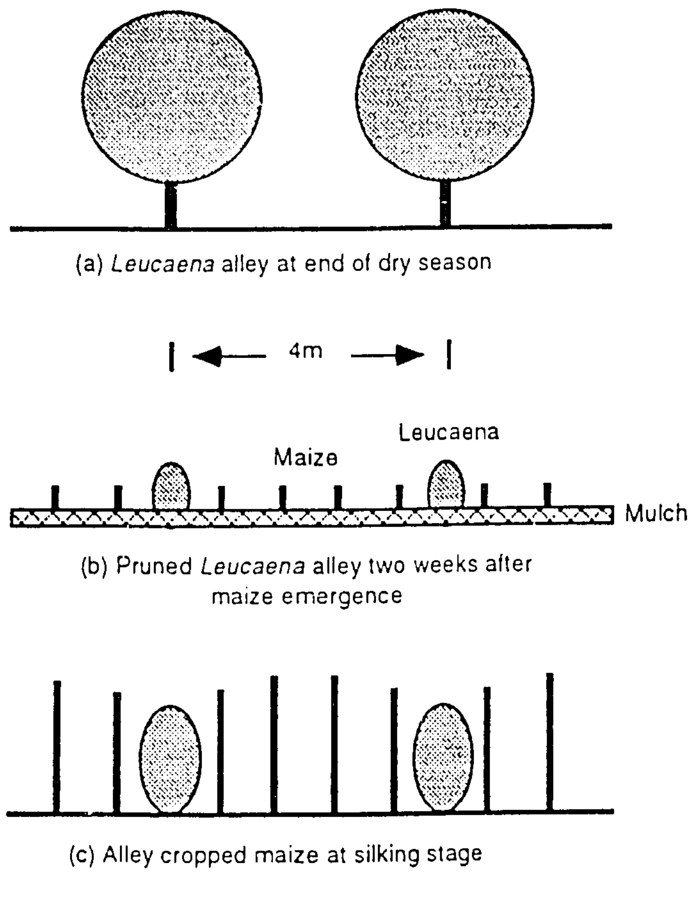

Figure 1. A schematic drawing showing three stages of *Leucaena*-maize alley cropping.

Alley cropping systems using *Leucaena leucocephala* and *Gliricidia sepium* system were subsequently evaluated in Nigeria for dry season fodder production on Alfisols (Atta-Krah et al 1985) and for erosion control on sloping land (Lal 1989; Kang and Ghuman 1991). As a soil management technology, the system retains the tree component of shifting cultivation while allowing continuous cropping with little or no external nutrient inputs. Moreover, the Leucaena (or Gliricidia)-maize-cowpea system has been developed for cultivation on Alfisols and other high base-status soils in the humid tropical regions where rainfall distribution allows planting two crops within a year. The three types of alley cropping developed on high base-satus soils at IITA and elsewhere may be summarized in Table 1. The choice of tree species, alley spacing and pruning frequency will depend on the goal set by the farm household.

Table 1. Goal and practice of alley cropping on small-holder farms on Alfisols and other well-drained high based-status soils in humid and subhumid tropics.

Goal	Practice
Crop production	Green manure is supplied annually by 2 to 4 prunings of trees with high N-fixing capacity, e.g. *Leucaena leucocephala.*
Crop production & fuelwood	Green manure is supplied by 2 to 4 prunings of trees during cropping season; one-year cropping followed by 1 or 2 years of fallow for wood production.
Crop production & fodder	Two woody species may be established in alternate rows in the same field; e.g. Leucaena to provide green manure and mulch to the annual crop and Gliricidia to provide fodder to livestock.

Note: On flat land, east-west hedgerows are recommended to minimize shading; on sloping land, hedgerows should be planted along contours at appropriate spacings to minimize runoff and erosion. Use 4 or 6-meter alley spacing on flat land and narrower spacing may be needed on sloping land.

A number of fast-growing tropical woody legume and non-legume species have subsequently been evaluated for their suitability to supply green manure and mulch for a variety of annual crops. The woody species tested include *Acacia auriculiformis, Alchornea cordifolia, Cajanus cajan, Dactyladenia barteri* (syn. *Acioa barteri), Calliandra calothyrsus, Senna siamea* (syn. *Cassia siamea), Senna spectabilis* (syn. *Cassia spectabilis), Erythrina poeppigiana, Flemingia macrophylla, Inga edulis, Gliricidia sepium, Gmelina arborea, Leucaena leucocephala, Paraserianthes falcataria* (syn. *Albizia falcataria).* Common food crops tested under alley cropping include cereals (maize, upland rice), grain legumes (cowpea, soybean, phaseolus beans), root crops (cassava, yam, cocoyam), plantain and vegetables.

On high base-status soils, two tree legume species, namely, *Leucaena leucocephala* and *Gliricidia sepium*, have proven to be the most suitable species for alley cropping. Both species can be easily established by direct seeding, can withstand repeated pruning, can continue to produce large amount of biomass and nutrients, and are long lived (Kang et al 1981; Kang et al 1991).

On strongly acidic Ultisols and Oxisols in the high rainfall tropics, growth and establishment of fast-growing tree legumes, such as Leucaena and Gliricidia, are often restricted due to low levels of P and Ca and high levels of soluble Al in the soil. However, some non-leguminous woody species, such as *Dactyldenia barteri* (syn. *Acioa barteri),* and acid-tolerant woody legumes, such as *Flemingia macrophylla* and *Calliandra calothyrsus*, have been tested for alley cropping with upland rice, maize, cassava and plantain on acidic, low base-status soils. These woody species can tolerate subsoil acidity and have desirable rooting patterns for alley cropping (Wilson and Swennen 1989; Juo and Kang 1989; Kang et al 1989; Evenson 1989; Ruhigwa et al 1992).

Fodder and fuelwood production are secondary goals in alley cropping. In the crop-fodder system, leaves of palatable tree legumes, such as Gliricidia and Leucaena, are harvested during the dry season to feed the livestock (cattle, goat and sheep) in the farm compound. It is essential to regulate the frequency of harvest to allow a rest period for the hedgerow to recover. Excessive fodder harvest during the dry season may severely reduce the amount of green manure production for the food crop. This may lead to rapid depletion of soil nutrient pool if manure is not returned to the soil. The use of leguminous trees to serve multiple purposes in alley cropping may be an attractive idea, but the long-term effects of nutrient removal by fodder and fuelwood on soil fertility and crop yield are little understood (Atta-Krah et al 1985; Lulandala and Hall 1989). Thus, as a sustainable soil management technology, the potential of alley cropping lies in the effective cycling of nutrients within the agroecosystem.

Published results indicate that alley cropping is best suited for food crop production on Alfisols and other high base status soils in the humid and subhumid tropics. It is not suited for semiarid tropics where soil moisture becomes a limiting factor for hedgerow establishment, or where the presence of hedgerow significantly affects soil water availability for the food crop. As a low-input system, it is also not suited for strongly acidic, low base status soils in the high rainfall tropics. On acidic soils, external inputs of lime, phosphorus and Rhizobium inculants would be needed for adequate growth and biomass production of the N-fixing trees.

Sustaining Crop Yield

As an alternative to shifting cultivation in the tropics, a major goal of alley cropping research is to achieve stability in crop yield while maintaining soil productivity. Four models of yield stability may be conceptualized (Figure 2). The models compare yield stability of alley cropping with no-till cereal-legume rotation, and continuous cereals monoculture at two levels of management, namely, chemical fertilizers plus no-tillage with residue mulch, and chemical fertilizers plus conventional tillage. Initially, yield level per ha under both monoculture systems would be greater than that of alley cropping. This is understandable because a significant portion of the field is occupied by the hedgerows. The initial soil fertility level is the same for all three systems assuming the field is newly cleared from forest fallow. The model further shows that crop yield under both monoculture systems would decline as a function of time due to certain changes in physical, chemical or biological properties of the soil resulting in a significant decline in soil productivity. On the other hand, crop yield is sustained under alley cropping assuming soil productivity is maintained.

These models were supported by the long-term field data obtained on kaolinitic Alfisol and Entisol at IITA in Nigeria (Juo and Lal 1977; Kang et al 1981; Kang and Juo 1986; Kang and Juo 1989). Maize yields under no-till monoculture with and without crop residue mulch declined significantly after 6 and 3 years of continuous cropping, respectively (Figure 3). The IITA experiments also demonstrated that on kaolinitic Alfisols, maize-cowpea rotation, maize grain yields could be sustained for longer periods of time than maize monoculture (Figure 4). Under alley cropping, maize yields of 2 to 3 t ha^{-1} could be sustained over a period of 10 years or more without fertilizer N application (Figure 5). However, for higher maize yields of 4 to 5 t ha^{-1} using improved maize cultivars, a top dressing of 45 to 60 kg ha^{-1} of fertilizer N would be required (Figure 5). As a nutrient cycling agent in alley cropping, Leucaena hedgerows growing on an Alfisol (pH 6) can produce a total of 7 t ha^{-1} of green manure (dry weight) annually from prunings which contain 250 kg N, 20 kg P, 185 kg K, 100 kg Ca and 15 kg Mg. In the IITA experiment, Leucaena prunings are applied as surface mulch, the low efficiency of N use may be attributed to the loss of mineralized N through leaching and volatilization. Hence, to sustain higher level of crop yield in alley cropping, further research is needed to improve crop N use efficiency and minimize N losses from prunings.

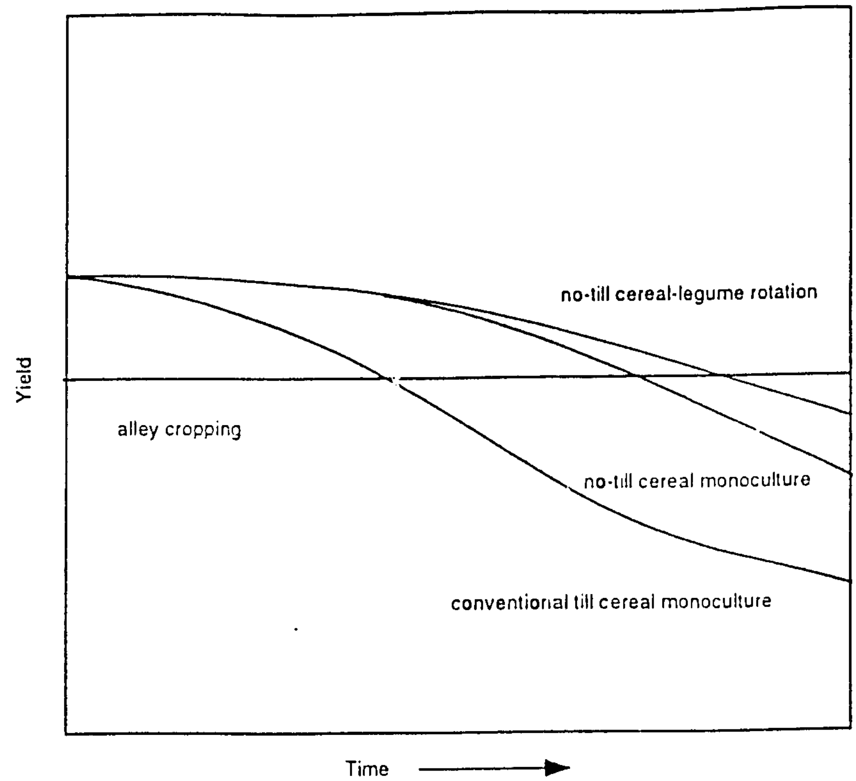

Figure 2. Conceptual models of crop yield as a function of time under three soil management systems: no-till with fertilizer application and crop residual mulch, conventional tillage with fertilizer application, and alley cropping.

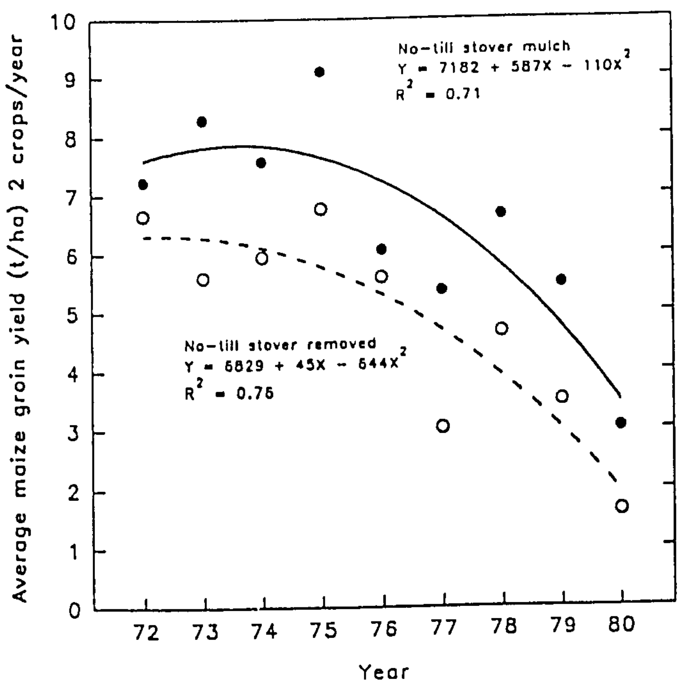

Figure 3. Long-term effect of no-tillage system on grain yield of maize (cv. TZB) under continuous maize monoculture with and without stover mulch on a kaolinitic Alfisol (Oxic Paleustalf) manually cleared from secondary forest at Ibadan, Nigeria.

(Kang and Juo 1986)

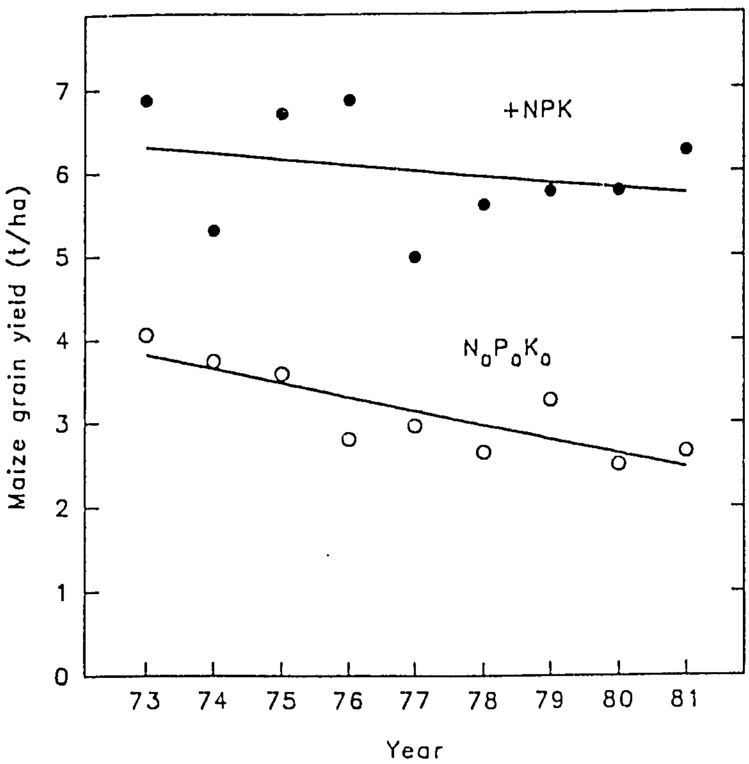

Figure 4. Maize yield on a kaolinitic Alfisol in rotation with cowpea and sweet potato with and without fertilizer application at Ibadan, Nigeria.

(Kang and Juo 1986)

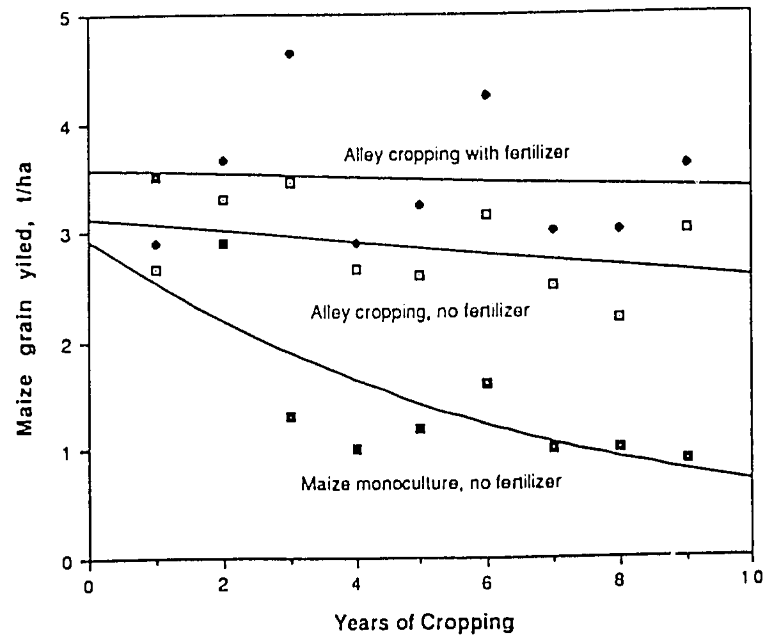

Figure 5. Main season maize yield from Leucaena alley cropping and monoculture on a kaolinitic Alfisol at Ibadan, Nigeria.

(B.T. Kang, Unpublished)

A number of alley cropping studies have been conducted in recent years to evaluate its yield potential in comparison with conventional soil management practices including the no-tillage system. Nevertheless, the results of these studies are varied. On the one hand, there is ample evidence indicating that alley cropping can sustain crop yields with low or no external nutrient inputs. On the other hand, published results have also suggested that alley cropping offers no advantage over conventional continuous cropping. However, a closer examination of the published results suggests that such discrepancies may be attributed to the following reasons: (i) the longest alley cropping trial was established less than 20 years ago, therefore, more experimental results are needed to validate the sustainability model as depicted in Figure 2; (ii) some experiments were established on eroded or degraded soils. This led to slow hedgerow establishment and consequently, low pruning yield. It may take several years to regenerate soil fertility to a level required for optimum crop yield. A good example can be found in comparing the results of the first six years as published by Lal (1989) and the seventh year results as reported by Kang and Ghuman (1991) from the same experiment established on a degraded Alfisol in Nigeria. During the first six years maize yields were lower and runoff and soil loss were higher in the hedgerow treatments than in the tilled control. But the trend was reversed during the seventh year and thereafter.

Maintenance of Soil Fertility

One measure of sustainability of alley cropping is its long-term effects on soil fertility. A distinct advantage of the alley system is that the legume hedgerows fix atmospheric N and supply green manure to the accompanying food crop through prunings during the growing season. It is hypothesized that the deep-rooted tree legume also serves the function of forest fallow by bringing mineral nutrients such as P, Ca, K, and Mg from the subsoil to the surface layer. These nutrients are then made available to the crop and the hedgerow through decomposition and mineralization of prunings. Evidently, such recycling process is more effective in nigh base status soils, (e. g. Alfisols) than in low base status soils (e. g. Ultisols and Oxisols). In many strongly acidic soils, a high degree of exchange Al saturation and low exchangeable Ca and Mg content in the subsoil may prevent normal root growth and penetration. Furthermore, the low C/N ratio of the legume green manure favors rapid decomposition and N loss through leaching. Thus, it is less effective than high C/N materials such as grasses and maize residue for soil organic matter accumulation and maintenance.

In terms of improving soil fertility through nutrient cycling and organic matter accumulation, the function of hedgerows in alley cropping also differs considerably from that of the trees and shrubs under forest fallow. The forest is a closed ecosystem in which fertility status of the surface soil is enriched by the forest litter with a wider range of C/N ratio which favors soil organic carbon accumulation in the surface soil during decomposition. Soil organic matter improves the cation exchange capacity and, consequently, increases exchangeable bases (i.e. Ca, Mg, and K) in the surface soil until a steady-state is reached (Nye and Greenland 1960). In alley cropping systems, the rapid decomposition of the legume prunings favors rapid recycling of nitrate and cations through leaching and plant uptake. Hence, the system cannot be considered as effective as the system of forest fallow in accumulating organic matter and cationic nutrients in the surface soil. In other words, the maintenance of soil fertility under alley cropping follows a dynamic model; whereas under the bush fallow system, the change in soil fertility status follows a equilibrium model. This is evidenced by the experimental results obtained by the researchers at IITA indicating that after several years of alley cropping on an Alfisol, significant decreases in pH and exchangeable K and Mg occurred in the surface soils from both fertilized and unfertilized treatments (Kang et al 1981; Yamoah et al 1986). Considering the low efficiency of N use from prunings, nitrate leaching could be a major factor contributing to the decline in soil pH and the loss of K and Mg from the surface soil under alley cropping. Unfortunately, little quantitative information is available at present regarding the processes and mechanisms of nutrient cycling under alley cropping and their long-term implications for soil fertility maintenance.

Control of Soil Erosion

In steepland farming systems, such as those practiced in many densely populated, mountainous countries in Asia and Latin America, a distinct advantage of alley cropping over continuous monoculture is the ability to better control of soil erosion. Alley cropping has been tested as a soil conservation practice on steepland farming systems. Research results obtained in Nigeria, Philippines, Peru and Costa Rica showed that runoff and soil loss were significantly reduced under alley cropping compared to traditional practice in which crops, such as maize, beans and upland rice, are planted on cleared and tilled slopes without soil conservation measures (Table 2).

Table 2. Effect of five or more years old alley cropping with various woody species on soil erosion (Source: Kang and Ghuman 1991; Paningbatan 1990; J.C. Alegre, personal communication; D.L. Kass, personal communication).

Soil/Parent material	Slope %	Treatment	Soil loss from one cropping season $t\ ha^{-1}$
Eroded Alfisol from gneiss	7	*Leucaena* alley-4m[1]	0.8
(Southwestern Nigeria)		*Leucaena* alley-2 m	0.2
		Tilled control	6.2
Alfisol from sediments	19	*Desmanthus* alley-6m	3
(Philippines)		Tilled control	127
Ultisol from sediments	16	*Inga* alley-4m	1
(Amazonian Peru)		Tilled control	54
Andisol	7	*Leucaena* alley -4m	nil
(Costa Rica)		Tilled control	nil

1. Alley spacing in meters.

The beneficial effects of alley cropping on runoff and soil erosion may be attributed to a combination of several factors: (i) the presence of prunings as mulch reduces the raindrop impact during heavy rainstorms, (ii) the contour tree barriers restrict downslope soil movement and reduce runoff, and (iii) the deep-rooted hedgerows and high soil faunal activity improve water infiltration.

Results in Table 2 also demonstrate the effect soil type and slope on erosion. Soils derived from quartz-rich and coarse-grained parent materials such as granites, gneisses and sandstones generally are more susceptible to water erosion than those derived from fine-textured, base-rich parent materials such as volcanic ash and mafic rocks. Soil derived from the latter group of parent materials usually have low bulk density and high permeability.

Technology Transfer and Adoption

Historically, few new agrotechnologies were readily adopted by farmers without governmental investment in infrastructure, extension, regulation and economic incentives. For example, the promotion of conservation tillage in the United States has been a costly effort involving government legislation and subsidies in spite of its obvious scientific merits. Farmers in the tropics are, perhaps, more resistant to change than their counterparts in the industrial nations, particularly when the basic food need of their own households is at risk.

In 1986, an international workshop on alley cropping research and extension jointly organized by the International Institute of Tropical Agriculture (IITA), International Livestock Center for Africa (ILCA), International Council for Research in Agroforestry (ICRAF), US International Agency for International Development (USAID) and Canadian International Development and Research Council (IDRC) was held in Nigeria. Among the many recommendations made by the participants, support for on-farm research and extension was specially emphasized. Subsequently, an international alley cropping network was established and funded to coordinate multilocation testing and evaluation in Africa (Kang and Reynolds 1989).

Economic incentive has always played a key role in new technology adoption. For example, in India, where land pressure is high, fuelwood and fodder are valuable, and fertilizer is subsidized, farmers have readily adopted alley cropping using Leucaena and other fast-growing woody species interplanted with food crops such as maize and blackgrams (Mittal and Singh 1989). Because of the high cash returns in fuelwood and fodder production, farmers are willing to sacrifice the extra yield of food crops from fertilized monoculture.

In humid and subhumid regions of Africa, the adoption of alley cropping is faced with several major obstacles: (i) the traditional land tenure system does not encourage tree planting on crop land; (ii) the lack of economic incentive to change; and (iii) the higher labor inputs needed for alley cropping as compared to the traditional 'slash and burn' system.

Land tenure can be a major obstacle to overcome in implementing alley cropping. For example, in forest regions of Africa, few farmers own the land which they farm. Most farmlands are either collectively owned by the farming community, by the government, or by absentee landlords. Under such circumstances, trees planted by the farmer are considered the property of the farmer. It is for this reason tree planting is often prohibited by the land owner. This is one of the reasons for the slow rate of adoption of alley cropping by farmers in Nigeria in spite of the many extension activities jointly organized by IITA and national agricultural institutions. Thus, the adoption of alley cropping in many densely populated areas of the humid tropics is as much a social issue as a technical problem.

It is also recognized that alley cropping is labor intensive. Initial tree establishment also requires some labor input for land preparation, planting and subsequent weeding. Farmers derive no economic benefits from the 2-year establishment phase. In a study on labor requirement during the cropping phase, Ngambeki (1985) reported that initial cutting and pruning of 4-m Leucaena alleys (approximately 15000 trees ha^{-1}) require 16 to 31 man-day per ha (assuming 6 hours of actual work per day). Each subsequent pruning requires about 7 hours per ha. As a food crop production system, the Leucaena alley cropping with two crops per year (i.e. maize in the main season followed by cowpea in the minor season at Ibadan, Nigeria), requires about 70 man-day per ha for the entire cropping season. This is about 25 to 37 percent higher than the total labor requirement for the monoculture control. Hence, without strong land pressure, government assistance, or an attractive short-term economic incentive (such as cash benefit from sale of grains, wood and fodder) it would be difficult to convince many subsistence farmers to adopt alley cropping on the basis of its scientific merits and long-term economic return.

As a soil conserving technology, the adoption of alley cropping to minimize soil erosion on steepland farming systems has produced promising results. In countries such as the Philippines, Nepal, Haiti and Honduras, food crop farming has extended to steep slopes as a result of increased land pressure. As there is little hope in the foreseeable future to return these steeplands to natural forests, national and international efforts have been made to implement soil conservation measures. Practices combining terracing, stone barriers, hedgerows or grass strips to minimize soil loss have been used. Plausible examples of such efforts are the Land Use Productivity Enhancement project (LUPE) in Honduras, and several agroforestry and farming systems project in Haiti.

In Honduras, to improve crop yields and to prevent siltation of stream and rivers, combinations of contour stone barriers, Leucaena/Gliricidia hedgerows and grass strips were established in farmer's fields on steep slopes (Thompson 1992). Fortunately, this capital intensive conservation program receives long-term support from national government and, in some cases, from international donor agencies. Moreover, the improved soil conservation and crop production systems are gaining acceptance and support by farmers and the local communities. In Haiti, international efforts of extending alley cropping and other agroforestry practices (Toussaint 1989; Rosseau et al 1993) have unfortunately been interrupted by recent political events in that country.

Conclusions

In terrns of adopting alley cropping as a sustainable soil management practice for food crop production in the tropics, the following conclusions may be drawn from a review of published results: (i) the system is superior to traditional 'slash and burn' agriculture as it allows continuous cropping while maintaining soil productivity; (ii) the system provides green manure and recycle subsoil nutrients with little or no need for external nutrient inputs; (iii) the system is suited for most upland crops including cereals, grain legumes, root crops and vegetables; (iv) among the several tree legumes tested on Alfisols, Leucaena is the most effective tree legume in terms of pruning and N yields; (v) the system is more suited for the high-base status soils (i.e. Andisols, Alfisols and associated Inceptisols and Entisols) than for the strongly acidic Ultisols and Oxisols; and (vi) the system is more suited for humid and subhumid tropical regions or at locations where soil moisture is not a limiting factor for hedgerow establishment and regrowth.

It should be pointed out that the primary purpose of alley cropping is to improve food production on small-holder farms in the humid tropics. A fundamental principle of agroforestry is to maintain biological diversity in order to avoid insect and disease outbreaks. Therefore, tendency to develop Leucaena alley cropping into a large-scale monoculture situation must be avoided. From ecological viewpoint, the long-term yield stability under alley cropping is influenced by both below and above ground factors including fertility status of the soil, the dynamics of insects and diseases in the alley system, and the below ground tree-crop interactions. Until alley cropping is studied as a whole agroecosystem by a multidisciplinary team of researchers, the question of sustainability will remain only partially answered based on limited information obtained by agronomists and soil scientists.

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Enclosed are two (2) copies two (2) technical publications from the Soil Management Collaborative Research Support Program, Project No. 9311311, under Grant No. DAN-1311-G-00-1049-00

Sincerely,

Roger G. Hanson
Director

RGH:sm

Enclosures