DYNAMICS OF FARMER ADOPTION, ADAPTATION, AND MANAGEMENT OF SOIL CONSERVATION HEDGEROWS IN HAITI

By

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DYNAMICS OF FARMER ADOPTION, ADAPTATION, AND MANAGEMENT OF SOIL CONSERVATION HEDGEROWS IN HAITI

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Understanding the conditions under which hillside farmers in Haiti adopt soil conservation practices helps programs to develop technologies that increase farmer revenue and stabilize or improve soil and water resources. Three studies were done in Haiti that examined biophysical and socioeconomic aspects of contour hedgerows, an agroforestry practice with the potential of stabilizing soil, conserving water for crops, increasing soil fertility, and producing wood and fodder.

An on-station study of soil water competition between *Leucaena leucocephala* (Lan.) de Wit hedgerows and adjacent maize (*Zea mays* L.) over three cropping cycles found that substantial maize yield reduction was caused by the hedgerow trees because of soil water competition. Polyethylene barriers between the hedges and the first row of maize improved maize yield in two subsequent seasons by 18% and 77% over plots without barriers. The percent increase in maize yield was highest during a season of very poor rainfall; but it was lowest in a season of adequate rainfall. Barrier installation

reduced *Leucaena* biomass production by about 1,500 kg/ha over seven months, but this effect was temporary. An examination of the distribution of *Leucaena* roots after the final maize harvest showed that the hedgerow roots in the plots with barriers had grown under the hedgerows and developed more fine roots at 200 cm from the hedges than plots without barriers.

An on-farm study comparing maize development in two kinds of hedgerows, rock wall terraces, and an untreated control was unable to detect differences in the rate of maize growth with respect to position within the alleys or with respect to position on the overall slope. However, the maize in the hedgerows developed more slowly than in the rock wall terraces or the control plot, indicating competitive interactions between maize and hedgerow plants. There were no differences in maize grain yield among treatments.

An on-farm questionnaire-based survey of 1,540 Haitian farmers showed that they considered plot characteristics, including mode of tenure, soil fertility, distance from the residence, and slope in their decisions to install different agroforestry practices. Tenure security and soil fertility appeared to be the most important plot characteristics in the decision to install, although it was not possible to separate them. Hedgerows were more likely to be installed in plots having less secure tenure and less fertile soil; the opposite was true for other agroforestry practices. Farmers' qualitative assessments of soil fertility were positively correlated with management quality of hedgerows.

CHAPTER 1
INTRODUCTION

The research presented here focuses on agroforestry technologies, which could contribute to increasing the revenue of small farms on the hillsides of Haiti in a sustainable, environmentally friendly way. This is a formidable goal, because Haiti is primarily a mountainous country long since shorn of its natural vegetative cover. Its once-rich soils are badly eroded, and their productive capacity severely diminished. Haiti is densely populated by very poor people who generally lack formal education or access to a functioning legal system. It has a long history of political instability that continues to this day. At best, agriculture is difficult in such a setting. But, Haitian farmers regularly experiment with new techniques.

This dissertation investigates the biological and adoption aspects of hedgerow intercropping, an agroforestry practice that involves growing food crops in the interspaces between rows of densely planted trees or shrubs. Two types of studies are included. One focuses on competition for growth resources between trees and crops while the other focuses on the factors that influence farmers' adoption of the technology. However, these different studies are linked together, because both social and biological aspects of agroforestry practices must be understood for providing efficient extension services to farmers.

The dissertation is presented in seven chapters. Chapter 1 briefly explains the background of the research and states its objectives. Chapter 2 describes Haitian

smallholder farms, the population of interest to the research. Following a definition of hedgerow intercropping, the agroforestry practice that is the subject of the research, Chapter 3 reviews its development in the tropics and in Haiti and examines how it is used as a soil conservation technique. Chapter 4 justifies the research, presents the hypotheses to be tested, and describes the studies used to test the hypotheses. The next chapter (Chapter 5) presents the two studies examining competition between hedgerows and adjacent crops. The first is done on station, the second on farm. The questionnaire-based survey of farmers who adopted soil conservation practices promoted by the PLUS project is the subject of Chapter 6. Finally, Chapter 7 synthesizes the previous chapters, and presents the overall conclusions of the dissertation.

The research was done while the author was employed by the Pan American Development Foundation (PADF) in Haiti. The PADF implements a U.S. Agency for International Development (USAID) project called Productive Land Use Systems (PLUS). The PADF/PLUS has worked with about 170,000 hillside farmers in soil conservation, tree planting and grafting, has improved food crop distribution and marketing, and has been strengthening local farmer organizations between 1992 and 1999. The on-farm study of maize (*Zea mays* L.) production between soil conservation structures discussed in Chapter 5 and the questionnaire-based study discussed in Chapter 6 were done as PLUS monitoring and evaluation exercises by PADF staff. The author designed the questionnaires and trained staff in their use.

The overall objective of this research is to understand how characteristics of Haitian farm families, their plots, and agroforestry practices affect the adoption and management of those practices. The purpose is not to use the data gathered in the course of this research to define and predict adopters so that nonadopters can be excluded from

extension efforts. It is rather an effort to understand how appropriate practices can evolve and be extended more rapidly.

In particular, the objectives of the three studies that comprise this dissertation are

- to determine, in the relatively controlled environment (for a research station), whether the competition for soil water between trees in hedgerows and adjacent maize is significant and can be reduced by the use of plastic root barriers,

- to understand whether tree-crop competition in farmers' steeply sloping fields is similar to that observed in the flat controlled environment of the research station, and

- to examine the factors (e.g., land tenure, perceived tree/crop competition, plot slope, soil fertility of the plot, distance from the residence to the plot, previous experience of the farmer, and the availability of other farm resources) that influence farmer adoption, adaptation, and management of hedgerow intercropping.

CHAPTER 2
HILLSIDE FARMING SYSTEM IN HAITI

Haiti is mainly hilly, with 20% of the land area below 185 m elevation and 40% above 450 m—about 75% highlands, 22% lowlands (Weil et al. 1973). The most common "life zones," according to Holdridge's (1945) classification, are subtropical moist forest and subtropical dry forest, but subtropical wet and rain forest zones are common in the middle and upper elevations. Limestone substrate underlies 80% of the land area; the rest is basaltic or alluvial (Ehrlich et al. 1985). According to Ehrlich et al. (1985) estimates, 1.3 million hectares (of 2.7 million total for the country) were under agricultural production; six times the area classified as "good agricultural land." The practice of annual agriculture on steeply sloping plots causes severe losses of arable soil due to erosion, estimated to be about 37 million tons annually in 1994 (UNDP, 1996).

Haitians have been practicing agriculture on small, privately held plots in the hills since the 1840s, as the large plantations and public domain lands were divided (de Young 1958, Leyburn 1941). Haitian peasants are not subsistence farmers in the strict sense that they do not live off the land self-sufficiently and independently, but rather produce for, and are linked closely to, the market (Murray 1981). Most farm families have some nonagricultural income and are net food buyers (Locher 1996). De Young (1958) describes the economic organization of Haitian farms as "horticultural" rather than agricultural, and gives the following characteristics that still hold true today:

- They are market directed, not subsistence directed.

- They give more importance to perennial rather than annual crops.
- The farm units are small parcels, and the land is used intensively.
- They are capital saving rather than labor saving. Farmers own only a few hand tools, have little invested in storage or farm buildings, and rarely use plows and animal traction.
- The farm animals are used mainly for transport to market.

Reducing risk is as important to most farmers as increasing production, and to this end they manage a network of ties to relatives and other farmers as social capital that can be leveraged in order to gain access to scarce land, labor, and capital (Smucker et al. 2000). Haitian families also spread out risk by diversifying human and economic resources via selective migration, emigration, and off-farm economic enterprises (Locher 1996). Therefore, not only is any one particular crop not the sole interest of a farm family, but agriculture is not the only domain of economic activity. It is quite likely that other activities, such as nonagricultural marketing or remittances from relatives overseas, bring in more cash.

Land

Haitian hillside farms are small and complex. Farm families usually manage or cultivate several parcels of land at any given time, held under a mix of land tenure arrangements (e.g., owned, tenancy, usufruct) (Bloch et al. 1987, Locher 1996) and often on sites differing in their physical characteristics (hillside, plain, irrigated, rainfed) and in distance from the residence. This is done as a purposeful strategy to reduce risk of harvest loss and to spread out crop harvest over the year (McLain and Stienbarger 1988, Murray 1981, Zuvekas 1979). Plot sizes are small and fallow periods are short. Plots are worked and then abandoned when yield decreases below the farmer's economical limits. Declining soil fertility, soil loss due to erosion, large variation in the timing of rainfall,

and the inability of traditional agricultural practices to harvest and store water in the soil limit agricultural production. Residences tend to be physically disbursed in the mountain regions instead of concentrated (Friedman 1955).

Two intertwining land tenure systems operate in Haiti, one official and the other customary (Smucker et al. 2000), created by disenfranchised peasants to protect themselves against loss of land via a corrupt justice system and government abuse. The land market is active. Most farmers own most of their land, but the majority of the transactions are done without recourse to expensive official processes (Smucker et al. 2000, Zuvekas 1979). The customary system provides farmers relatively secure access to land, but some tenure classes are more stable over time than others so mixed tenure configurations that change over time are the norm (Locher 1996). Zuvekas (1979) reviewed data from 12 studies done in Haiti and found that the percentage of farmers owning (by purchase or inheritance) at least part of their land ranged from 58 to 100%. Secondary modes of access to land include rental from private owners, lease, and sharecropping. Usufruct rights to land are also obtained from relatives or by acting as caretaker for an absentee landowner

Information about farm size is available from several studies related to agroforestry projects from various parts of the country (Lea 1994a, Lea 1996, Swanson et al. 1993a, 1993c, White 1992a). The total size of all farm plots ranges from less than one to about three hectares. The average farm family works two or three plots (Zuvekas 1979) that vary in size from about one half to just over one hectare each.

Haitian laws of inheritance have French antecedents and require that all siblings inherit; therefore, land holdings are, in general, getting smaller. In 1950, 39% of households held less than 1.3 hectares; by 1971 this proportion had increased to 71%

(Murray 1981). Brochet (1993) compared the average size of home gardens in one area of Haiti over fifty years, and found that the average holding that was one hectare per family in 1910 had decreased to 500 m^2 (0.05 ha) by 1970. This study was done in an area mined for bauxite by Reynolds Aluminum, so sale of land to the mining company may have accelerated the rate of decrease, but in general average sizes of holdings grow smaller as the population increases. One strategy adopted by Haitian families to ensure that a plot is large enough to harvest a crop worth planting is to bequeath land to children undivided, but this may discourage investing in improvements to the plot if the siblings are contentious. Older farmers are likely to own a larger proportion of their holdings (Lundahl 1997, McLain and Stienbarger 1988).

Other types of land tenure found in Haiti include purchased, inherited but separated, rented from private owners, and rented from the state. Usufruct rights to land also are obtained by sharecropping (on land owned by the sharecropper as well as on land owned by another) and by acting as caretaker for an absentee landowner. A recent survey of 5000 fields across the country (USAID, 1996) showed the following pattern of land tenure: purchased 39%, inherited/divided 20%, inherited/undivided 14%, rented 12%, share cropped 5%, gift 1%, and other 9%.

Crops

Since small and scattered plots must provide food, fuel, building material, animal fodder, and other household necessities, agroforestry has traditionally been practiced. The farm plots, except the plot containing the residence and surrounding tree and medicinal crops (sometimes called the home garden), are spatially dominated by cereal grains and grain legumes (pulses), but income from roots, tubers, tree crops, and animals is probably more important economically, and is able to shield farmers against variations

in rainfall better than grains and pulses. Home gardens include many tree crops such as mango (*mangifera indica* L.), breadfruit (*Artocarpus altilis* [Parkinson] Fosberg), citrus (*Citrus* spp.), royal palm (*Roystonia borinquena*), and coconut (*Cocos nucifera* L.). Timber and fuelwood trees are planted or tended where they sprout around property perimeters, scattered throughout plots, or as small woodlots. Trees are considered to be a crop, and are managed as a savings account, to be harvested when cash or building materials are needed (Murray 1981, Smucker and Timyan 1995). Fuelwood and animal fodder are in short supply in many parts of the country.

Many different combinations of crops are grown. These vary with the season, land tenure, distance from the residence, market demand, availability of seed, and the rainfall and soil characteristics. The most common grain crops are maize (*Zea mays* L.) and sorghum (*Sorghum bicolor* (L.) Moench) on the hillsides, and rice (*Oryza sativa* L.) in the few irrigated plains. Pulses include beans (*Phaseolus vulgaris* L.), pigeon pea (*Cajanus cajan* (L.) Millsp.), and peanuts (*Arachis hypogaea* L.). It is common for the spring maize crop to fail, because of poor rainfall. Beans are able to generate important income for farmers, but also fail often--rain is insufficient, or rain falls during flowering (eliminating pod formation), or rain falls before seeds are dry causing them to germinate in the pods. Root and tuber crops include yams (*Diascora* spp.), cassava (*Manihot esculenta* Crantz), and cocoyam (*Xanthosoma sagittifolium* (L.) Schott). Plantains (*Musa* spp.) are commonly grown in ravines and near the home. Living fences surround the property where the house is located, and are commonly built of plants serving protective functions due to the presence of spines or poisonous sap, such as bayonette (*Yucca aloifolia* L.), pencilbrush (*Euphorbia tirucalli* L.), raquette (*Euphorbia lactea* Haw.), and penguin (*Bromelia pinguin*) (Ashley 1986).

A 1996 USAID survey of 6,900 fields during a single spring planting season (USAID, 1996) found that 27% of the plots had crops growing in association (two or more crops present simultaneously in the same field for part or all of the cropping cycle), and 21% in monoculture. There were 16 main maize associations and 98 minor (<5000 ha. each) ones. In addition, there were 12 important associations of other crops, 134 minor ones, and 14 main kinds of monocrops. This does not include the many different kinds of tree and medicinal crops, crops found during the fall growing season, or animals. The most commonly seen grain crop in the fall season is sorghum, usually intercropped with pigeon pea. The USAID study notes only the physical presence of the crops, not their relative economic importance.

Labor

Households function as separate economic units, but the members participate in labor and food exchanges with other farmers (Murray 1981, Smucker and Dathis 1998). The family itself provides the labor for most agricultural activities. This labor pool is expanded periodically according to seasonal demands for land clearing, working the soil, planting, weeding, and harvesting crops. Labor is a scarce resource, and has been more difficult to supply and afford as the deteriorating social and economic situation in Haiti has forced many rural inhabitants into political refuge or into taking jobs in the neighboring Dominican Republic (Balzano 1997, Smucker and Dathis 1998). Farmers form groups to exchange farm labor, earn cash, or to save money to attain a future goal. However, this communal pooling is restricted to labor, not to the sharing of land or produce (Murray 1991). Access to labor is crucial because working steep slopes is labor intensive, and frequently must be done on short notice because rainfall varies so much over short distances in the mountains. Crops must be planted as soon as the first rains

arrive. Farmers without access to labor at the right time will suffer. Work groups generally consist of 3 to 15 members from the same socioeconomic level, and can be permanent or formed for a single task (Murray 1991, Smucker and Dathis 1998, Swanson et al. 1993a, 1993b 1993d, 1993e). The names given to labor groups differ from place to place within Haiti, and even from farmer to farmer (Smucker and Thomson 1999). The two main kinds of groups are those that are for labor exchange only and those that are formed to work for cash. Client farmers paying cash for labor are generally not group members, and are better off economically. A wealthy farmer may join a labor exchange group just for the purpose of gaining access to the labor. Another kind of work party is called the *koumbit*, where the host farmer provides one or two meals and sometimes alcohol to other farmers invited to clear or prepare a field (Swanson et al. 1993a). It is not possible to control the number of participants, the length of time they stay, or the quality of the work done, and for this reason the koumbit is becoming rare (Swanson et al. 1993e). Finally, individual farmers also are engaged by others to do specific tasks. This is referred to as a *djob* (job).

Typically, men form labor exchange groups for agriculture while women form mutual credit supply groups that permit them to engage in commerce. Women have always participated in some aspects of agricultural labor, and this appears to be on the rise because of the out-migration of men during times of political and economic troubles mentioned above (Smucker and Dathis 1998).

Farmer Development Groups and Local NGOs

Indigenous development groups are of interest because, since the early 1980s, most donor-financed development work, including agroforestry extension, has been done through them. This happened because of the difficulty in controlling the use of funds

disbursed through the Haitian government, which has always been a predatory structure serving the interests of the urban elite to the exclusion of the rural majority (Smucker and Thomson 1999).

Smucker and Dathis (1998) give a comprehensive description of these groups, on which the rest of this section is based. These groups vary widely in origin and composition, ranging from community organizations, cooperatives, youth groups, women's groups, work exchange groups, traditional groups, and religious groups. Agricultural cooperatives began in the 1930s and expanded in number in the 1950s. The community council movement began in the 1950s and was politicized by the Duvalier regime in the 1970s. The Catholic Church created nonhierarchical farmer development groups beginning in the 1960s that became known as *groupement* and eventually stood in opposition to the community councils. After the fall of the Duvaliers in 1986 the numbers of groups based on the *groupement* model increased dramatically; but they were persecuted, and they went underground after the 1991 coup d'etat. All of the groups have economic survival objectives, but are not limited to that. They look for more control over the factors of production, including agricultural inputs, credit, grain storage, more control over export crops, and investment in soil conservation and trees. They are now experiencing growing pains as their membership increases and they take on more objectives, without the legal recognition that would permit them to defend their interests and open bank accounts. These difficulties increase as their growth pushes them to depart from the basic characteristics of the traditional local groups, which are direct participation, small size with common interests, hope of tangible profits, direct investment of members' resources, and links of reciprocity and rotation. Farmers would be better able to invest in necessary agroforestry practices if these groups were stronger.

For example, a group with juridical personality, basic accounting skills, and a bank account would be more likely to succeed in negotiating crop sales to large buyers. Profits from sales would allow them to buy labor to protect the plots that produce the crops being sold.

CHAPTER 3
THE HEDGEROW INTERCROPPING SYSTEM

Developments in the Tropics

Definition

Hedgerow intercropping, also known as alley cropping and alley farming (Rao et al. 1998), has been suggested as an approach to address decreasing soil fertility and for controlling erosion (Kang et al. 1990). It is an agroforestry practice consisting of closely planted and regularly spaced rows of fast-growing, repeatedly pruned trees, usually N_2-fixing legumes, with short cycle agricultural crops cultivated in the alleys or spaces between the hedges (Kang et al. 1990). It is classified as a simultaneous (trees and crops present in the field at the same time) and zonal (trees are concentrated in the field rather than dispersed) agroforestry practice (Nair 1993). The hedges and crops are managed together for a common purpose, and there are significant above- and below-ground ecological interactions between them (Sinclair 1999). The most common objective of hedgerow intercropping is to increase crop production in the alleys by applying the pruned tops of the hedgerow trees to the soil as a green manure to improve soil fertility. This objective is pursued by attempting to balance the facilitative and competitive effects inherent in the practice (Vandermeer 1998). The more leaf biomass harvested from the trees, the more green manure available to improve soil conditions and thereby increase crop yield. However, more leaf biomass is obtained by increasing the number of hedgerows and this reduces the space available to crops. It also increases the area of

tree-crop interface (Ong and Leakey 1999) and therefore creates more possible competitive interactions (shading, soil water competition, nutrient competition) with the crops, potentially depressing yield (Vandermeer 1998). Hedgerows fulfill other purposes as well, including soil erosion control and production of fodder and fuel.

Origins

Hedgerow intercropping developed independently both in the western humid lowlands of Africa and in southeast Asia. In Nigeria, traditional farmers have for several generations planted and managed hedges of a shrub, *Dactyladenia barteri* (Hook f. ex Oliver), for the purposes of contributing nutrients to crops, controlling weeds, and production of fodder and stakes (Kang et al. 1984). Looking for a way to respond to soil impoverishment due to the shortening cycle of traditional slash and burn agriculture, researchers began investigating similar ways to use trees. The principles suggesting intercropping plants with complementary root systems occupying different soil regions (Weaver 1920) and the possibility of tree roots capturing nutrient resources out of the reach of crops (Nye and Greenland 1960) were familiar, but had not yet been applied systematically to agroforestry associations by nonfarmer researchers. The International Institute for Tropical Agriculture (IITA), based in Ibadan, Nigeria, began trying woody species to improve the fertility of low-activity clay soils. This led to the development of alley cropping (also referred to as hedgerow intercropping), avenue cropping, and alley farming if fodder production was a main objective (Kang and Wilson 1987). The first alley cropping trial at IITA began in 1976; on-farm trials were established in the 1980s (Tripathi and Psychas 1992).

An earlier start was made in Indonesia. Development of hedgerow intercropping in this region appears to be related to the introduction of *Leucaena* spp. to the Philippines

and Indonesia by the Spanish from Mexico (Dijkman 1950) and its promotion by the Dutch as a shade tree for coffee (*Coffea arabica* L.), cacao (*Theobroma cacao* L.), tea (*Camelia sinensis* (L.) Kuntze), and tobacco (*Nicotiana tabacum* L.) in the 18th century (Wirjodarmodjo and Wiroatodjo 1983). Dutch journal articles from the 1930s report the use of *Leucaena* contour hedges to support bench terraces on slopes (Dijkman 1950). Tacio (1993) cites a traditional ruling in the 1930s obliging all farmers in a region of Timor, Indonesia to plant contour hedges of *Leucaena* 3 m apart in cropped areas. Metzner (1976) notes *Leucaena* thickets were promoted by the Indonesian government in the 1930s to recuperate nonarable lands, but farmers did not do it because they feared the weedy qualities of *Leucaena*. By the 1950s, Leucaena was commonly used in the Pacific as contour hedges for erosion control (Dijkman 1950). Hernandez (1961), cited in Benge (1980), discusses results of Indonesian hedgerow intercropping research done in 1953. The hedgerows decreased erosion and improved maize yield by 380% on the treated plots, compared to traditional cultivation. Extension of hedgerows to farmers, supported by the Indonesian government and religious groups, expanded greatly during the 1970s (Metzner 1976, Tacio 1993, Wirjodarmodjo and Wiroatodjo 1983).

The Rise and Fall of Alley Cropping

Research on alley cropping in West Africa in the 1980s generated widespread interest (Kang and Wilson 1987) and led to trials and extension in many parts of the world. In trials examining their technical performance, hedgerows had positive effects on the yield of adjacent food crops through the application of tree prunings as green manure (Tonye and Titi-Nwel 1995), increased rainwater infiltration into the soil (Kiepe 1995), and reduced soil erosion when installed on sloping land (Paningbatan et al. 1995). Some economic analyses indicated that alley cropping, in spite of its high labor

requirement, can be profitable under certain environmental conditions (Ehui 1988). Based on these initial results, project based extension of hedgerow intercropping to farmers in developing countries grew quickly (Ongprasert and Turkelboom 1995, Sanchez 1995, Scherr 1994).

However, after a few years many came to believe that alley cropping had been oversold and had much less applicability than previously thought, and that its potential for adoption was limited to certain niche areas (Carter 1995, Sanchez 1995). Based on a review of hedgerow trials covering some of the possible biophysical conditions and hedgerow configurations, Sanchez (1995) lists the conditions where alley cropping is most likely to succeed: areas having fertile soils with no major nutrient limits, adequate rainfall during the cropping season, sloping land with erosion hazard, ample labor and scarce land, and secure land tenure. In spite of the apparent productive advantages discovered in controlled studies and the enthusiasm of project extension technicians, adoption among farmers remained generally low. This has been observed in many regions, including Indonesia and the Philippines (Fujisaka 1991, Nelson et al. 1997), Thailand (Ongprasert and Turkelboom 1995), Central America (Kass et al. 1995), West Africa (Lawry et al. 1994), and East Africa (Mutsotso and Gicheru 1995). Several reasons for poor adoption of hedgerows are given, including damage by grazing animals (Fujisaka and Cenas 1993, Mutsotso and Gicheru 1995), land tenure issues (Fujisaka et al. 1995, Lawry et al. 1994), and competing farm and off-farm activities (Fujisaka 1993, Ongprasert and Turkelboom 1995), but by far the most common reasons are the high costs of labor for installation and management (David 1995, Fujisaka et al. 1995, Kass et al. 1995, Mutsotso and Gicheru 1995, Nelson et al. 1997, Ongprasert and Turkelboom

1995, Stark 1996) and farmers' need for short-term economic returns from their plots (Fujisaka 1993, Ongprasert and Turkelboom 1995, Steiner and Scheidegger 1994).

Initial positive results from alley cropping trials were eventually modified by later studies that showed decreased crop production from alley cropping in certain biophysical settings or prohibitive costs of installation and management to farmers in certain socioeconomic settings. The claims made for the potential of alley cropping, it was felt, were exaggerated. But criticisms of alley cropping, summarized in a review written by Sanchez (1995), have also been exaggerated due in part to its having been tested in limited and inappropriate situations (Nair 1998), and may have caused an unwarranted backlash among researchers (Vandermeer 1998).

Rao et al. (1998) reviewed 29 hedgerow intercropping trials that had been conducted for four or more years, mostly on small plots, over a wide range of soils and climates, but no studies done on sloping land were included. They found both positive (15 studies indicated positive results for cereals, 8 trials showed positive results for noncereal crops) and negative (13 trials showed negative results for cereals, 1 showed negative results for noncereal crops) effects of hedgerow intercropping on crop yields across the tropics. Including only the studies showing crop yield increases in hedgerow systems greater than 15% (assuming this would be a minimum level to interest farmers), positive effects on crop yield were found in only 2 of 10 studies in semiarid (<1000 mm rainfall) regions, and 7 of 11 studies in subhumid (1000 to 1600 mm) regions where soils were either inherently fertile or supplemented. In 4 out of 8 trials in the humid tropics (>2000 mm) maize and taro (*Colocasia esculenta* (L.)Schott) did not benefit from hedgerow intercropping, but bean and cowpea yields did. The authors conclude that the

hedgerow intercropping system is location specific and sensitive to management, and that generalizations are difficult to make.

One can understand the caveats attached to prescribing or proscribing hedgerow intercropping as a general solution; however, a more balanced approach to both research and extension of hedgerow intercropping is now emerging. There is a growing recognition that its success or failure depends on many site-specific factors including the type of crops grown, the species of plants used as the structural component of the hedgerows, rainfall amount and distribution, soil type, and a host of socioeconomic variables (land and tree tenure, labor costs, etc.), including equity issues, extension approaches, and allowance for adaptation of the practice over time to optimize its economic returns to farmers (Mercer and Miller 1998, Nair 1998, Rao et al. 1998, Sanchez 1995, Scherr and Current 1997).

Developments of Hedgerow Intercropping in Haiti

Hedgerow intercropping using *Leucaena leucocephala* (Lam.) de Wit was tried on a small scale in Haiti for the first time in the early 1980s, but there are earlier examples of vegetation-based soil conservation structures. Mintz (1962) notes that Haitian farmers have been building seasonal crop stover barriers staked roughly on the contour to harvest water and soil since the 1950s. These structures, known as *ranp pay* in Creole, are still being built in some parts of the country. They last only a single planting season. Some farmers say that stover barriers provide habitat for rats and insects, and so they prefer to burn the crop residue. Contour structures have been promoted by development projects since the 1950s. A UNESCO project in the community of Marbial paid people to plant sisal (*Agave sisalana* Perrine ex Engelm.) on the contour to control soil erosion in the early 1950s, and a FAO project near the town of Les Cayes in the late

1960s promoted contour hedges of napier grass (*Penisetum purpureum* K. Schumach.), lemon grass (*Cymbopogon citratus* (DC.) Stapf), vetiver (*Vetiveria zizanioides* (Linn.) Nash), and guinea grass (*Panicum maximum* Jacq.) (G. Brice, personal communication: 1998). These were done by farmers who were paid stipends based on the number of hedges installed, and they were not always appropriately designed. The napier grass hedgerows were planted on shallow, droughty soils. Many eventually grew taller than their shallow roots could support, and toppled over. This also happened to some of the sisal, a crop that is traditionally planted up and down the slope so that farmers harvesting the sharply pointed leaves do not injure themselves if they fall.

In contrast to the historically widespread nonadoption of soil conservation strategies designed by technicians, there is an example of a successful practice designed by Haitian farmers responding to a particular market opportunity. This involves the yearly, labor-intensive construction of contour soil bunds (*tram*) to conserve expensive chemical fertilizers used to produce high-value vegetables in a small region close to the capital city (Murray 1980).

Initial interest in tree-based hedgerow intercropping was stimulated by reports of developments in West Africa, Indonesia, and the Philippines, and by the general interest in the use of *Leucaena leucocephala* as a fuelwood tree. There is a variety of *Leucaena* native to Haiti, known locally as *delen, oriman, ti movye*, or *ti pingi*. This variety is not suited to hedgerow construction because it is extremely invasive and does not produce sufficient biomass, and is therefore very unpopular among farmers. To promote the use of *Leucaena*, USAID introduced seeds of productive varieties to Haiti in 1978 (Benge 1985). Seeds of *Leucaena* K8, K28, and K67 from trees grown in the Philippines were distributed, and later seeds from Flores, Indonesia were introduced. In 1979, a USAID

agronomist also introduced the concept of using *Leucaena* in hedgerows, and re-wrote an existing paper on *Leucaena* hedgerows especially for Haiti (M. Benge, personal communication: 1995).

The number of hedgerows reported by PADF as built by farmers participating in PLUS and its two predecessor projects probably represents the largest percent of the hedgerows in Haiti. During the seven-year period from 1985 through 1991, 848 km of hedgerows were reported (PADF 1990). The number of hedgerows installed has been much greater under the PLUS project, with over 12,000 km. having been installed from 1993 through mid-1999 (PADF 1999). If the number of hedgerows ever installed by farmers working with all aid projects in Haiti is estimated at 15,000 lineal km, and if there is an average of 5 meters between rows, then approximately 7,500 hectares of hillside gardens have had hedgerows. Although this represents less than one-half of a percent of the total land area, it is a significant figure for a new technique whose management is still being developed.

Hedgerows have been recommended as a potentially appropriate agroforestry technology and are commonly promoted in Haiti as part of project or government-based soil conservation and natural resource strategies (Bannister and Nair 1990). Garrity and Van Noordwijk (1995) note three paradigm shifts in hillside conservation management: (1) an engineering approach using rock and earthworks in contour structures has increasingly given way to vegetative structures; (2) top-down prescriptive watershed management has evolved to a bottom-up, participative approach; and (3) tree-based alley cropping has diversified to include a wider array of economically interesting plant materials as structural components of contour hedgerows. All three of these shifts have occurred in Haiti. Early attempts at erosion control promoted by projects in Haiti were

mainly based on rock walls constructed across the contour, but these were poorly maintained because they did not respond to farmers' economic situation and the extension approach was inappropriate (Murray 1980). The increasing emphasis on vegetative barriers happened during the 1980s, as noted above, along with as-yet incomplete attempts to manage natural resources participatively.

However, the ideotype of contour hedgerows is not static in Haiti. Farmers continually modify the structural composition and management of hedgerows according to their household needs, their ability to invest resources, their experience with hedgerows, and changing marketing opportunities for crops and products derived from hedgerow trees. *Leucaena leucocephala* was originally the predominant hedgerow species, but that is changing. During 1995, PADF reported hedgerows made with 22 different tree, perennial food crop, grasses, and other perennial species planted in 54 different combinations. *Leucaena* was present in only 46% of the hedgerows. In addition, hedgerows are evolving into perennial crop contour bands in some areas. These bands, called *bann manje* (a play on words—either "band of food" or "a lot of food") consist of rows of food crops planted across the contour, with a dimension up and down the slope of more than one meter. Perennial crops such as pineapple (*Ananas comosus* (L.) Merr.) or sugar cane (*Sacharum officinarum* L.) serve as the structural components, but annuals such as yam and sweet potato (*Lpomoea batatas* (L.) Lam.) are also planted within the band. Field crops are planted in the interspaces, as in hedgerows. During 1999, 20 different combinations of nine species of perennial food crops, trees, and other perennials were used in crop contour bands (PADF 1999). This evolution is based on farmers' needs for short-term cash return. The structural crops, such as pineapple, respond directly to a marketing opportunity—a quintessentially Haitian strategy (Murray

1991), and one found in indigenous agroforestry associations in other cultures (Khaleque and Gold 1993). This reinforces the notion that hedgerow intercropping should be considered as a seed technology (Sumberg and Atta-Krah 1988, Wiersum 1994), to be adapted and modified by farmers as a matter of course to fit into their unique agricultural systems as they discover (or not) its as-yet unknown economic possibilities.

The cycle of enthusiastic promotion of hedgerow intercropping followed by disappointment has a parallel in Haiti, although it is not documented apart from some protest about the widespread promotion of *Leucaena* hedgerows in the early 1990s (Swanson et al. 1993d, 1993e). It mainly takes the form of disappointment, informally expressed by officials of donor agencies, that hedgerows do not yet cover every garden in Haiti. More often the criticism of nonadoption has been aimed at the extension methodology rather than the practice per se (Sieder 1994,Villanueva 1993). This has been due, in part, to the development-driven agenda mentioned by Nair (1998) resulting in the promotion of large numbers of an untested practice by donor-funded projects. Reasons for farmer adoption, adaptation, or rejection of hedgerows are not well studied in Haiti. The best available studies were done in a small region of the central plateau near the town of Maissade (White 1992b), which noted farmers' reasons for nonadoption of hedgerows as lack of time (39%), don't own land (21%), and land not appropriate (17%). Vaval (1997) studied the same project area later, and documented the disadvantages of hedgerows as expressed by adopting farmers as the time required for management and loss of crop land due to the presence of hedgerows.

Hedgerow Intercropping and Soil Conservation

Because of the greater risk of soil erosion, performance of hedgerows on sloping lands is not identical to their performance on flat land. Three kinds of biophysical

differences to consider include (1) the overall effect of hillside contour hedgerows on crop production and soil erosion, (2) the gradients of soil accumulation/loss, soil physical properties, tree/crop competition, and crop yield across the overall slope from the top hedgerow to the bottom one, and (3) the same gradients within the alleys.

The concerns about the poor performance of alley cropping summarized by Sanchez (1995) did not extend to hedgerow intercropping on sloping land. In part, this is due to the proven ability of contour hedgerows to control soil erosion. Sanchez (1995) stated that the hypothesis that contour hedgerows can substantially reduce soil erosion has been definitively proven. This has been shown in many areas of the world, for example a review of ten years of research in Thailand concluded that hedgerows controlled erosion in areas of 18 to 55% slopes (Ongprasert and Turkelboom 1995); in Rwanda on 23% slopes hedgerows reduced erosion to less than 2% of the runoff from unprotected plots (Roose and Ndayizigiye 1993); in Malawi on 44% slopes hedgerows reduced soil erosion to 2 t/ha compared to 80 t/ha on maize-only plots (Banda et al. 1994); in India on 9% slopes hedgerows significantly reduced soil erosion compared to cassava-only plots or bare fallow (Ghosh et al. 1989); and in the Philippines there are many examples of hedgerows substantially reducing erosion on sloped land (Agus et al. 1999, Comia et al. 1994, Paningbatan et al. 1995, Tacio 1993). The studies cited cover a range of soil types from sandy loams (Banda et al. 1994) to gravelly sandy clays (Ghosh et al. 1989) to heavy clays (Comia et al. 1994).

However, in spite of their proven ability to control erosion, in many cases researchers have not been able to show crop yield improvements in hedgerow plots compared to traditional systems. The principal reason for this appears to be the same on slopes as it is in flat land alley cropping systems--the tradeoff between the production of

biomass for mulch or green manure needed to increase crop yield, and the loss of cropping space caused by the presence of the hedgerows that produce the biomass (Vandermeer 1998). The inter-row spacing required for the crops does not allow enough biomass production from the hedgerows to improve soil fertility, so maize yield, for example, is not improved unless inorganic fertilizer is applied (Ongprasert and Turkelboom 1995, Roose and Ndayizigiye 1993). On steep slopes the Soil Changes under Agroforestry (SCUAF) model (Young and Muraya 1990) predicts this might be explained by high rates of leaching and organic matter decomposition, despite reductions in the rate of erosion (Nelson et al. 1998). Crop yield declines are especially important in newly established hedgerows as biomass application will not have yet contributed much to soil improvement, although cropping space will have been reduced. Data taken from 89 hedgerow plots planted with maize on sloping plots in the Philippines showed a decrease in maize yield in new hedgerows due to the loss of cropping space. The same study estimated 8 years would be required for soil improvements caused by hedgerows to compensate for loss in maize yield at a 5 m inter-row spacing (Shively 1998). In some cases, however, soil conditions are improved by hedgerows sufficiently to maintain a stable, if low, level of maize production on slopes compared to traditional cultivation, where maize yield falls off over time (Banda et al. 1994, Comia et al. 1994). There are also examples where crop yields in hedgerows on slopes were significantly greater and more stable than those in unprotected control plots, as in a four-year study in Costa Rica on farms having relatively fertile soils (Kass et al. 1995).

Gradients of soil water, soil physical properties, and crop yield have been documented in alley cropping systems, as noted earlier in this chapter. For example, infiltration rate and number of soil macropores were greater under the hedgerow trees

than in the middle of the alleys on a 14% slope in Kenya (Kiepe 1995). Competition for light, water, and nutrients between hedgerow plants and adjacent crops is also noted on slopes. Rice yield was depressed in the first two rows away from hedgerows on 15% slopes in the Philippines, but the depression varied with different hedgerow species; it was greatest near grass (*Penisetum purpureum*) hedgerows (Garrity and Mercado 1994). It has also been found that food crops in the alleys can restrict the growth of adjacent hedgerow trees (Ghosh et al. 1989).

But as the slope increases a redistribution of soil fertility across the alley is often seen that differs from that of flat plots (Garrity 1994, Ongprasert and Turkelboom 1995). Increases in soil macropores near *Calliandra callothrysus* hedgerows in Reunion were greater on the uphill side of the hedges than on the downhill side (Tassin et al. 1995). A study done in the Philippines on 22 to 30% slopes found that average mid-alley maize yields were greater than yields near hedgerows of *Gliricidia sepium*, *Paspalum conjugatum*, and *Penisetum purpureum*; and that the Ap soil horizon was thicker on the lower part of the alleys (Agus et al. 1999). Garrity (1996) reviewed this phenomenon, and noted that it was caused in a large part by the displacement of soil during crop tillage. He has pointed out that on unprotected slopes there is often no net loss of soil from the mid-slope area because any soil loss is replaced by soil eroding from the upper portion of the hillside. The presence of hedgerows prevents a net accumulation of upslope soil into the alleys, but the same displacement effect occurs within the alleys on a smaller scale. Crop yield response on sloped hedgerow plots skews after a few years of cultivation because scouring due to tillage displaces soil from the upper part of the alley to the lower part, changing the soil profile, slope length, soil depth, and hydrological properties. These changes combine with competitive interactions between the crop and the hedgerows. The result is lower crop yields on the upper parts of the alleys and higher

yields on the lower middle part, with a slight decrease again as crops approach the lower alley near the next hedge. The net yield curve across the alley is due to a combination of soil scouring and competition with hedgerow trees. The effect of soil scouring on yield is usually more important than that of tree/crop competition. Solera (1993), cited in Garrity (1996) put in 50 cm plastic barriers between *Gliricidia sepium* hedgerows and adjacent upland rice on a 20% slope, and found that the across-alley yield response was unchanged by the barriers, and so was not due to competition between the hedgerows and crop. Yield in the upper rows was 50% lower than that in the lower rows within the alleys. The effects of slope on hedgerows are important because in wide alleys the soil displaced from the upper position may lead to long-lasting crop yield depression in that area, and because invalid comparisons between yield in hedgerows are often made against an adjacent no-hedgerow control plot in the mid-slope area that has thicker soil (Garrity 1996).

Conclusions

Hedgerow intercropping is an evolving technology meant to address the increasingly rapid destruction of soil resources in developing countries. The defining paradox in its history is that researchers and extension agents initially addressed it as a technical solution, whereas farmers looked at it primarily as a potential economic solution. Crop yield improvements due to hedgerow intercropping in certain regions of the world justify continuing research. However, it has not yet been widely adopted even in those regions, mainly due to high initial costs of installation and adaptation and farmer need for short-term returns in the face of the probability of a yield loss in hedgerow plots during the first few years after installation. Both the technical and socioeconomic aspects of hedgerow intercropping must be resolved in order for adaptation and adoption to increase.

CHAPTER 4
ORGANIZATION OF THE STUDY

This study is presented in three parts, beginning with an on-station study of competitive interactions between hedgerows and adjacent maize, followed first by an on-farm study of the performance of maize in hedgerows on sloping plots, and then by an extensive field survey of the biophysical characteristics of plots and socioeconomic characteristics of farmers who have constructed hedgerows and other soil conservation practices with the PADF/PLUS project. The hypotheses to be tested correspond to some of the biophysical and socioeconomic hypotheses referred to by Sanchez (1995) as being fundamental to agroforestry, namely, biophysical hypothesis number 16: competition for water in agroforestry systems can be reduced by modifying the spatial arrangement of trees; and socioeconomic hypotheses numbers 1, 3, and 4:

- the identification of key driving socioeconomic and ecological processes within land-use typologies permits the spatial delineation of target and recommendation domains for agroforestry interventions;
- the adoptability of a new agroforestry practice is determined by 5 principal components–the farmers' natural resource base, their resource endowment, degree of market integration, cultural preferences and perceived benefits; and
- at the farming systems scale, agroforestry adoption has different impacts for different classes of farmers, such as their gender.

Justification

Declining farm productivity is a major problem confronting Haitian hillside farmers. It is caused and exacerbated by a number of factors. Important among these are soil degradation as a consequence of erosion, and farmers' difficulty in making capital

investments to support improvement of lost soil fertility and farm productivity. Traditional agroforestry systems such as home gardens, shade coffee, and living fences have not been able to cope with the degradation of soil resources on hill slopes as population increased. Although rural migration to the cities has steadily increased (Locher 1996), there is no reason to suppose that this will result in a significant decrease in the population density in the mountains. Haiti's population might already have exceeded the ecological carrying capacity of the land (Ewel 1977). Two decades ago, the Haitian landscape was described as the victim of mismanagement: "the ruthless application by the rural population of ecologically inappropriate and catastrophic lumber extraction and gardening techniques which have transformed the once lush landscape of entire regions into grim, denuded savannas" (Murray 1980, page 3). In addition to decreasing productivity of individual hillside plots, inappropriate farming practices also led to other local and regional environmental problems, including transport of rock overburden that covers productive soil of farms on lower slopes and plains, reduction in the water supply from springs, road washouts, and destruction of houses by water and debris flows.

Hedgerow intercropping has gone through a cycle of research, widespread promotion based on expected positive performance, extension by governments and funded development projects, mounting criticism when expected performance was not achieved, a resulting waning interest on the part of researchers and projects, and a concern that alley cropping might be rejected due to inadequate identification of the biophysical and socioeconomic conditions where it might succeed. This point was discussed in more depth in Chapter 3.

Consequent to the reported promise and potential of hedgerow intercropping technology in other parts of the tropics in the 1980s (Kang et al. 1984), it was introduced in Haiti in the middle 1980's through externally funded development projects (Murray 1997, PADF 1986). As with most project-driven interventions, hedgerow intercropping has had varying degrees of success. Several reasons could be attributed to this, both biophysical and socioeconomic. They might include inappropriate extension approaches, mismatch between farmer objectives and project objectives, inappropriate choice of hedgerow species, competition between hedgerows and adjacent crops, high cost of hedgerow establishment and management relative to the resulting effect on crop yield, and farmers' and technicians' ignorance of the costs and benefits of hedgerows. But the list of relevant factors contributing to hedgerow success or failure is poorly understood. Indeed, farmers, extension agents, technicians, and project administrators have varying definitions and perceptions of success and failure. The same cycle of widespread interest followed by disappointment seen on the international level has been repeated on a smaller scale in Haiti, where hedgerow intercropping has sometimes been labeled a failure by consultants and donors who tend to observe the practice at an early stage of development, in a small number of locations, or without a complete understanding of important nontechnical parameters of the practice.

During the period 1984 to 1999, hedgerow intercropping technology has been installed on approximately 10,000 hectares by farmers working with various funded projects in Haiti (PADF 1990, PADF 1999). This is a significant coverage for a development activity involving a relatively new and evolving technology. The rate of hedgerow construction appears to have surpassed the level of understanding of how and why they are installed and managed.

A number of studies have been published regarding various aspects of hedgerow intercropping in Haiti. These include the effect of hedgerows on soil erosion (Cunard and Lorcy 1990, Regis 1990), financial analysis of some of the benefits of hedgerows (Bellerive 1991, Lea 1993, White and Quinn 1992), choice of hedgerow species (Isaac and Shannon 1994, Shannon and Isaac 1993, Toussaint 1989, Treadwell and Cunard 1992), management of hedgerow tree biomass (Isaac et al. 1995), farmer adoption (Chéry 1990, Emmanuel 1990, Lea 1994a, 1994b, Villanueva 1993, White 1992a), and farmer adaptation and management (Lea 1995, Pierre et al. 1995, Swanson et al. 1993a, 1993b, 1993c, 1993d, 1993e, White 1992b).

Of the nine papers cited above reporting adaptation and management of hedgerow intercropping in Haiti, only the one by Pierre et al. (1995) was specifically designed to study how farmers manage hedgerows. They studied at 105 hedgerow gardens installed before March 1994 in one region of southwestern Haiti. Although the study reported a number of valuable observations on the management and performance of hedgerows, it did not correlate the management quality indicator (the number of unrepaired breaches) with other factors. Furthermore, the observations were based only on hedgerows constructed of *Leucaena leucocephala* in a limited area of project intervention.

Another major study on hedgerows in Haiti was the series of qualitative, questionnaire-based diagnostic surveys (Swanson 1993, Swanson et al. 1993a, 1993b, 1993c, 1993d, 1993e,) done just after the first field season of the PLUS project at the request of PADF and Cooperative for American Relief Everywhere (CARE), the implementing organizations. These studies were targeted at the whole farming environment, not particularly at hedgerows. The diagnostic team visited over 200 farmers in fifteen small watersheds, interviewing individual farmers in their plots and

speaking with groups of farmers. The majority of the hedgerow gardens seen by the team were installed under the Agroforestry II (AFII) project (1990-1991). The number of hedgerow gardens visited was not stated, and the survey did not attempt to link hedgerow management to specific conditions on the farms. Several useful observations were made regarding hedgerows, however both the composition and management of hedgerows have evolved since that time, and the number of hedgerows installed by farmers has increased dramatically. In addition, an evaluation of the PLUS project monitoring and evaluation system done in 1995 (Romanoff et al. 1995) suggested that the sampling areas used were not representative of the whole project. They recommended that project impact be measured over the whole area of intervention.

Competition between hedgerow trees and adjacent crop plants for soil water has been the subject of an increasing number of studies in recent years (Chirwa et al. 1994a, Govindarajan et al. 1996, Korwar and Radder 1994, 1997, Ong et al. 1991, Rane et al. 1995, Schroth et al. 1995a, Schroth and Zech 1993, Ssekabembe et al. 1994). This is potentially a problem in Haitian hedgerow gardens because of the highly variable timing of seasonal rainfall and the inability of eroded soils on steeply sloping land to absorb and store water. Ewel (1977) referred to this as pseudo-drought, a condition that results from a decrease in the water-holding capacity of the soil rather than from decreased rainfall. The literature on hedgerow-crop soil water competition shows that, under some conditions, hedgerows compete to the disadvantage of adjacent crops (Fernandes et al. 1993), (Govindarajan et al. 1996, Kamasho 1994, Korwar and Radder 1994, Ong et al. 1991, Salazari et al. 1993, Singh et al. 1986) and under other conditions, they do not (Bohringer and Leihner 1997, Chirwa et al. 1994a, Haggar and Beer 1993, Jeanes et al. 1996, Schroth and Zech 1993).

One possible influence on farmer adaptation and management of hedgerows is farmers' perception of the importance of soil water competition between the hedgerow species and the interplanted crops. Experience in Haiti shows that maize (*Zea mays*) and bean (*Phaseolus vulgaris*) crops, even without hedgerows, very often fail because of drought conditions. Therefore, hedgerow trees are likely to compete with interplanted crops for soil water at some time during the cropping cycle. The degree of competition may also vary according to the position of the crop on the slope relative to the hedgerows (Garrity 1996). However, it is not clear if farmers consider this competition as more or less important than other perceived problems caused by hedgerows. Do farmers modify hedgerow structure and management to compensate for perceived soil water competition? Neither competition for soil water between crops and hedgerows, nor crop yield relative to slope position and /or relative to hedgerows have been studied in Haiti.

Since intensive agriculture is practiced on small steeply sloping plots, it is necessary to look for economically rational ways to maintain the soil's ability to sustain crop production and to protect the local environment. Development of new agroforestry systems that build upon traditional practices is needed. Hedgerow intercropping has been shown to produce desirable results under certain circumstances. However, adoption or lack of adoption may depend on factors extraneous to the characteristics of the technology itself, including the socioeconomic status of farm families and the kinds of land they access for agriculture. The extremely degraded condition of Haitian natural resources makes it necessary to try any practice that could improve the economic condition of Haitian farmers. Because of experience gained from agroforestry projects operating in Haiti since the 1980s, there is reason to believe that adaptations of hedgerow intercropping may increase farm stability and productivity in some areas of the country.

This study will help inform decision makers regarding the potential for use of hedgerow intercropping in Haiti, and possibly avoid premature decisions to discontinue the effort to adapt the technology.

Thus, hedgerow intercropping, a rapidly evolving and yet unproven technology, has been extended in Haiti without the necessary supporting studies and documentation. Development and extension resources could be used more efficiently by responding to two documented shortcomings of agroforestry research that seem particularly appropriate to the Haitian situation: that there is an inadequate understanding of below-ground biophysical interactions in hedgerow systems; and that socioeconomic and biophysical research must be linked, as adoption of the appropriate agroforestry practice depends upon both (Rao et al. 1998).

Hypotheses

On-station Study

- *Leucaena* hedgerows reduce the amount of soil water available to adjacent maize, thereby causing a reduction in maize growth and yield.
- Root barriers installed next to *Leucaena* hedgerows increase the amount of soil water available to adjacent maize, thereby causing an increase in maize growth and yield.
- Cutting the roots of *Leucaena* hedgerows affects the production of tree biomass.

On-Farm Study

- The pattern of competition between hedgerow trees and adjacent crops is different on slopes vs. flat land, and maize growth varies with regard to the position of the crop within the alleys and on the slope.

On-Farm Survey

- Family characteristics influence the adoption and management of hedgerow intercropping.

- Plot characteristics influence the adoption and management of hedgerow intercropping.
- Problems and benefits with hedgerow intercropping as perceived by the adopting farmer influence management quality.

General Description of Hypothesis-Testing Procedures

The study of soil water competition between *Leucaena* hedgerows and adjacent maize was done on an NGO-operated research station located near Port au Prince. Four treatment combinations were tested in nine replications: hedgerows with and without root barriers between the trees and the adjacent row of maize, and maize fertilized or not fertilized. Data for three maize seasons are reported, including gravimetric soil water; maize height, leaf width, growth stage, leaf water potential, and final harvest; and *Leucaena* height and biomass production. A pre-study examination of the distribution of *Leucaena* hedgerow roots at a different location was done, and a post study count of the distribution of *Leucaena* roots in hedgerows with and without barriers was done on-station. A pot study of the correspondence between soil water percent and maize leaf water potential was done as well.

The small on-farm study was an attempt to relate the on-station findings on flat land under "controlled" conditions to sloping land managed by farmers. The study collected maize growth and yield data for one season from four farms having previously established trials of *Leucaena* hedgerows, crop contour bands, rock wall terraces, and traditional cultivation. Maize growth data were collected by position in the alleys and on the slopes. The four farm plots had been a part of an abandoned PLUS project research effort previously carried out by the Southeast Consortium for International Development (SECID)/Auburn University in conjunction with PADF. The author designed the data collection protocol and performed the analysis.

A large list-frame questionnaire-based study was conducted, which provided on-farm data about households adopting agroforestry soil conservation practices (including hedgerows), how they were managed, and the characteristics of the plots where they were installed. The study was undertaken by the author with the help of PADF PLUS technicians as part of project monitoring during the early part of 1996. We visited 1,540 PLUS project agroforestry adopters and collected information regarding all plots controlled by the family, and information regarding family members. We then visited 2,295 plots where farmers had installed at least one PLUS project agroforestry practice. Data were collected on the biophysical parameters of the plots, the amount and condition of the agroforestry practices installed on the plot, and the opinions of the farmers regarding problems and benefits of the practices. Because farmers' assessment of soil fertility appeared to influence where hedgerows were installed, soil samples were collected from 175 farms. These were analyzed for percent organic carbon and soil nutrients, and compared to farmers' classification of soil fertility.

Details of data collection and analysis for the on-station and on-farm hedgerow/crop competition studies are reported in Chapter 5. Those for the on-farm survey are reported in Chapter 6.

CHAPTER 5
HEDGEROW/CROP COMPETITION

Introduction

This chapter looks at competitive interactions between hedgerows and adjacent maize on station and on farm. Competition is important because it is a key consideration in designing agroforestry practices, it is difficult to measure, and farmers make adoption and adaptation decisions based on its perceived severity. Competition is a central issue in agroforestry because of the potential advantage in combining plants in such a way that they capture more growth resources in combination than they would growing separately, thereby producing greater physical yields (Cannell et al. 1996). The cost of the positive effects of facilitation gained by growing plants in close proximity is the negative effects of competition. In hedgerow intercropping in particular, the competitive characteristics of the trees (they take up space, light, soil water, nutrients) must be balanced with their facilitative characteristics (they impede soil erosion, capture soil water and nutrients out of reach of the crops, improve soil fertility through biomass additions, improve the microclimate, improve soil physical properties) (Vandermeer 1998). It is hard to develop a hedgerow system that attains that balance because so many combinations of plants, physical environments, and socioeconomic situations are possible. It is also difficult to measure competition and to identify the processes that contribute to it because competitive interactions change as the environment changes (Anderson and Sinclair 1993), and the hedgerows themselves change the environment—indeed, that is their

function. The way hedgerows and adjacent crops interact varies according to the age of the hedgerows, relative size of the crops and hedgerows, population density, and the supply of and access to limiting growth resources (Ong and Leakey 1999).

Farmers make adoption decisions based on competition between hedgerows and crops. For example, farmers in the Philippines eliminated napier grass as a hedgerow component because it was too competitive with crops grown in the alleys (Fujisaka et al. 1995), where it decreased maize yield by 86% by the second year after establishment (Garrity and Mercado 1994). Therefore, competitive characteristics are important considerations in the design of hedgerow systems.

Leucaena has characteristics that make it an aggressive competitor for growth resources, including rapid growth and roots that occupy approximately the same soil depth as that of maize (Jonsson et al. 1988), the crop of interest in this research. It was noted several decades ago in Southeast Asia that *Leucaena* used as shade trees in plantations rarely competed with the crop plants; but did so in times of drought, when signs of water competition with coffee and rubber were reported (Dijkman 1950). In more recent alley cropping studies, competition is a frequent subject of investigation, but results vary with the specific site and plant components. *Leucaena* has been shown to compete for soil nutrients to the detriment of rice (Salazari et al. 1993) and grasses (George et al. 1996). In the semiarid tropics especially it has been shown to reduce the amount of soil water available to pigeon pea, but less so for sorghum and millet (*Pennisetum glaucum* L.) (Singh et al. 1986). In other areas of the semiarid tropics, however, yields of both sorghum (Korwar and Radder 1997) and millet (Ong et al. 1991) were significantly reduced in *Leucaena* hedgerows.

The on-station and on-farm studies reported on here both have maize planted in the interspaces between *Leucaena* hedgerows. This combination has produced both positive (Akonde et al. 1996, Banda et al. 1994, Hauser and Kang 1993, Hernandez 1961, Mugendi et al. 1999, Mureithi et al. 1994) and negative (Chirwa et al. 1994b, Govindarajan et al. 1996, Jama et al. 1995, Kamasho 1994) results. The positive results in the cited studies ranged from maintaining the existing maize yield (versus a decrease without hedgerows) to increases of 26%, 44%, 50%, and 400% in grain yield compared to traditional cultivation. Positive results tended to be from subhumid or humid areas with soils of moderate or better fertility, and from sloping areas. The negative results ranged from 16% to 20% decreases in maize yield. These tended to be from semiarid, moisture limiting, low fertility sites.

Effects of competition between maize and *Leucaena* are noted in several studies, even where the overall effects of hedgerows are positive. In an early report of alley cropping research in Ghana, Balasubramanian (1983) mentioned that soil water competition with *Leucaena* might be a partial explanation of yield depression in adjacent maize. Later hedgerow studies have attributed yield depression in adjacent crops to competition for soil water (Govindarajan et al. 1996, Korwar and Radder 1997, Ong et al. 1991, Ssekabembe et al. 1994), nutrients (Chirwa et al. 1994b, Livesley et al. 1997, Mureithi et al. 1994), or light (Kang et al. 1981, Lal 1989, Tilander et al. 1995, Welke et al. 1995, Zoschke et al. 1990). Some studies claim all three resources are competed for (Gaddanakeri et al. 1994). It is difficult to use these location-specific results to make predictions about the probable success of a hedgerow intercropping system in another location. However, Rao et al. (1998) have drawn some general conclusions: (1) In water limiting areas, low yield of hedgerow prunings and competition for water between hedgerows and adjacent crops were the major reasons for the negative results.

Inadequate water limited the response of crops even though hedgerows improved soil fertility in certain sites of the semiarid tropics. (2) In poor soils, low yield of hedgerow prunings and competition for nutrients were responsible for negative results. (3) The advantages of hedgerow intercropping are more common on relatively fertile, N-deficient soils in subhumid and humid environments, in areas where hedgerows produce a large quantity of prunings, and where there is adequate water for both hedge and crop growth. They also note that if competition is substantially reduced, even in semiarid climates, hedgerows may be able to increase crop yields even where relatively small fertility contributions are made by the hedges—but the cost of managing the hedges could be too high to be practical.

Much of Haiti is subhumid, and there are still soils having a little remaining fertility, on sloping land where hedgerows may be appropriate. The discussion to be presented in this chapter will focus on the biophysical aspects of hedgerows and so will necessarily be incomplete, lacking the socioeconomic elements, which will be discussed in Chapter 6.

On-Station Studies: Effect of Root Barriers on the Growth of Maize and Leucaena

The objectives of this experiment were to test whether or not permanent root barriers placed on either side of *Leucaena leucocephala* hedgerows affect the production of maize grown in the alleys and the production of *Leucaena leucocephala* biomass. The hypotheses were that the barriers will reduce competition for soil water between *Leucaena* and adjacent maize, thereby increasing maize yield; and that production of *Leucaena* will not be adversely affected by the barriers. If maize yield were to be increased significantly an appropriate modification of the barrier could then be devised for use on-farm, or a less competitive tree could be sought to construct hedgerows.

Crop yield depression close to trees is common. It has been reported for mustard growing under *Acacia nilotica* in semiarid central India, where a yield depression of 54% extending up to 8 m from the tree was correlated with increasing shallowness of the tree roots (Yadav et al. 1993). Yield depression of maize and soybean near Siberian elm (*Ulmus pumila*) and eastern cottonwood (*Populus deltoides*) windbreaks in Nebraska was significantly relieved by plowing parallel to the trees (Rasmussen and Shapiro 1989). A study done in the savanna region of Kenya reported that *Acacia tortilis* trees competed more intensely with understory grasses and herbs in wetter sites where the tree roots terminated near the crown region, than in drier sites where the roots extended farther into the grassland (Belsky 1994). Yield depression in millet extended significantly beyond the area shaded by eucalyptus shelterbelts in Nigeria, corresponding to the area of tree root growth (Ojyewotu et al. 1994). Nadagouda et al. (1994) found that severing the roots of eucalyptus trees in India improved yield of adjacent maize.

Unless effective experimental controls are put into place, it is difficult to separate the effects of above- from below-ground competition, and the effects of competition for water from those of nutrients. Corlett et al. (1992b) describe a study done in the semiarid tropics of India in which millet was grown alone and in *Leucaena* hedgerows, either with or without barriers between the tree and crop roots. Millet yield was the same in the sole crop and in the hedgerows with root barriers, but was 36% less in the hedgerows without barriers. The authors proposed that, although one might have concluded that the yield difference was due solely to below-ground competition, a better explanation was that the millet adjacent to hedges with barriers grew taller because it had access to more soil water than millet in hedgerows without barriers, and avoided light competition with the *Leucaena*. There was an interaction between above- and below-ground processes.

Common methods used for studying the effects of below-ground competition in alley cropping research include root pruning (Fernandes et al. 1993, Korwar and Radder 1994, Sitompul et al. 1992), trenching (Schroth et al. 1995b) or the installation of permanent plastic barriers between the hedgerow trees and the crops (Corlett et al. 1992b, Hauser and Gichuru 1994, Ong et al. 1991, Schroth et al. 1995a, Schroth and Lehmann 1995, Schroth and Zech 1993, Solera 1993c, Ssekabembe et al. 1994). The usual practice is to open a narrow trench to a depth of 50 to 100 cm between the hedgerow trees and the first crop row, install plastic awning or polyethylene sheeting, and then fill in the trench.

Studies using plastic barriers have produced results specific to the characteristics of the site, species of hedgerow tree and crop, alley width, planting density and distance between the hedgerow and crop, and the top-pruning regime (height and timing of cut) used on the hedgerow. Ong et al. (1991) showed that yield of millet in hedgerows without barriers was 40% less than yield in sole-cropped millet in semiarid India, but where barriers were parallel to hedgerows the yield was the same as that in sole cropping. They also showed that the barriers did not affect the production of the *Leucaena* hedgerows, but the barriers did cause a redistribution of the *Leucaena* roots. Schroth and Lehman (1995) found in subhumid Togo that barriers increased the yield of maize in *Calliandra callothyrsus* hedgerows, but when the hedgerow species were *Senna siamea* or *Gliricidia sepium* the presence of barriers was associated with a decrease in maize yield. They concluded that *Calliandra* was relatively competitive compared to the other trees, and that the barriers reduced the volume of exploitable soil available to the roots of the other two species. The results obtained by studies using plastic barriers between trees and crops do not always show competition for soil water. Two studies done in the West African humid tropics put plastic barriers to 90 cm between *Gliricidia* hedgerows and

adjacent crops of rice, maize, and peanut. They showed crop yield improvement in hedgerows compared to the sole cropping controls, but crop yield in hedgerows was not affected by the presence of barriers (Schroth et al. 1995a, Schroth and Zech 1993). A study done in the United States was able to isolate the effect of *Robinia pseudoacacia* hedgerows on soil water at two sites having different soil characteristics (Ssekabembe et al. 1994). The plots were irrigated, no crops were grown in the alleys between the hedges, and the soil was covered with plastic to reduce evaporation. At the site having a higher soil organic carbon content, hedgerows without barriers reduced soil water content of the alleys by about 8%. At the second site, where higher gravel content impeded the growth of tree roots, hedgerows without barriers reduced soil water content by 32%, and there was significantly less water in alleys without barriers.

Materials and Methods

The experiment was carried out over a period of six years, from the spring of 1990 through the spring of 1995. During this period data collection was interrupted several times by civil unrest in Haiti,[1] so although six maize crops and one sorghum crop were planted only three successive maize crops from spring 1994 though spring 1995 are

[1] There was a coup d'etat in September 1991, which resulted in several missed observations due to curfews. A night guard at the Operation Double Harvest (ODH) site, where the experiment was installed, was killed by soldiers during that period, preventing pre-dawn leaf moisture potential measurements. I was evacuated to the U.S. in October 1991 and returned to Haiti in September of the following year. By that time, the Direction of ODH had changed hands, requiring that I obtain permission to continue my work on the plot. This took several months, and the removal of a leaking irrigation line installed next to the plots was necessary. During the regime of the *de facto* military government (September 1991 to September 1994), fuel shortages were common because of an international embargo, again interrupting data collection. Farmers with friends in the local police station let donkeys into my plots, ruining the Fall 1993 harvest. Farm workers bathing in the plots behind the screen provided by the *Leucaena* also prevented soil moisture observations from being taken at least twice. The U.S military intervention in September 1994 made adequate data collection difficult during that period as well.

discussed. Data available from the three maize crops were not identical, again due to civil unrest and equipment problems. The spring 1991 data are used only for the discussion of the effect of trenching on *Leucaena* height and biomass.

Trial site

The trial site was located at 18°33' north latitude 72°11' west longitude, with an elevation of 80 m above sea level on property owned by Operation Double Harvest (ODH), a nongovernmental organization (NGO) operating a farm and tree nursery in the Cul de Sac plain, 30 minutes northeast of Port au Prince near the town of Croix des Bouquets, Haiti. The soil was a vertisol of zero slope. From observations made in a soil pit near the trial plots, heavy texture predominated to a depth of 1.1 m, where there was an abrupt change to sandy, unconsolidated limestone to at least 1.7 m, the depth of the pit. Soil texture from the surface to 30 cm depth was silty clay, changing to silty clay loam in the 30-45 cm depth. Table 5-1 shows texture and organic carbon content for the trial site.

Table 5-1: Soil texture and organic carbon at the trial site.

Depth	% Sand	% Silt	% Clay	% Organic Carbon	Texture
0-15 cm	8.4	49	42.6	1.71	silty clay
15-30 cm	7.2	41	51.8	1.10	silty clay
30-45 cm	7.2	53	39.8	1.0	silty clay loam

A pot study was established in January 1994 to determine how soil water depletion at the ODH site correlated with plant water stress (Appendix A). When soil water percent in the root zone decreased below about 25%, leaf water pressure passed

below 10 bars. Maize plants began to exhibit signs of drought stress at this point. Field capacity at the site was reached at 41% soil water content.

Average annual rainfall based on data collected by ODH staff since 1977 was 968 mm per year. Distribution is bimodal, with most of the spring rains falling from April through June, and the fall rains from August through November. The total annual rainfall since 1977 varied from a low of 670 mm to a high of 1.301 mm, but in most years rainfall was at least 900 mm. The trial site was located to the north of a small-container tree nursery, and was previously used for tractor cultivation of hybrid sorghum. The area to the east was used for composting sugarcane *bagasse*. A low earth barrier separated the trial area from the composting area, to prevent water used for composting from entering the trial.

Trial design

The trial design was a 2 by 2 factorial randomized complete block having 11 hedgerows of *Leucaena leucocephala* variety K636 planted at a within-row density of 10 trees per meter and a between row spacing of 5 meters. Each block consisted of a hedgerow 22 meters long running through the center of four maize plots, to which were randomly assigned the four treatment combinations. The hedgerows were laid out exactly on an east-west axis, with hedgerow (block) 1 on the north end of the site and hedgerow (block) 11 on the south side (Figure 5-1). The symbol T+ denotes a trenched plot, T--a nontrenched plot; the symbol F+ denotes a fertilized plot, F--a nonfertilized plot. All plots received the designated treatments throughout the three seasons of the study. Figure 5-2 shows the layout of one of the plots within a block.

Each plot was centered on the hedgerow, and included four rows of maize on the north side and four on the south side at 50, 100, 150, and 200 cm distances from the

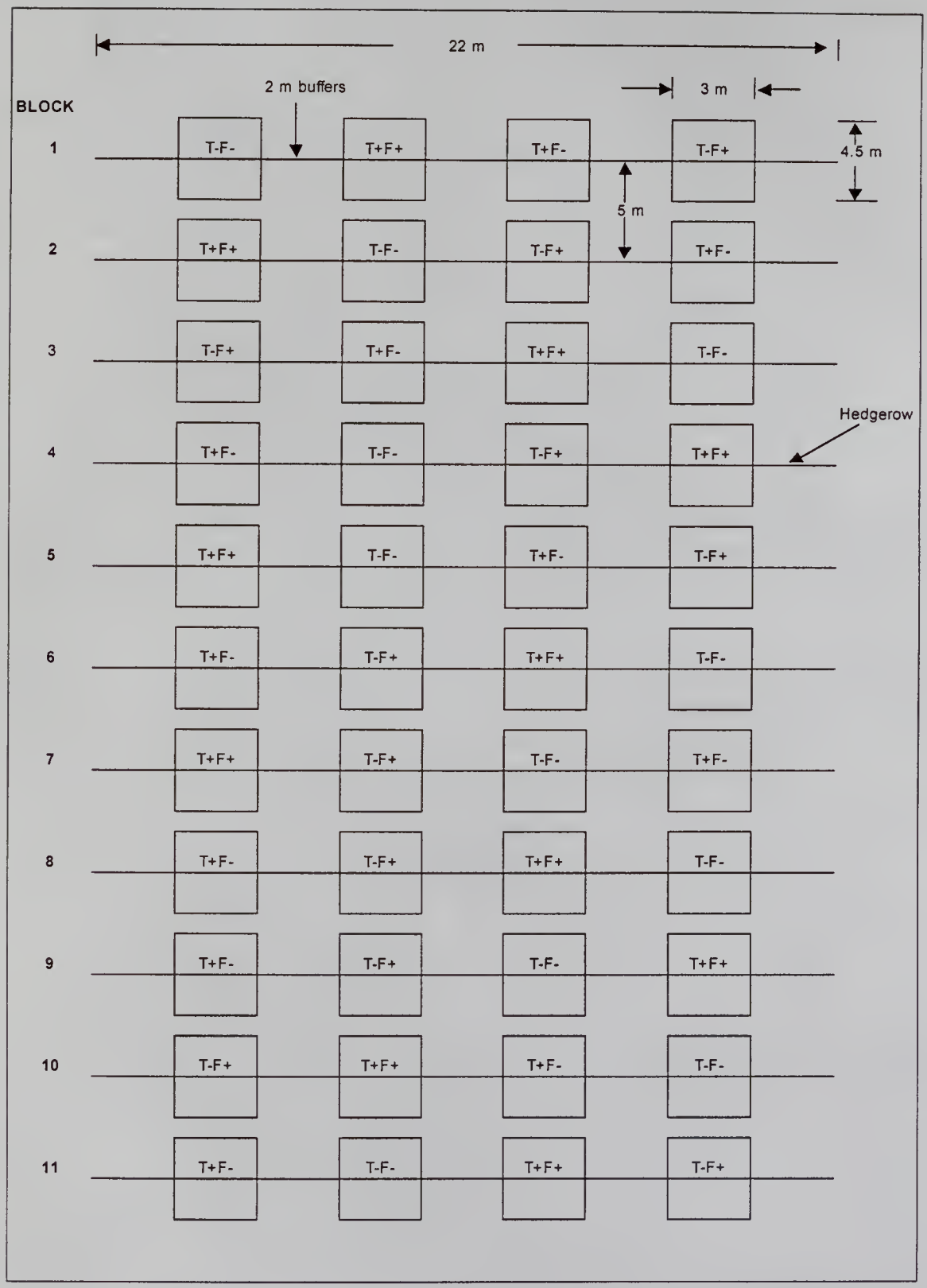


Figure 5-1: Layout of the *Leucaena*/maize hedgerow trial on Operation Double Harvest property near Croix des Bouquets, Haiti

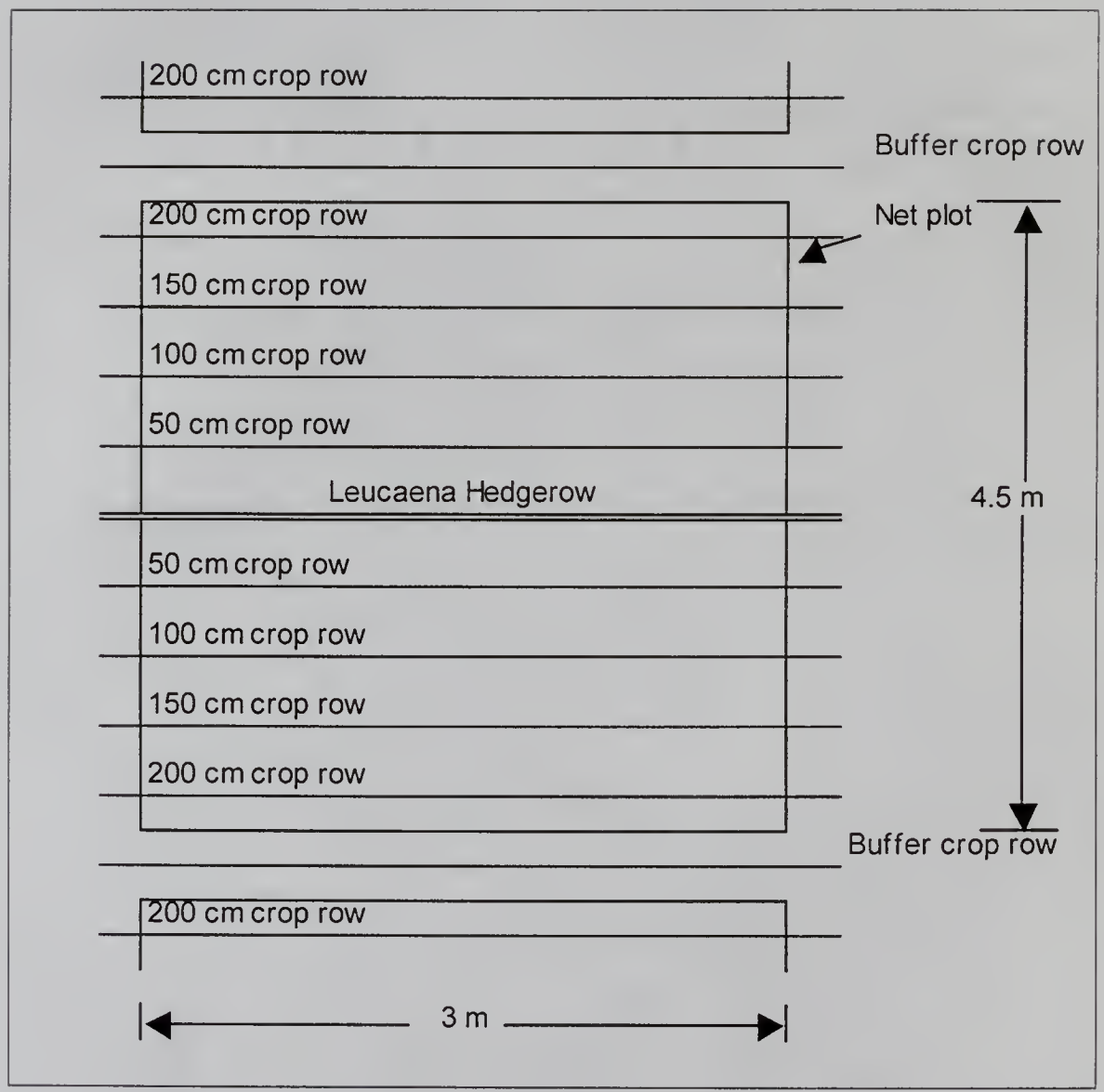


Figure 5-2: Diagram of one plot showing relative positions of a *Leucaena* hedgerow and the adjacent rows of maize at four distances.

hedgerow, respectively. Buffer rows of maize were planted at 250 cm from the hedgerows, marking the middle of the alley between hedgerows. Two-meter buffers separated the plots within the blocks. Rows 1 and 11 were borders from which no data were collected. Hedgerow experiments have been criticized for producing invalid results because the no-hedgerow controls (sole crop plot) have been exploited by hedgerow roots growing into adjacent plots, thereby over-estimating the benefits of hedgerow intercropping (Hauser and Gichuru 1994). Some more recent studies have compensated for this by digging trenches between hedgerow plots and control plots (Chamshama et al. 1998, Mugendi et al. 1999). Although the study reported here does not have sole crop plots, and a two-meter buffer was left between plots, it is possible that *Leucaena* roots in plots both with and without barriers exploited the soil in adjacent plots. This could not be confirmed in this experiment.

Treatment installation

The hedgerow trees, grown in the ODH nursery, were planted out in April 1990 as one-year-old seedlings. The trees were cut to 50 cm stumps on 23 March 1991. In April 1991, two randomly selected plots in each block were trenched to a depth of 30 cm at a distance of 20 cm from each side of the hedgerows. The trenching was done with picks, severing all roots. Plastic sheeting was put into the trenches to inhibit root re-growth; the small canals created during root cutting were backfilled with soil. Trenching extended for one meter beyond each side of the net plot boundaries, halfway into the two-meter buffer between each plot. The decision to cut the roots to a depth of 30 cm was based on a preliminary study of *Leucaena* roots done at a location off-station (Appendix B). That study indicated 70% to 96% of the very fine roots (< 1 mm diameter) were found in the top 30 cm of the soil, the lowest percent being found 150 cm

and 200 cm uphill from the hedgerow. A lesser percent of the fine roots (1-5 mm diameter) were found in the top 30 cm (20 to 83%), with the least (20%) at the 200 cm uphill position. Very few medium and large roots were found, but of those that were, 50% or more were deeper than 30 cm. Studies in semiarid India also found the majority of *Leucaena* hedgerow root biomass in the top 30 cm of soil (Ong et al. 1991, Singh et al. 1996).

Due to my forced absence after the spring 1991 maize season the *Leucaena* hedgerows in the main experiment were not top pruned between October 1991 and September 1993. By that time, the hedgerow trees had grown to basal diameters of up to 10 cm. They were then cut back to a 50 cm stump height. Because the Spring 1994 maize harvest indicated the effect of trenching had almost disappeared, the plots were re-trenched to a depth of 50 cm in August 1994 before the fall maize planting. Plastic barriers were buried as before. The plastic barriers from the first root pruning were still in place, but were missing or stiff and degraded in spots. In some places, soil had covered the top of the barriers during cultivation, and *Leucaena* roots had grown over the barriers into the alleys.

A selected local maize variety, known as chicken corn, was planted between the hedgerows. The within-row spacing for maize hills was 75 cm, with 50 cm between rows. Hill positions were laid out precisely using nylon cord with flagging tied at 75 cm intervals. Maize was planted by hand three seeds per hill, and later thinned to two plants per hill. The maize density of the interspaces at full stocking was then 53,333 plants per hectare. If the space occupied by the hedgerows is included, maize plant density was 48,000 plants per hectare. Observations of 28,000 and 40,000 maize plants per hectare were made on two farms in the south of Haiti at harvest time (after substantial mortality

during the season) in plots without hedgerows. Farmer interviews in one region of northern Haiti indicated a higher density at planting, 62,500 plants per hectare (Swanson et al. 1993a).

The fertilizer was to have been applied according to recommendations of the Ministry of Agriculture, Haiti (MARNDR 1990): an initial broadcast application of 15-15-15 (NPK) of 175 kg/ha at seeding followed by two applications of banded urea at 50 kg per hectare. In practice, however, due to the timing of rainfall and political instability delaying travel to the site, only the spring 1995 maize crop received the complete fertilizer treatment. The spring 1994 crop received only the initial application of 15-15-15, and the fall 1994 crop received the 15-15-15 and the first urea application. Once a given plot had been designated as fertilized, it remained a fertilized plot throughout the three seasons reported here.

Operations by maize season

The spring 1994 maize crop was planted on 30 April. There had been 51 mm of rain during the previous 7 days, 93 mm during the previous 14 days. Most of the rain during the growing season fell between 11 and 21 DAS, with only one substantial rain event after that, 23 mm at 67 DAS. A total of 206 mm of rain fell between sowing and final harvest. The stand was thinned to two plants per hill at 28 DAS, and was weeded once at 16 DAS. Insecticide was applied twice during the season. Fertilizer was applied at a rate of 175 kg/ha at planting only; no urea was applied. *Leucaeana* top pruning was done 35 days before sowing, then at 33 DAS (when trees were about 2.3 m high, including the stump), and 65 DAS (when trees were about 1.8 m high). Figure 5-3 shows the amount and timing of the rainfall in relation to the growth of *Leucaena* and maize, and the timing of the agronomic interventions made to the plots during the spring 1994

season. The fall 1994 maize crop was planted on 10 September; two weeks after the hedgerows were re-trenched to a depth of 50 cm (Figure 5-4). No measurable rain fell during the 7 days preceding sowing, but 49 mm fell during the previous 14 days. Tropical Storm Gordon passed over Haiti on 14 November (65 DAS) and dropped over 150 mm of rain in a 24-hour period on the trial site. This surpassed the capacity of the rain gauge, so an accurate measurement was not recorded. This was the rainiest season of the three, with at least (because of the inaccurate measurement during Tropical Storm Gordon) 374 mm measured between sowing and final harvest. Most of the seeds had germinated and had attained a height of 10 cm by 21 DAS, when they were weeded and thinned to two plants per hill. Insecticide and urea (50 kg/ha) were applied at 26 DAS, when the maize was about 25 cm tall. Because the effect of trenching was weak during the previous season, the hedgerows were re-trenched to a 50 cm depth on 27 August 1994, 14 days before sowing the maize. Fewer measurements were made this season than in others due to the U.S. military intervention in Haiti on 19 September, and the events preceding and subsequent to it. Figure 5-4 shows the amount and timing of the rainfall in relation to the growth of *Leucaena* and maize, and the timing of the agronomic interventions made to the plots during the fall 1994 season.

The spring 1995 maize was planted initially on 26 March, but this planting failed due to lack of rain. A new planting was done on 22 May. During the seven days before sowing, 20 mm of rain had fallen, for a total of 39 mm during the 14 days before sowing. After planting no rain was recorded until the 34th day, then 171 mm fell between 34 and 73 DAS. However, because the technician responsible for recording rainfall was on vacation between the planting date and 36 DAS, two or three rainfall events were not recorded. No additional rain fell before final harvest. I applied 15-15-15 at sowing and

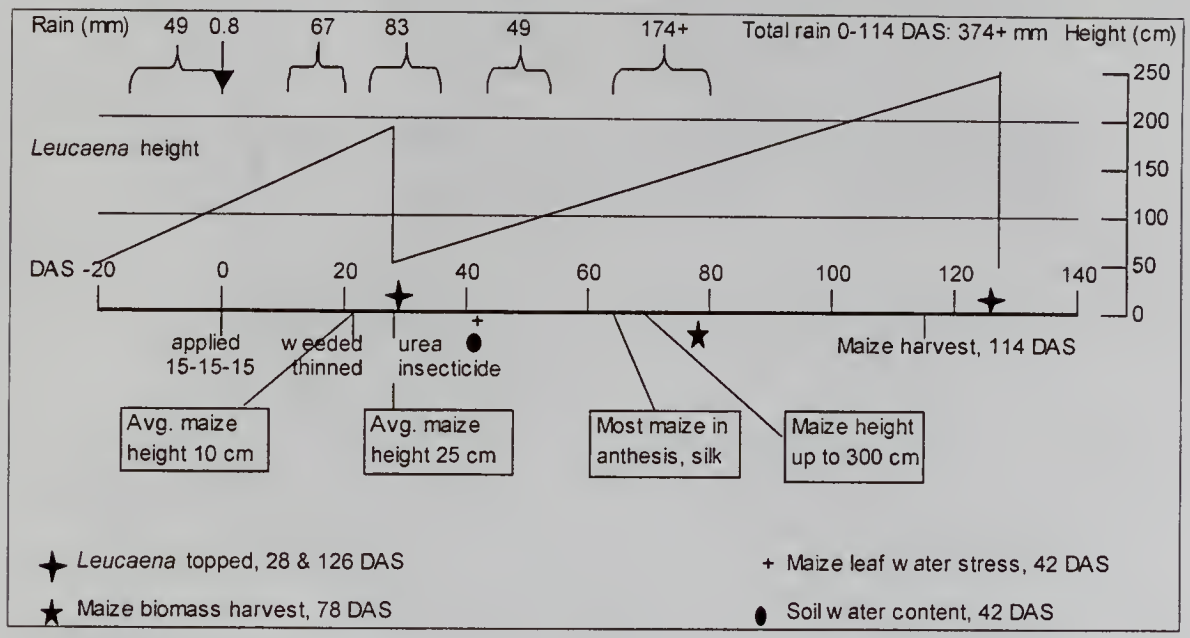


Figure 5-3: Rainfall, *Leucaena* and maize growth, and agronomic inputs; spring 1994 maize cropping season

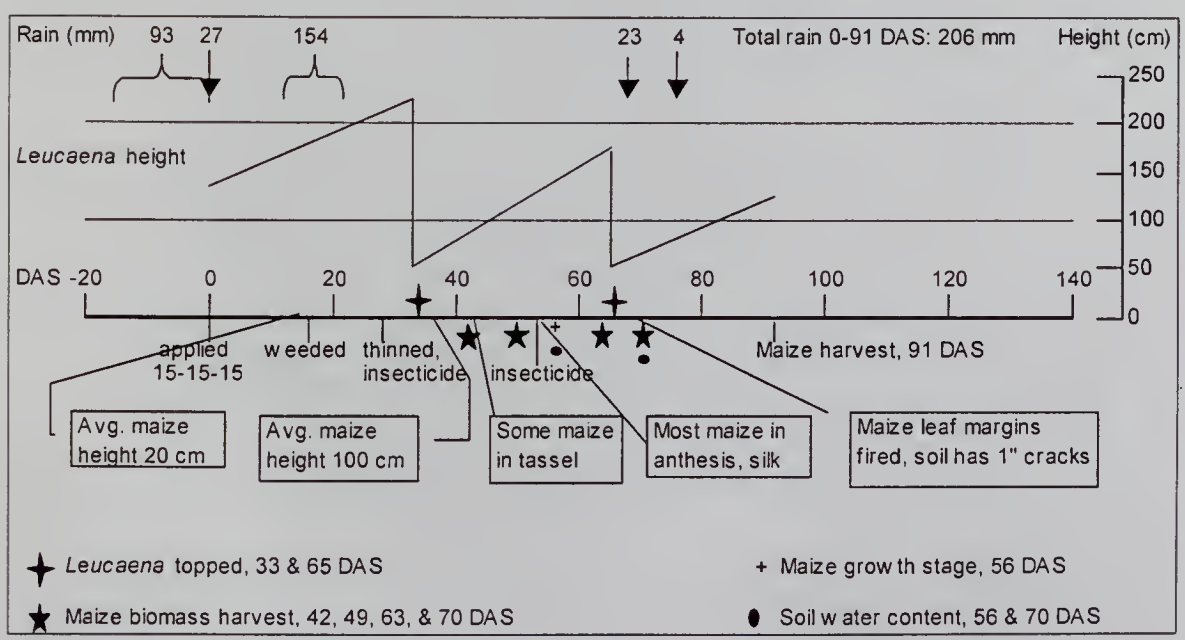


Figure 5-4: Rainfall, *Leucaena* and maize growth, and agronomic inputs; fall 1994 maize cropping season

banded urea at 12 and 37 DAS. The maize was thinned to two plants per hill at 12 DAS. The plots were weeded four times during the growing season; insecticide was applied twice. Figure 5-5 shows the amount and timing of the rainfall in relation to the growth of *Leucaena* and maize, and the timing of the agronomic interventions made to the plots during the spring 1995 season.

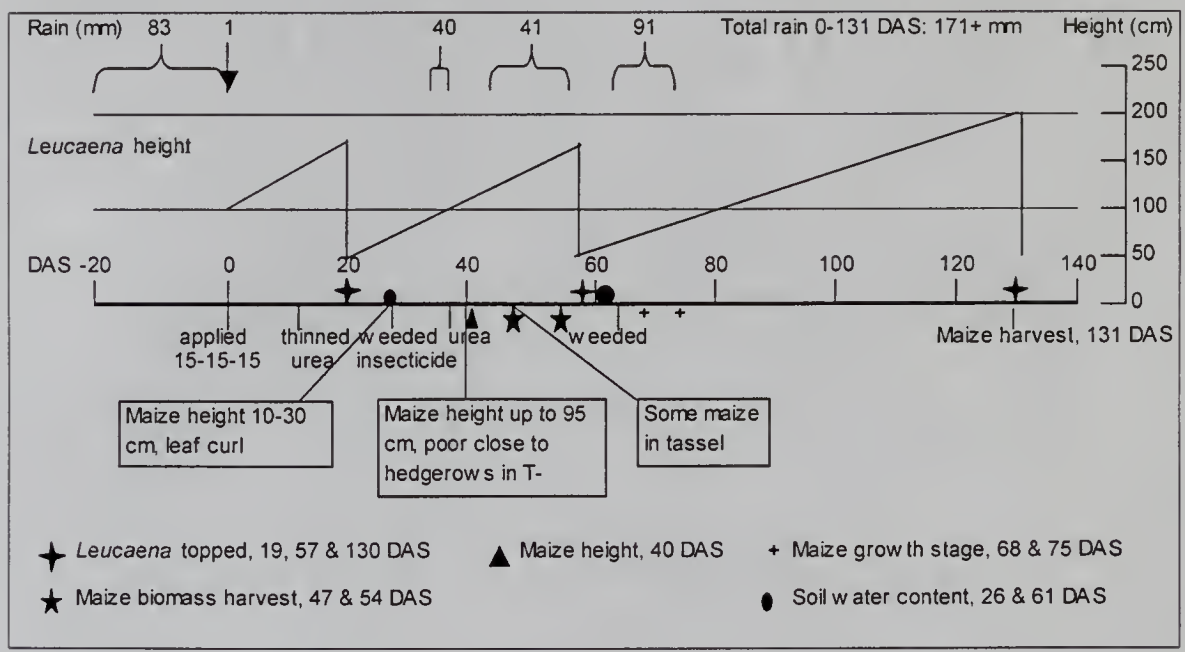


Figure 5-5: Rainfall, *Leucaena* and maize growth, and agronomic inputs; spring 1995 maize cropping season

Measurements recorded

The following observations and measurements were made during the three maize cropping seasons:

Maize height. This was done only for the spring 1995 season. Height to the top of the highest fully open leaf of the tallest plant in each hill in blocks 2, 4, 6, and 8 was measured at 40 days after sowing. Analysis was done on the mean height of eight plants in each of the four hills to the north and four hills to the south of the hedgerow at a given

distance in each plot. If all plants in a hill had died, a height of zero was assigned for that hill.

Maize growth stage. Growth stages of the plants were noted at 56 DAS in the spring 1994 season, and at 68 and 75 DAS in the spring 1995 season. In the spring 1994 season, the scale was: 0=no maize plant present, 1= vegetative growth, 2=tassel, 3=anthesis, 4=silk. For the spring 1995 season, the scale was changed to include the presence of ears: 0=no maize plant present, 1=vegetative growth, 2=tassel/anthesis, 3=silk, 4=ear. Observations were made in blocks 2, 3, 5, 6, 8, and 9 on every maize plant (2 plants per hill) in the spring 1994 season, and on only the most developed plant per hill in the spring 1995 season.

Maize biomass during the growing season. For each of the four distances and in each of the four plots in blocks 4, 7, and 10, the combined weight of one hill of maize on the north side and one hill on the south side of the hedgerow was recorded. The plants were cut at ground level, and then dried in a Watlow drying oven at 70 degrees C until a constant weight was obtained.

Maize leaf water pressure. Predawn leaf water pressure was taken using a PMS pressure chamber for one leaf at each distance in blocks 3, 6, and 9. A 2 cm by 10 cm section was cut from the highest fully expanded leaf, one end was placed in a zip-lock bag, and the sample was inserted into the pressure chamber. Compressed nitrogen gas is normally used in the chamber, but as this was not available in Haiti compressed air was used instead. This measurement was to have been done periodically throughout each maize season, but was done only once because of the security problems discussed in the footnote on page 44.

Maize yield. Grain yield, number of plants, and number of ears were measured from blocks 2, 3, 5, 6, 8, and 9 at 91 DAS for the spring 1994 harvest, 114 DAS for the fall 1995 harvest, and 131 DAS for the spring 1995 harvest. At each of the four distances (50, 100, 150, and 200 cm), plants were harvested from a 3-meter length on the north and south sides of the hedgerows, for a total of 6 meters (8 hills, or 16 plants maximum) harvested in each plot at each distance. Because the grain moisture meter ceased to function correctly, field dry grain weights are shown in the tables and figures. Harvests for all treatments were made at the same time, and all samples were weighed at the same time. Final harvest measurements are converted to per hectare equivalents by dividing the sample weight or count for a given distance from the hedgerows by six (six meters per plot were sampled) and multiplying by 4,500 (each distance represented 4,500 meters per hectare given a 50 cm row spacing). The per-hectare contributions of the rows at each distance were then summed to give a total per hectare figure, which included the 2,000 m occupied by the hedgerows.

Soil water percent. Soil cores were taken using a JMC Back-saver corer. Each core was divided into three sections, 0-15 cm, 15-30 cm, and 30-45 cm. Four cores for each depth and distance were combined for each measurement. The samples were weighed wet in the field and dried in an oven at 70 degrees C until a constant weight was obtained. Soil water content was determined gravimetrically by dividing the weight of water lost in drying by the dry weight of the sample. The range of soil water content that could be sampled at this site was narrow due to the heavy texture of the vertisol. When the soil was very dry, the 0-15 cm depth often was not retained in the sampling tube, and when the soil was wet, the end of the tube plugged and did not allow soil to enter. For the calculation of field capacity, a large-diameter hammer-driven corer was used. This is

a slow procedure and the large-diameter corer could not be used under normal circumstances due to the necessity of completing 192 cores in a single day each time sampling was done. Soil water content was sampled twice during the spring 1994 growing season, at 56 and 70 DAS. The first, at 56 DAS, was done on blocks 3 and 6 only because the corer shaft broke. All subsequent samplings were done on blocks 3, 6, and 9. A single sample was taken in fall 1994 at 42 DAS, and two were taken in spring 1995 at 26 and 61 DAS. An additional attempt was made to measure soil water content at 54 DAS, but this was not successful because the soil was too wet and the corer jammed.

Leucaena small stem and leaf biomass and height. *Leucaena* tops were cut back to a 50 cm stump height using a machete. Leaves were not separated from stems; they were weighed together in the field with a spring scale. Sub-samples were taken and dried in a Watlow oven at 70 degrees C until a constant weight was obtained. Height above the stump of the tallest stem in each plot was measured with a fiberglass tape. All leaves and stems were removed from the site after harvest.

Leucaena root intersections in trenched and nontrenched hedgerows. After the spring 1995 maize harvest was completed, numbers of *Leucaena* roots were counted in trenched and nontrenched hedgerows to discover what influence plastic barriers had on root distribution. Transects perpendicular to the hedgerows were excavated through rows 4, 5, and 6 (Figure 5-1), where there happened to be three trenched plots adjacent to three nontrenched plots. Work began on 13 January 1996, 105 days after the maize harvest. The plots were weeded three times during that period to keep out roots of grasses and weeds. Thirty sections 1.2 m wide by 1 m deep parallel to the trenched hedgerows and an equal number parallel to the nontrenched hedgerows were mapped, at 20, 50, 100,

150, and 200 cm distances. A Plexiglas plate inscribed with a 10 by 10 cm grid was pinned to each cut surface. The positions of the roots were marked on plastic sheets clipped over the Plexiglas plate, a separate symbol was used for each of four diameter classes: very fine (<1mm), fine (1-5 mm), medium (5-10 mm), and large (>10 mm).

Statistical analysis

Statistical analysis was done using the SPSS version 9.0 univariate GLM ANOVA procedure. The model used for the dependent variables *Leucaena* leaf and small stem biomass and height above the stump was as follows:

$$y_{ijkl} = \mu + block_{i} + t_{j} + f_{k} + t*f_{jk} + error_{ijkl}$$

where: y=dependent variable, t=trenching, f=fertilizer

i=2, 3, 4, 5, 6, 7, 8, 9, 10

j=0, 1 where 0=not trenched and 1=trenched

k=0, 1 where 0=no fertilizer applied and1=fertilizer applied

For each kind of field measurement taken at the four fixed distances and/or the three soil depths, three levels of analysis were done—an overall ANOVA (referred to as the complete model throughout the text) that included all the main effects and their interactions, ANOVAs done separately for trenched and nontrenched plots that included all other effects, and ANOVAS done separately for each distance from the hedgerows that included only trenching and fertilization factors and their interaction. For percent soil water, separate ANOVAs were done for each combination of distance from the hedgerows with each of the three depths (0-15 cm, 15-30 cm, 30-45 cm). If there were significant trenching by fertilization interactions produced by the ANOVAs done separately for each distance and depth, contrast statements were run to determine at which levels the interactions were significantly different.

The following example shows the complete ANOVA model used for the dependent variables: maize biomass taken during the growing season, maize height, maize leaf water pressure, maize grain at final harvest, number of maize plants at final harvest, and number of maize ears at final harvest.

$$y_{ijklm} = \mu + block_i + t_j + f_k + t*f_{jk} + d_l + t*d_{jl} + f*d_{jl} + t*f*d_{jkl} + error_{ijklm}$$

where: y=dependent variable, t=trenching, f=fertilizer, d=distance

i=2, 3, 5, 6, 8, 9 (blocks used varied for each dependent variable)

j=0, 1 where 0=not trenched and 1=trenched

k=0, 1 where 0=no fertilizer applied and1=fertilizer applied

l=50, 100, 150, 200 cm distance from hedgerows

The overall mean square error was used to test the effect of distance and its interactions. However, because measurements were taken at fixed distances and depths, giving a split-plot characteristic to the experimental design, an "error a" term was computed by adding sums of squares for the interactions of blocks with trenching and fertilizer. This was used to test the effects of trenching and fertilizer and their interaction.

The complete model for the percent soil water ANOVAs was:

$$y_{ijklmn} = \mu + block_i + t_j + f_k + t*f_{jk} + d_l + t*d_{jl} + f*d_{jl} + t*f*d_{jkl} + dp_m + t*dp_{jm} + f*dp_{km} + d*dp_{lm} + t*f*dp_{jkm} + error_{ijklmn}$$

where: y=dependent variable, t=trenching, f=fertilizer, d=distance

i=3, 6, 9

j=0, 1 where 0=not trenched and 1=trenched

k=0, 1 where 0=no fertilizer applied and1=fertilizer applied

l=50, 100, 150, 200 cm distance from hedgerows

m=0-15, 15-30, 30-45 cm depth from soil surface

In addition to the "error a" term computed and applied as above. for the soil water ANOVAs an "error b" term was computed to test the effects of distance and its interactions with trenching and fertilizer. Sums of squares for the interactions of blocks with distance and its interactions with trenching and fertilizer were added to compute this term. The overall error term was used to test the effects of depth and its interactions.

"Error a" and "error b" and the corresponding F values were computed by hand; SAS version 7.0 was used to compute the appropriate p-values. Soil water was expressed as a percent, however the range of values was narrow (13% to 39%) and not extremely high or low, so an arcsin transformation to stabilize the variances was not applied before running the ANOVAs (Ott 1992).

Not all of the interactions that resulted in significant tests were meaningful due to the very low numerical values of the differences. P-values for all factors and their interactions are shown in Appendix C for all of the ANOVAs and contrasts.

Paired t-tests were used to detect significant differences in the numbers of root intersections between trenched and nontrenched plots. This was possible because each pair of measurements at each distance and depth were taken from physically adjacent positions.

Results and Discussion

Results for each maize season are presented separately in this section, followed by the results of the root distribution study and a general discussion.

Spring 1994 season

Two factors made this season differ from the two subsequent ones—the 30 cm root barriers installed in the trenched plots in 1991 apparently no longer presented an effective obstacle to the passage of *Leucaena* roots from the hedgerow into the alleys, and the rainfall was poorly distributed.

Rainfall was 206 mm for the growing season and there was good soil water at planting (51 mm fell in the 7 days prior to planting). However, most of the rain during the growing season fell between 11 and 21 DAS (154 mm), and then no rain fell until 67 DAS (23 mm), which was the last effective rainfall event before final harvest. The plants had reached about 20 cm height by 14 DAS. At 35 DAS the height was about 1 m, but the soil was dry and cracking. Maize was always shorter than *Leucaena* until the 33 DAS hedgerow pruning; at that time the maize was about one meter high and the hedgerows 50 cm. Maize tasseling began about 42 DAS, with most of the plants in anthesis or silk by 50 DAS. The plants showed increasing signs of stress as the season progressed. Many of the plants had fired leaf margins, and soil cracks opened to about 2.5 cm after 60 DAS.

Maize biomass production. Aboveground biomass production during the growing season was not affected significantly by trenching or by fertilizer application, but the amount of biomass did differ with distance from the hedgerows. The four measurements of maize biomass are shown together in Figure 5-6.

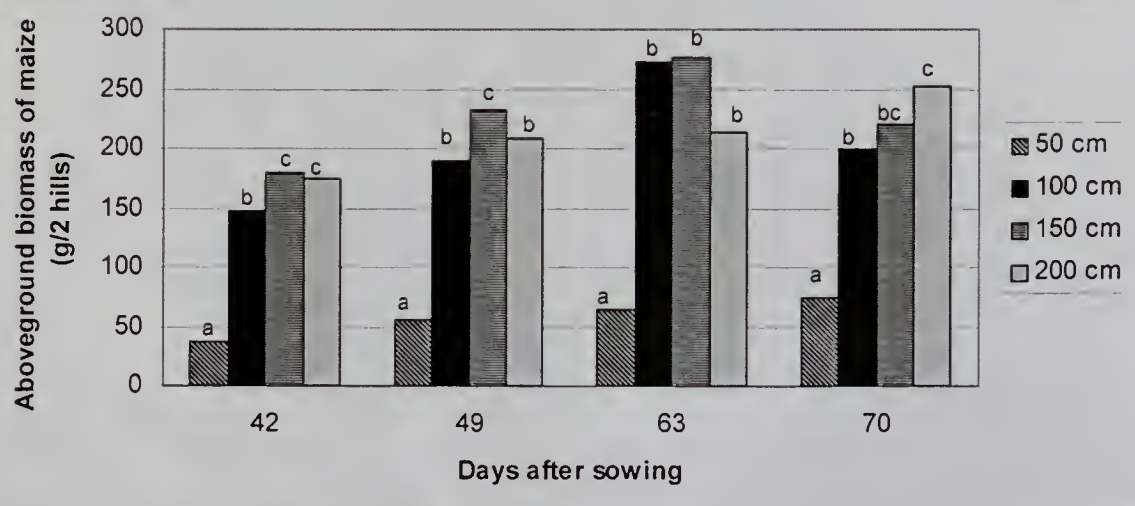


Figure 5-6: Maize biomass yields at 50, 100, 150, and 200 cm from the hedgerows at four times after sowing during the spring 1994 season

For the ANOVA model that included distance, there were no significant effects of fertilization (α=.05 or α=.10) on the weight of maize biomass, and only one case where trenching was significant (p = .085) at 63 DAS. P-values for the effect of distance on maize biomass were <.001 at all four observations. The weight of maize biomass produced was always significantly lower at 50 cm from the hedgerows. It appeared to peak at 150 cm for the first three observation periods, although that distance was significantly greater than the others only at 49 DAS (Figure 5-6). At 70 DAS, the weight of biomass peaked at 200 cm. Competition between the maize and the trees clearly extended to 100 cm at 42 DAS, and to 50 cm thereafter.

When the analyses were done separately at each distance, the effect of trenching was significant only at 50 cm from the hedgerows at 42 DAS and at 63 DAS (Table 5-2). In these two cases, the amount of maize biomass produced in trenched plots was at least double that produced in nontrenched plots.

Table 5-2: Effect of trenching on the production of maize biomass 50 cm from the hedgerows at 42 and 63 DAS; spring 1994.

	42 DAS	**63 DAS**
Trenched biomass (g)	50	93
Nontrenched biomass (g)	25	37
p-value	.039	.039

There were also four instances when the effect of fertilizer was significant. More maize biomass was produced in the nonfertilized (F-) plots at 49 DAS at both the 50 cm and 100 cm distance from the hedgerows (Table 5-3). At both 42 and 49 DAS there was a significant interaction of fertilizer and trenching at the 150 cm distance from the hedgerows, in both cases more maize biomass was produced in trenched (T+) plots

(Table 5-3). However, at 42 DAS this effect was seen only between trenched and nontrenched plots that were also fertilized, while at 49 DAS the effect was seen only between plots that were not fertilized.

Table 5-3: Effect of fertilizer on the production of maize biomass 50, 100, and 150 cm from the hedgerows at 42 and 49 DAS; spring 1994.

	49 DAS			**42 DAS**	**49DAS**
	50 cm	**100 cm**		**150 cm F+**	**150 cm F-**
Maize (g) F+	50	168	Maize (g) T+	196	238
Maize (g) F-	62	209	Maize (g) T-	163	174
p-value	.063	.002	p-value	.055	.010

Maize growth stage. Numerical values corresponding to maize growth stages were assigned at 56 DAS using the scale 0=absent, 1= vegetative growth, 2=tassel, 3=anthesis, 4=silk. On average, the plants at 50 cm were in the vegetative stage, all others were in tassel or anthesis (Figure 5-7).

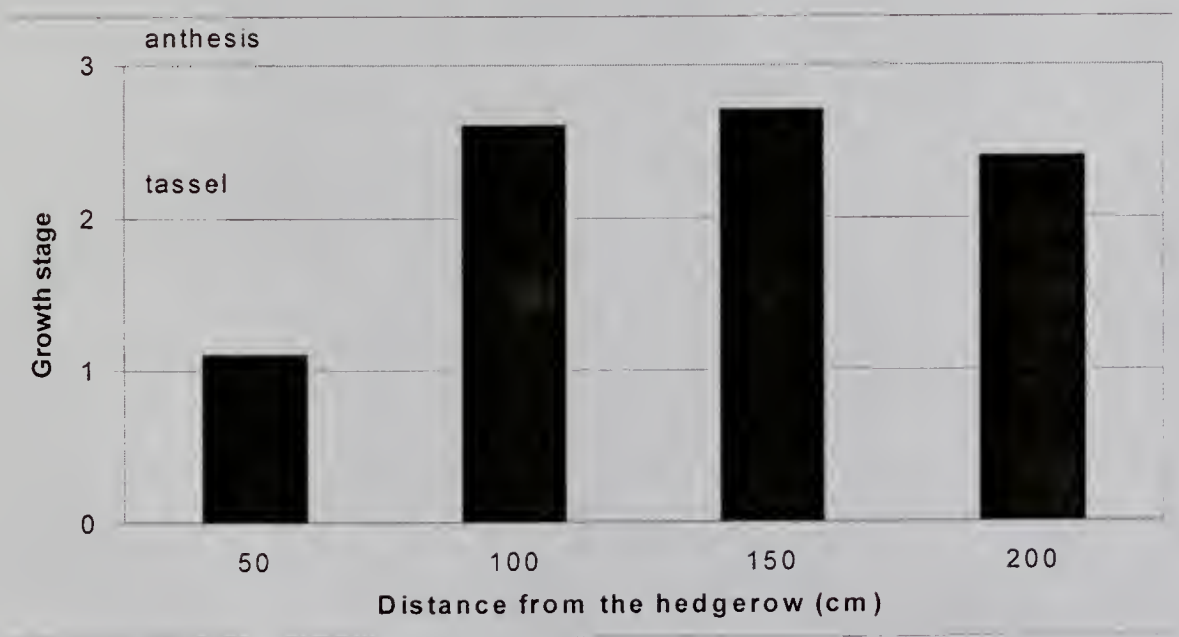


Figure 5-7: Growth stage of maize at four distances from hedgerows, 56 DAS; spring 1994.

Soil water content. This was measured twice during this season, at 56 and 70 DAS. The ANOVAs that included both distance and depth in the model did not reveal any differences in soil water due to trenching, fertilization, or distance from the hedgerows. There were differences among depths below the surface, as shown in Table 5-4. At 70 DAS the surface 15 cm had more soil water than the deeper layers, probably because 23 mm of rain fell just three days before the measurement. This was the first rain since 21 DAS. At 56 DAS the water content of the soil increased steadily with depth. The water content of the 30-45 cm layer was the same for both observations.

Table 5-4: Soil water at three depths below the surface at 56 and 70 DAS; spring 1994.

	Soil Water %—Gravimetric	
	56 DAS	**70 DAS**
0-15 cm	15.0 a	24.0 c
15-30 cm	21.6 b	22.2 a
30-45 cm	23.5 c	23.4 b
p-value	<.001	<.001

The complete model also indicated significant soil water interactions between trenching and fertilizer ($p = .081$) at 56 DAS, and between trenching and distance ($p = .020$) and fertilizer and distance ($p = .007$) at 70 DAS. When ANOVAs were done separately for each depth and distance, with trenching and fertilizer as the only independent variables, there were no significant differences in soil water percent between the two trenching treatments at any distance or depth. In only two cases were the differences between the two fertilizer treatments significant: at 56 DAS 100 cm distance in the 30-45 cm depth the fertilized plots had 23.1% soil water vs. 24.2% for the unfertilized plots ($p = .004$), and at 70 DAS 200 cm distance in the 15-30 cm depth

fertilized plots had 21.1% soil water vs. 23.1% for the unfertilized plots ($p = .027$). At 56 DAS there was a significant interaction at the 100 cm distance from the hedgerows: at the 0-15 cm depth trenched plots had less soil water than nontrenched plots where no fertilizer was applied ($p = .067$); the reverse was true in the fertilized plots ($p = .034$). The meaning of these interactions is not clear, since fertilizer was not significant as a main effect. P-values for all interactions are listed in Appendix C, but not all will be discussed as they are too numerous and add little to the understanding of the treatment effects.

Maize yield. Grain yield for this season was very low, with no significant differences due to trenching or fertilizer. A per-hectare equivalent corresponding to the average values per six-meters as shown in Figure 5-8 is 182 kg/ha maize grain, with only 5.2 kg/ha of the total contributed by the 50 cm rows. As with maize biomass and sexual development, grain yield was affected only by distance from the hedgerows. In addition, the peak production in grain yield and number of ears appeared at 150 cm from the hedgerows, then declined slightly at 200 cm. This is also similar to the pattern observed in biomass production and sexual development, with a decline between 150 cm and 200 cm, although it was only statistically significant at 49 and 56 DAS.

Apparently, competition between maize and hedgerows affected the survival of maize plants differently than grain yield or number of ears. There were significantly fewer surviving plants at harvest time in the row closest to the *Leucaena*, but in the other three more distant rows maize plant survival was the same, and did not decrease between 150 and 200 cm (Figure 5-9). Full stocking for each distance depicted in Figure 5-9 would have been 16 plants (per 6 m, or per 8 hills), equal to 12,000 plants per hectare at each distance, totaling 48,000 plants per hectare if all had survived. Maize plant survival

with distance from the hedgerow was 48%, 84%, 87%, and 80% at 50 cm, 100 cm, 150 cm, and 200 cm from the hedgerows, respectively.

Figure 5-8: Yield of maize grain per six meters at four distances from the hedgerows; spring 1994.

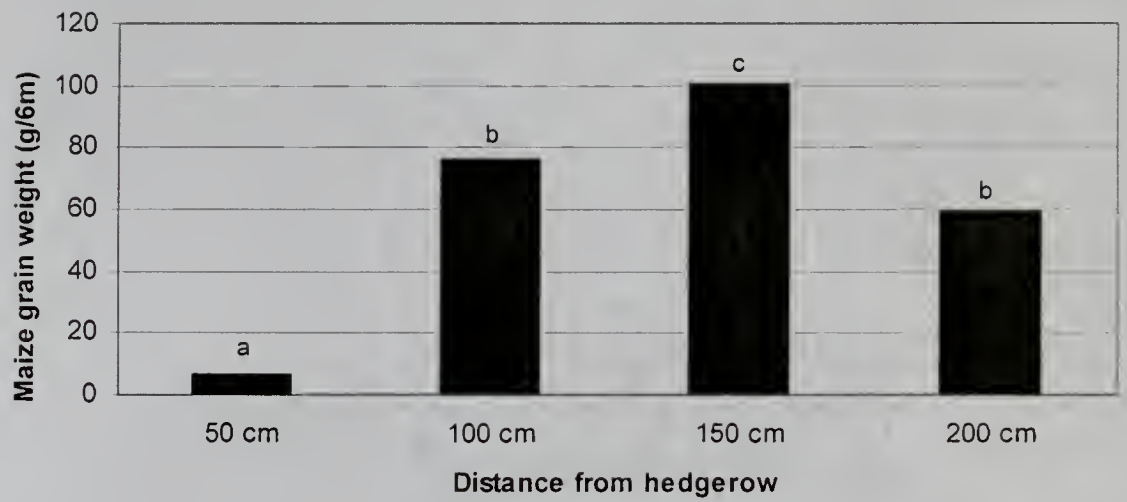
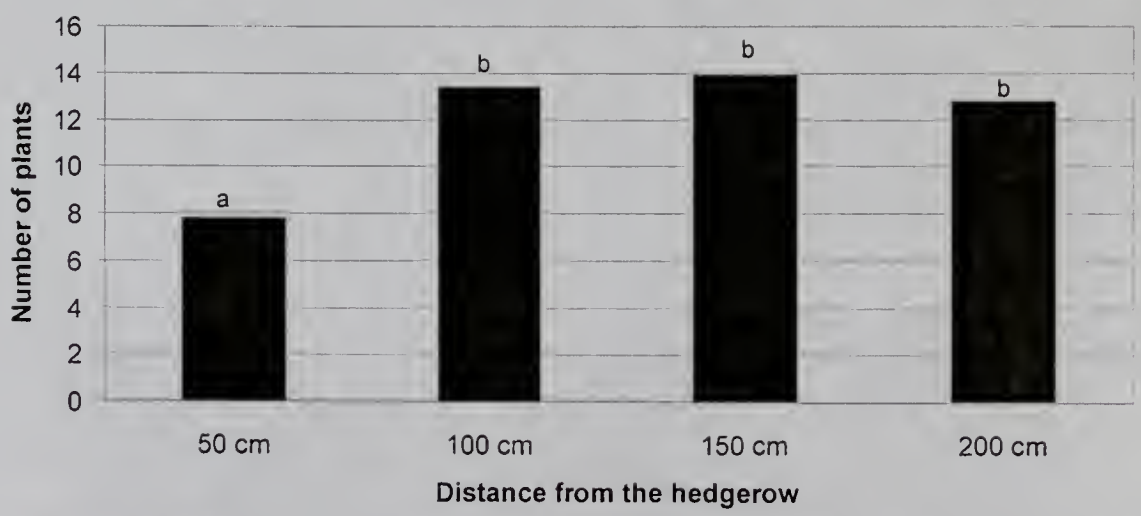


Figure 5-9: Number of maize plants per eight hills at four distances from the hedgerows; spring 1994.



Since the number of ears did not differ significantly between 100 and 150 cm (Figure 5-10) and the grain yield did differ, the implication is that grain yield per ear was lower at 100 cm than at 150 cm. This was the case, with the grain weight (g) per ear for the four distances being, respectively, 3.5, 10.8, 13.0, and 9.7.

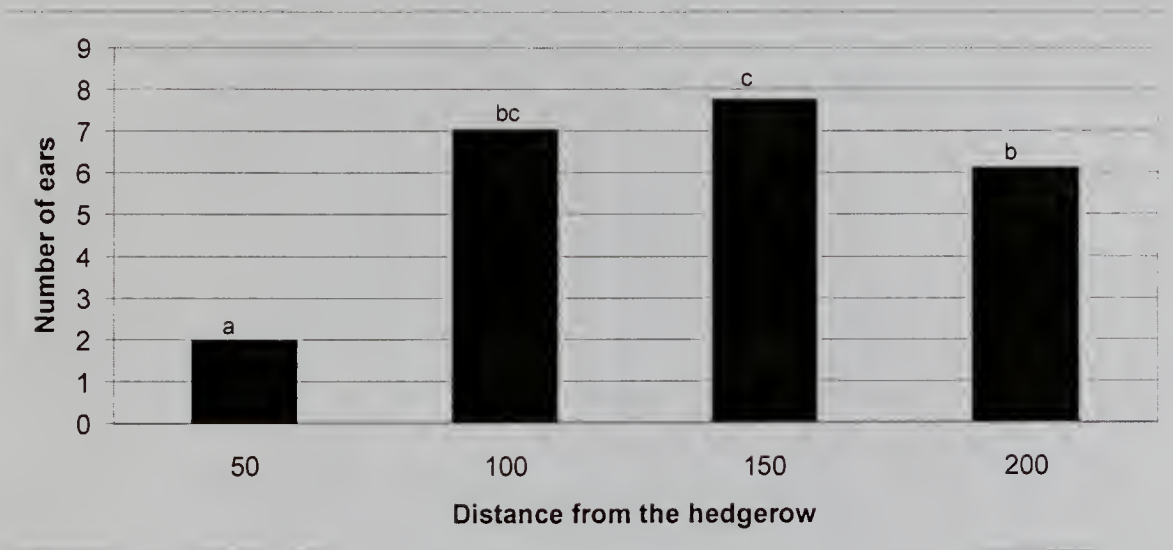


Figure 5-10: Number of maize ears per eight hills at four distances from the hedgerows; spring 1994.

Table 5-5 shows the data presented in Figures 5-8, 5-9, and 5-10 on a per hectare basis.

Table 5-5: Maize grain weight, number of plants, and number of ears at four distances from the hedgerows and as a total per hectare, with p-values for the differences between distances.

Distance (cm)	Grain (kg)	No. of plants	No. of ears
50	5.2 a	5,813 a	1,500 a
100	56.9 b	10,031 b	5,281 bc
150	75.3 c	10,406 b	5,813 c
200	44.6 b	9,563 b	4,594 b
Total/ha	182.0	35,813	17,188
p-value	<.001	<.001	<.001

Leucaena biomass–production and height. The four *Leucaena* harvests discussed in conjunction with the spring 1994 maize season are those made after my post-*coup d'etat*-return to Haiti, but before the hedgerows were re-trenched prior to the fall 1994 maize season. The 20 November 1993 harvest was the first re-growth after the overgrown trees were cut back to 50 cm stumps, but this was before the first application of fertilizer to a maize crop so the F+ and F- designations are not meaningful for this harvest. Table 5-6 shows the weight of biomass harvested and Table 5-7 shows the height above the stump for the four treatment combinations. The 33 and 65 DAS harvests were taken during the spring 1994 maize season.

Table 5-6: Stem and leaf biomass harvests and daily growth increments of *Leucaena* hedgerows 33 and 65 DAS; Spring 1994.

	20 Nov 93		2 Jun 94		4 Jul 94		20 Aug 94	
	Biomass (kg/m)	Increment (g/m/d)	Biomass (kg/m)	Increment (g/m/d)	Biomass (kg/m)	Increment (g/m/d)	Biomass (kg/m)	Increment (g/m/d)
T+F+	1.1	17.8	0.9	12.4	0.4	11.5	0.5	10.0
T+F-	1.2	18.3	0.9	12.6	0.3	10.4	0.4	9.1
T-F+	1.4	21.7	1.0	14.1	0.4	12.2	0.5	10.2
T-F-	1.2	18.9	0.9	12.5	0.4	11.3	0.5	10.9
p-value T	.074		.139		.300		.283	
p-value F	.358		.224		.187		.941	
p-value TxF	.198		.091		.994		.400	
DSPH[a]	63		69		32		47	
RSPH (mm)[b]	162		312		0		53	
DAS	42[c]		33		65		between crops	

a: Days since previous hedgerow harvest
b: Rainfall since previous hedgerow harvest
c: DAS (days after sowing) is reported because a fall 1993 maize crop was growing in the plots at this time. This maize season is not reported here, as it was lost due to animal damage.

It appears that the effect of the initial trenching on *Leucaena* biomass production did not last beyond 20 November 1993, when there was a small reduction in biomass

production in the trenched plots (p = .074). Trenched plots produced 1.15 kg/m, while nontrenched plots produced 1.3 kg/m. A five-meter spacing means there are 2,000 meters of hedgerow per hectare, so this amounts to a reduction of 300 kg/ha due to trenching. There was no significant trenching effect in the subsequent three harvests, nor did fertilizer application to the maize influence *Leucaena* production. The reduction in *Leucaena* daily growth rate beginning in July and continuing in August was probably a response to less rainfall during that period.

Table 5-7: Height above a 50 cm stump and daily growth increments of *Leucaena* hedgerows prior to the second root trenching, 33 and 65 DAS; Spring 1994.

	20 Nov 93		2 Jun 94		4 Jul 94		20 Aug 94	
	Height (m)	Increment (cm/d)	Height (m)	Increment (cm/d)	Height (m)	Increment (cm/d)	Height (m)	Increment (cm/d)
T+F+	2.1	3.3	1.8	2.6	1.2	3.8	1.4	3.0
T+F-	2.1	3.3	1.8	2.6	1.3	4.1	1.4	3.0
T-F+	2.0	3.2	1.8	2.6	1.2	3.8	1.4	3.0
T-F-	2.2	3.5	1.7	2.5	1.2	3.8	1.5	3.2
p-value T	.725		.462		.095		.403	
p-value F	.076		.840		.393		.640	
p-value TxF	.129		.329		.160		.640	
DSPH[a]	63		69		32		47	
RSPH (mm)[b]	162		312		0		53	
DAS	42[c]		33		65		between crops	

a: Days since previous hedgerow harvest
b: Rainfall since previous hedgerow harvest
c: DAS (days after sowing) is reported because a fall 1993 maize crop was growing in the plots at this time. This maize season is not reported here, as it was lost due to animal damage.

Leucaena height growth is a less precise measure than the biomass yield, and was taken to the nearest 10 cm. Neither trenching nor fertilizer application appeared to affect height growth during the four harvests shown in Table 5-7. The p-value of .076 for the effect of fertilizer on 20 November 1993 is difficult to explain, because this was before

the first fertilizer application to the maize crop. The significant ($p = .095$) effect of trenching on 4 July is associated with a very small numerical height advantage in the trenched, nonfertilized plots. It is interesting to note that while daily *Leucaena* biomass increment decreased after 2 June (Table 5-7), daily height growth rate increased. The July and August cutting intervals were shorter than the previous two, so this may mean that *Leucaena* puts on stem height first, then adds stem diameter, leaf biomass, or new stems later in the cycle.

Fall 1994 season

The fall 1994 season was the best of the three in terms of maize production, because it had the highest rainfall and the best rainfall distribution through the growing season. After the *Leucaena* was pruned at 28 DAS, the maize quickly gained a height advantage over the hedgerow trees and maintained it throughout the rest of the season in both the trenched and nontrenched plots, including the rows closest to the trees. Most of the plants were in flower (tassel and silk) by the time tropical storm Gordon passed at 65 DAS. By 70 DAS the maize was about 3 m tall, taller by about 1 m than the *Leucaena* hedgerows.

Maize biomass production. Maize biomass production was measured only once during the season, at 78 DAS. The ANOVA for the complete model (including distance) was significant for trenching ($p = .018$) and distance from the hedgerow ($p = .023$). ANOVAs separate by distance showed that only at the 50 cm distance from the hedgerows was trenching a statistically significant factor ($p = .037$). At all other distances trenched plots produced more maize biomass than nontrenched plots, but the difference was not significant (Figure 5-11). The complete model also indicates an interaction between trenching and fertilizer at the 150 cm distance ($p = .093$). There was

significantly more biomass produced in trenched (509 g) than nontrenched plots (307 g) where they were not fertilized, but the difference was not significant in fertilized plots.

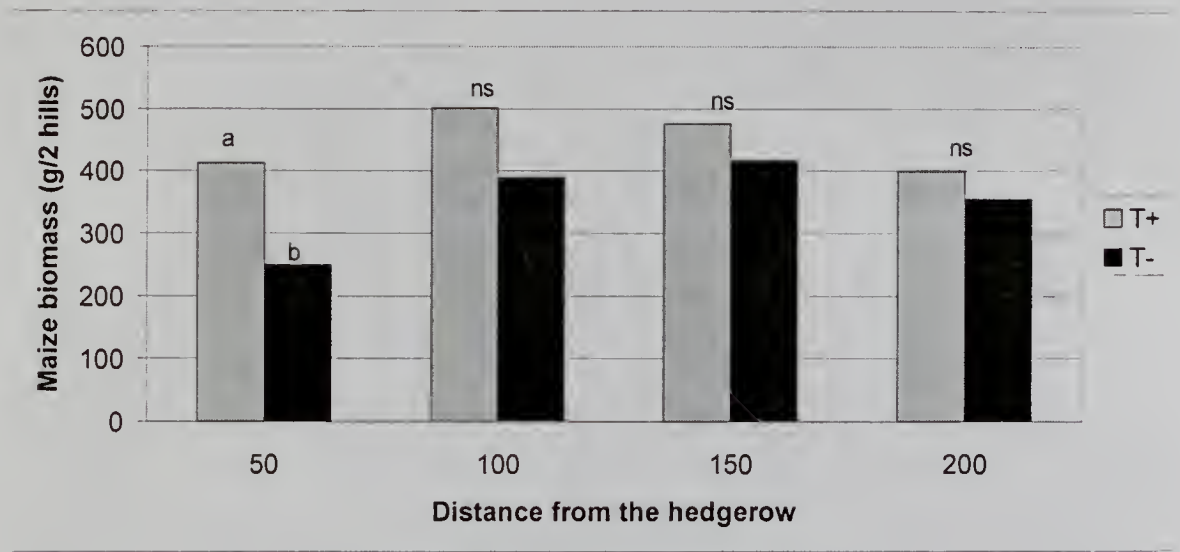


Figure 5-11: Trenched and nontrenched plots at 50, 100, 150, and 200 cm from the hedgerows, 78 DAS; fall 1994.

ANOVAs run separately for trenched and nontrenched hedgerows showed that distance was a significant factor only for nontrenched hedgerows, with the 50 cm distance producing less biomass than the other distances. This was not the case for trenched hedgerows, where no significant difference in biomass production was detected over the four distances (Table 5-8).

Table 5-8: Maize biomass in trenched and nontrenched plots over four distances from the hedgerows, 78 DAS; fall 1994.

Distance (cm)	Trenched (g/2 hills)	Nontrenched (g/2 hills)
50	412.6 a	249.2 a
100	501.9 a	389.1 b
150	475.5 a	416.4 b
200	400.6 a	356.2 b
p-value	.485	0.001

Maize leaf water potential. The complete ANOVA model did not show any significant leaf water potential differences among factor levels for any factor. However, when the ANOVAs were run separately for each distance, maize plants in trenched plots indicated less leaf water pressure than did those in nontrenched plots ($p = .081$) at the 50 cm distance from the hedgerows (Figure 5-12). Differences were not significant at the other distances.

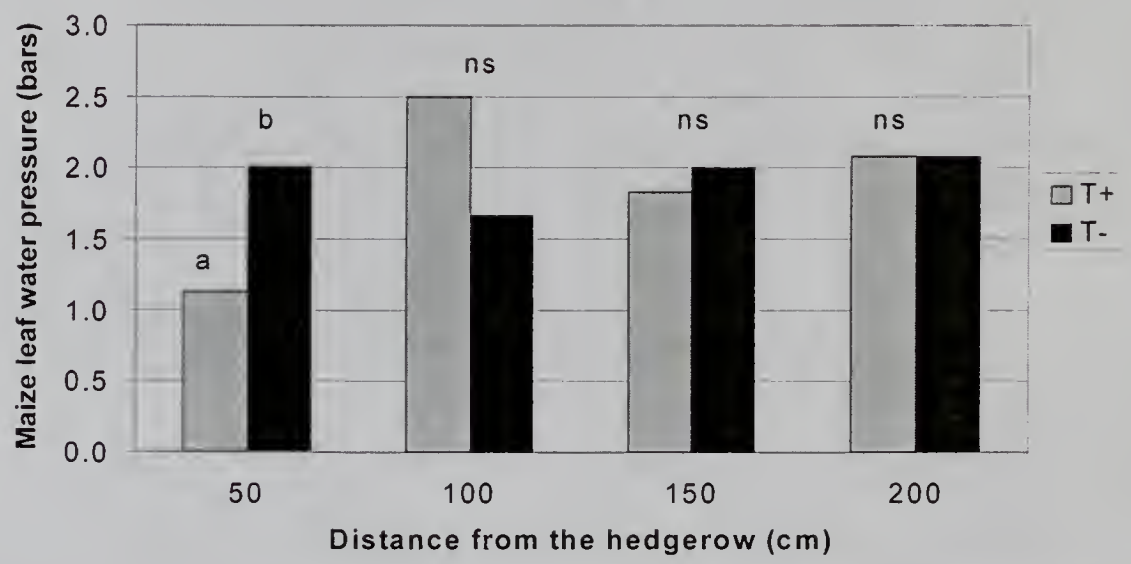


Figure 5-12: Maize leaf water potential in trenched and nontrenched plots at four distances from the hedgerow, 42 DAS; fall 1994.

Similarly, when ANOVAs were run separately for trenched and nontrenched plots, there was no significant difference in maize leaf water potential among the four distances for the nontrenched plot. For the trenched plots, however, the leaf water potential in the 50 cm plots was significantly lower ($p = .008$) than in the other three distances (Table 5-9).

Table 5-9: Maize leaf water potential in trenched and nontrenched plots over four distances from the hedgerows, 42 DAS; fall 1994.

Distance (cm)	Trenched (bars)	Nontrenched (bars)
50	1.1 a	2.0 a
100	2.5 b	1.7 a
150	1.8 b	2.0 a
200	2.1 b	2.1 a
p-value	.008	.917

Soil water content. Soil water was measured on the same day as maize leaf water potential. Figure 5-13 shows the soil water percents for trenched plots at all combinations of distance and depth. The differences in soil water percents between trenched and nontrenched plots are shown in parentheses. The overall model indicated that trenching ($p = .042$), distance from the hedgerow ($p < .001$), and depth below the surface ($p < .001$) were significantly affecting soil water content. The effect of fertilizer was not significant ($p = .352$). Separate ANOVAs for each combination of distance and depth were not significant for either trenching or fertilizer in the 0-15 cm depth. There were significant differences due to trenching in the lower depths. In the 15-30 cm layer, soil water percent was higher in trenched plots at the 50 cm ($p = .033$) and 150 cm ($p = .095$) distances from the hedgerow. In the 30-45 cm layer, soil water percent was higher in trenched plots at the 50 cm ($p = .002$) and 100 cm ($p = .014$) distance from the hedgerow.

The effect of distance from the hedgerows was significant in trenched plots at the 15-30 cm ($p = .004$) and the 30-45 cm depths ($p < .001$), with more soil water present close to the hedgerows. In the surface layer distance was significant for trenched plots at the a=.10 level, with more soil water at the 50 cm distance than the 150 distance ($p = .078$). In Figure 5-13, cells having the same letter, in a given row, are not significantly

different. Soil water percent in nontrenched plots did not differ significantly with distance from the hedgerow in any of the three depths.

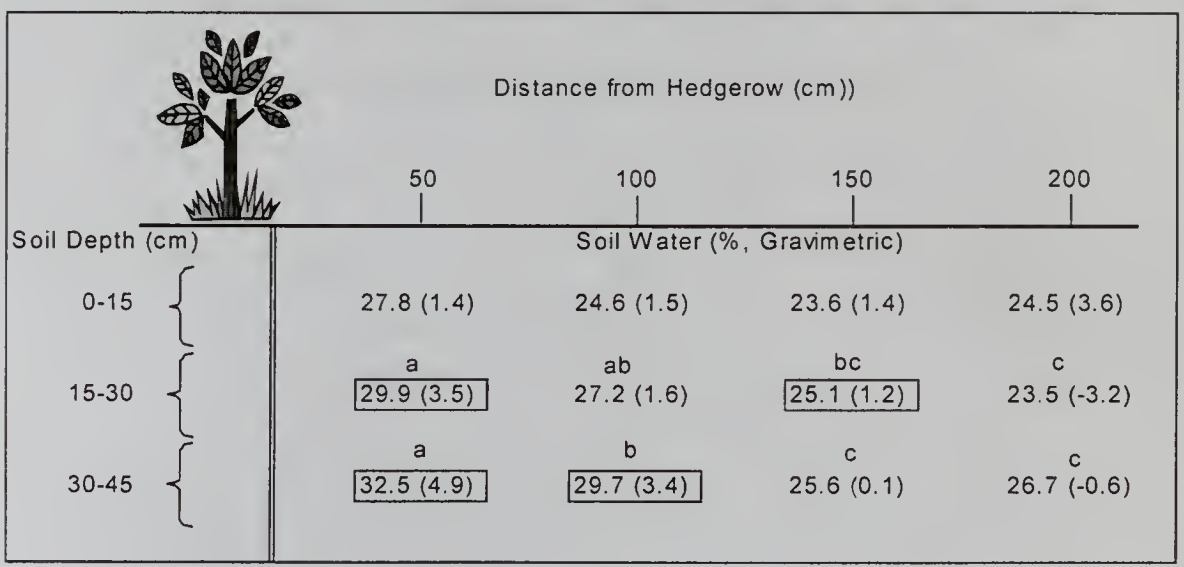


Figure 5-13: Soil water in trenched plots (and difference between T+ and T- plots) at 42 DAS, fall 1994. Cells with solid border (a=.05) or dashed border (α=.10) indicate significantly greater soil water in trenched plots than in the corresponding nontrenched plots at that position. Letters indicate differences between distances within a depth for trenched plots (α=.05).

Soil water percent increased with depth differently in trenched plots than in nontrenched plots. In the trenched plots (Table 5-10), soil water increased with depth at the 50 cm distance ($p = .066$) and the 100 cm distance ($p = .020$), with the deepest layer having significantly more water than the surface layer. However, there were no significant differences in soil water with depth at the 150 and 200 cm distances. In contrast, the nontrenched plots had significantly more soil water with depth at the 100 cm, 150 cm, and 200 cm distances, but did not show significantly more soil water with depth at the 50 cm distance.

Table 5-10: Soil water in trenched and nontrenched plots by depth and distance from the hedgerow, 42 DAS; Fall 1994.

Distance (cm)	Depth (cm)	Trenched (%)	Nontrenched (%)
50	0-15	27.8 a	26.4
	15-30	29.9 ab	26.3
	30-45	32.5 b	27.6
	p-value	.066	.820
100	0-15	24.6 a	23.1 a
	15-30	27.2 ab	25.6 ab
	30-45	29.7 b	26.3 b
	p-value	.020	.075
150	0-15	23.6	22.2 a
	15-30	25.0	23.9 ab
	30-45	23.6	25.5 b
	p-value	.368	.012
200	0-15	24.4	20.8 a
	15-30	23.5	26.7 b
	30-45	26.7	27.3 b
	p-value	.502	.048

Maize yield. The complete model for maize grain was significant for the effect of trenching ($p = .009$) and distance from the hedgerows ($p = .076$), but not for the effect of fertilizer ($p = .385$). The complete models for number of plants and for number of ears were not significant for any of those factors. ANOVAs done separately at each distance showed that maize grain from trenched plots was significantly greater ($\alpha=.10$) than that from nontrenched plots at the 50 cm ($p = .071$) and 100 cm ($p = .068$) distances from the hedgerows (Figure 5-14). There was also a statistically significant difference between the numbers of plants in trenched plots vs. nontrenched plots at the 100 cm distance ($p =$

.020), with the nontrenched plots having about one more plant per six-meter sample at that distance.

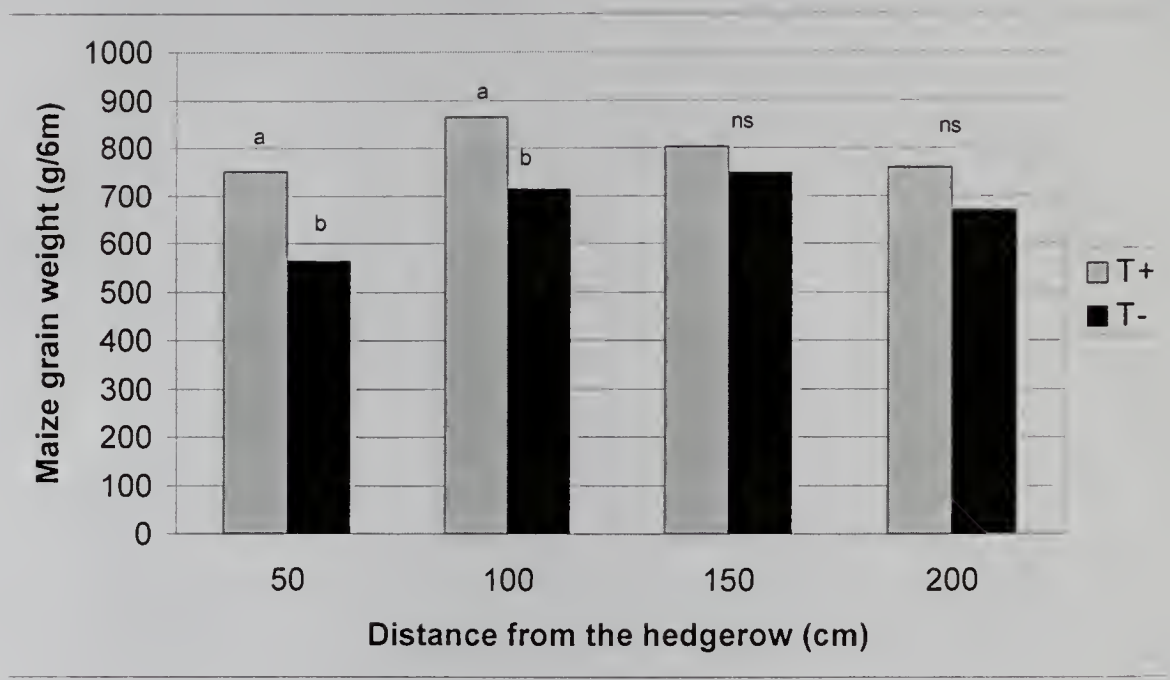


Figure 5-14: Maize grain yield in trenched (T+) and nontrenched (T-) plots at four distances from the hedgerow, Fall 1994.

Final harvest is presented on a per-hectare basis in Table 5-11. Although there were differences in grain yield between trenched and nontrenched plots at 50 and 100 cm from the hedgerows (α=.10, Figure 5-14 above), there was no significant difference in grain, number of plants or number of ears over distance from the hedgerows, for either trenched or nontrenched plots.

In general, there were no strong differences in yield parameters this season, probably due to the adequate, well-distributed rainfall partially negating the potential advantages of the root barriers. If only the differences in grain weight at 50 cm and 100 cm are accepted as significant, then trenching made a difference of 252 kg maize

grain/ha, an increase of 12% over the nontrenched plots. However, since the effect of trenching for the complete model was significant (p = .009), then the advantage of trenching increased to 360 kg/ha (2,382 kg-2,022 kg), an increase of 18% over the nontrenched plots. Since there were no differences in the numbers of plants or ears, the advantage of trenching was manifested in more grain weight per ear in trenched plots, especially at the 50 and 100 cm distances.

Table 5-11: Maize grain weight, number of plants, and number of ears at four distances from the hedgerows and as a total per hectare, with p-values for the differences between distances, Fall 1994.

	Grain (kg)		No. plants		No. ears	
Distance (cm)	**T+**	**T-**	**T+**	**T-**	**T+**	**T-**
50	563.1	423.1	10,563	10,625	11,250	10,313
100	648.1	535.6	10,188	11,125	10,750	11,313
150	601.3	561.3	11,188	10,813	11,313	11,688
200	569.4	501.9	10,938	10,875	10,688	10,750
Total/ha	2,382	2,022	42,875	43,438	44,000	44,063
P-value	.488	.103	.152	.637	.869	.314

Leucaena biomas—production and height. Four *Leucaena* harvests are presented in Tables 5-12 and 5-13—the first was done during the fall 1994 maize season at 28 DAS, the others were done after the fall maize harvest but before the spring 1995 maize was sown. The reaction of *Leucaena* to the re-trenching to 50 cm depth done in August 1994 is clear. In every case, the trenched plots produced less biomass than the nontrenched plots. The loss of small stem and leaf biomass due to the effect of trenching was 532, 452, 422, and 154 kg per hectare for the four pruning dates in Table 5-12, respectively, for a total loss over this seven-month period of 1,561 kg per hectare. The

relatively slow growth rate between the 8 October and 14 January harvests in spite of the plentiful rainfall was probably due to insect damage (species not identified) in the southeast quarter of the trial site, in blocks 6-10. The damage affected trenched and nontrenched plots equally. Fertilizer application on the adjacent maize did not affect *Leucaena* biomass or height growth. The significant trenching by fertilization interaction at the 6 May harvest does not appear to be important in magnitude.

Table 5-12: Stem and leaf biomass harvests and daily growth increments of *Leucaena* hedgerows after the second root trenching, Fall 1994.

	8 Oct 94		**14 Jan 95**		**16 Mar 95**		**6 May 95**	
	Biomass (kg/m)	**Increment (g/m/d)**	**Biomass (kg/m)**	**Increment (g/m/d)**	**Biomass (kg/m)**	**Increment (g/m/d)**	**Biomass (kg/m)**	**Increment (g/m/d)**
T+F+	0.3	6.8	0.4	3.8	0.5	8.5	0.4	7.1
T+F-	0.3	6.5	0.4	3.6	0.5	8.6	0.3	5.9
T-F+	0.6	12.0	0.5	5.3	0.7	11.3	0.4	7.3
T-F-	0.6	12.2	0.7	6.8	0.8	13.0	0.4	8.7
p-value T	<.001		.005		<.001		.013	
p-value F	.985		.401		.301		.919	
p-value TxF	.745		.255		.358		.033	
DSPH[a]	49		98		61		51	
RSPH[b] (mm)	174		320+		56		76	
DAS	28		between crops		between crops		between crops	

a: Days since previous hedgerow harvest
b: Rainfall since previous hedgerow harvest

Trenching significantly reduced *Leucaena* height growth only for the first two harvests following re-trenching (Table 5-13). Height difference between trenched and nontrenched plots was not significant during the third harvest, even though the difference in small stem and leaf biomass was significant.

Table 5-13: Height above a 50 cm stump and daily growth increments of *Leucaena* hedgerows after the second root trenching, Fall 1994.

	8 Oct. 94		14 Jan. 95		16 Mar. 95		6 May 95	
	Height (m)	Increment (cm/d)	Height (m)	Increment (cm/d)	Height (m)	Increment (cm/d)	Height (m)	Increment (cm/d)
T+F+	1.3	2.7	1.9	1.9	1.5	2.5	1.4	2.7
T+F-	1.4	2.9	1.8	1.8	1.5	2.5	1.3	2.5
T-F+	1.5	3.1	2.2	2.2	1.6	2.6	1.5	2.9
T-F-	1.5	3.1	2.2	2.2	1.6	2.6	1.5	2.9
p-value T	.005		.038		.113		.311	
p-value F	1.000		.945		.633		.311	
p-value TxF	.471		.331		.447		.030	
DSPH	49		98		61		51	
RSPH (mm)	174		320+		56		76	
DAS	28		between crops		between crops		between crops	

a: Days since previous hedgerow harvest
b: Rainfall since previous hedgerow harvest

Spring 1995 season

This season had less rainfall during the growing season than fall 1994, but the distribution was better than that during the spring 1994 season. Germination initially appeared to be good, with the tallest plants 20 cm tall at 19 DAS. However, at 26 DAS it was evident that germination at the 50 cm distance was poor. Maize height was up to 30 cm at that time, but some plants were showing leaf curl. Flowering began at 47 DAS; by 54 DAS most of the plants were flowering. At this time there appeared to have been an underground leak in the irrigation system (used in the nearby tree nursery) that might have increased soil water content in the east side of blocks 9 and 10. The only measurement that might have been influenced was the maize biomass harvest done at 54 DAS. Since maize was cut in blocks 4, 7, and 10 and the eastern-most plot in block 10

was a nontrenched plot. an inadvertent increase in soil water content in that plot only strengthens the result of the ANOVA that showed a significant difference in maize biomass due to trenching.

The effect of trenching on maize development and yield was more pronounced than during the other two seasons. However, even though this was the only season for which the complete amount of fertilizer recommended by the Ministry of Agriculture (MARNDR 1990)was applied, there were no significant effects of fertilizer on any of the parameters measured for the complete ANOVA models.

All the ANOVAs run using the complete model for maize growth and yield during this season produced very significant p-values for the effects of trenching. with trenched plots producing more than nontrenched plots. especially close to the hedgerows. All but the two maize biomass harvests were significant for distance from the hedgerow and the trenching by distance interaction (Appendix C). Much of the difference was due to the poor survival of maize plants in the nontrenched plots, especially in the two rows closest to the trees.

Maize height. Figure 5-15 shows a significant maize height advantage at 40 DAS in trenched plots at all four distances from the hedgerows ($p < .001$). Missing plants were assigned values of zero because the mortality was attributed to competition with the hedgerows. There were more missing plants in nontrenched plots than in trenched plots: at the 50 cm distance 84% of the hills in nontrenched plots had no surviving plants vs. 20% for trenched plots; at the 100 cm distance the corresponding numbers were 25% in the nontrenched plots and 4% in the trenched plots.

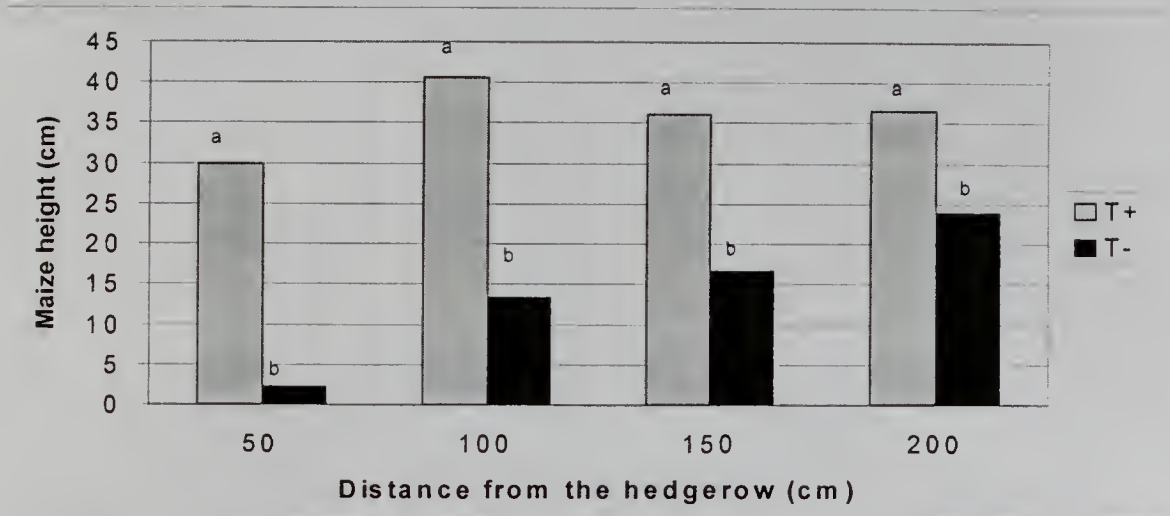


Figure 5-15: Maize height trenched and nontrenched at four distances from the hedgerow, 40 DAS; Spring 1995.

Distance from hedgerows was significant for both trenched and nontrenched plots, but not in the same way. Maize height in trenched plots reached a maximum at 100 cm, and then decreased (although not significantly) at 150 and 200 cm. Maize height in nontrenched plots was minimum at 50 cm, and then increased progressively with distance but never attained the height as maize in trenched plots (Table 5-14).

Table 5-14: Maize height in trenched and nontrenched plots at four distances from hedgerows, 40 DAS; Spring 1995.

Distance (cm)	Trenched (cm)	Nontrenched (cm)
50	30.0 a	2.2 a
100	40.6 b	13.5 b
150	36.1 ab	16.8 b
200	36.5 b	23.9 c
p-value	.009	<.001

Maize height was less than *Leucaena* height until the hedgerows were pruned at 60 DAS (Figure 5-5). This raises the question of whether the maize on the north side of

the hedgerows experienced a shade regime different from that on the south side. No direct measurements of light were done, but maize height at 40 DAS was analyzed for the effect of aspect. Neither the complete model (including distance as a factor) nor the separate models for each distance showed orientation with respect to the hedgerows to be a significant influence on maize height (data not shown).

The effect of fertilizer on maize height was significant only at the 50 cm distance from the hedgerows and only in the trenched plots ($p = .035$), where fertilized maize was 10 cm shorter than nonfertilized maize.

Maize biomass production. Differences between maize biomass harvested in trenched and nontrenched plots at 47 and 54 DAS were similar, and continued the pattern of differences in maize height discussed above. However, the statistical tests produced higher p-values than did those for height, probably due to smaller samples sizes and high variability caused by three outliers in block 10 at the 50 and 100 cm distances. The irrigation system leak causing water contamination in blocks 9 and 10, discussed above, was probably responsible. The complete model ANOVA at 47 DAS was significant for trenching ($p = .035$), but not for fertilizer or distance from the hedgerow. The 54 DAS complete model was significant only for trenching at $a=.10$ ($p = .085$).

At 47 DAS, ANOVAs done separately for each distance showed that trenched plots produce significantly more biomass at all four distances from the hedgerows (Figure 5-16). P-values for trenching are = .030, .096, .016, and .017 for the four distances. At 54 DAS, the difference due to trenching is significant only at the 50 cm distance ($p = .072$). The difference between trenched and nontrenched plots at the 100 cm distance shown in Figure 5-17 was numerically large, but because of the outliers discussed above, did not result in a significant difference.

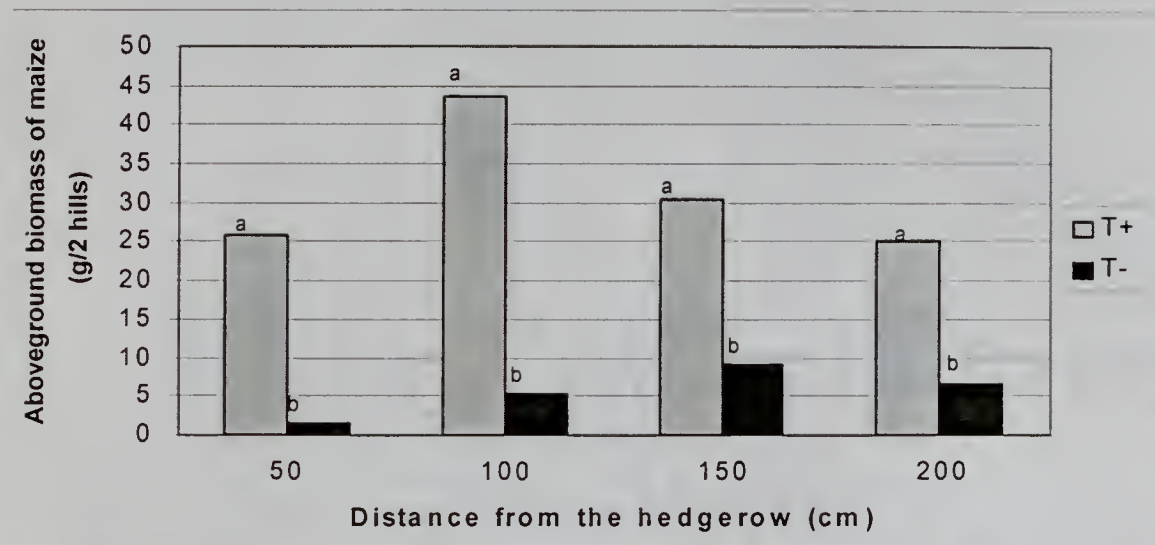


Figure 5-16: Maize biomass in trenched and nontrenched plots at four distances from the hedgerow, 47 DAS, Spring 1995.

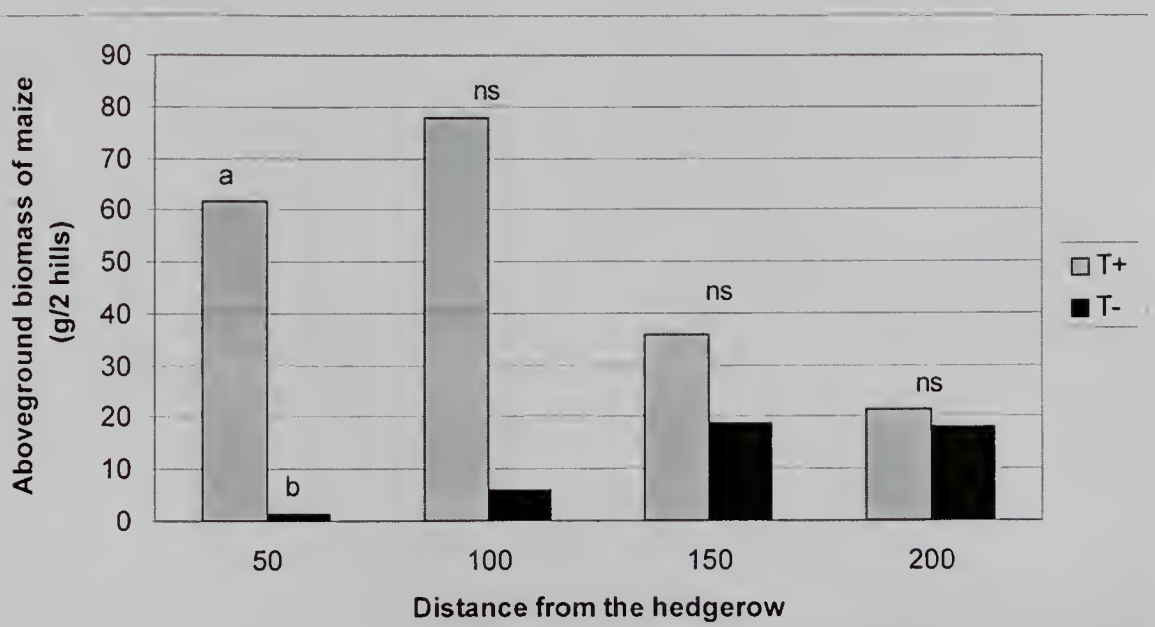


Figure 5-17: Maize biomass in trenched and nontrenched maize weight at four distances from the hedgerow, 54 DAS, Spring.

The changes in biomass over distance were similar for both observation dates. In neither case were there significant differences over distance for trenched plots. In both cases, maize biomass in nontrenched plots was less in the two rows closest to the hedgerows than in the more distant rows (Table 5-15).

Table 5-15: Maize biomass in trenched and nontrenched plots at four distances from the hedgerow, 47 and 54 DAS; Spring 1995.

	47 DAS		54 DAS	
Distance (cm)	**T+ (g)**	**T- (g)**	**T+ (g)**	**T- (g)**
50	25.9	1.6 a	61.9	1.3 a
100	43.7	5.3 ab	77.9	6.0 a
150	30.4	9.2 b	36.1	18.8 b
200	25.0	6.5 b	21.3	18.3 b
p-value	.232	.010	.118	.007

Maize growth stage. Maize in trenched plots had attained a more advanced stage of development than maize in nontrenched plots at both 68 and 75 DAS. Competition with the trees retarded development of maize plants growing in nontrenched plots increasingly as they neared the hedgerows. This was not the case for maize plants growing in trenched plots—development was most advanced at 100 cm from the hedgerows.

Figures 5-18 and 5-19 use different scales to indicate maize growth stage (see Materials and Methods). A four-number scale was used at 68 DAS: 0=missing, 1=vegetative growth, 2=tassel/anthesis, 3=silk, and 4=ear. At 75 DAS a five-number scale was used: 0=missing, 1=vegetative, 2=tassel, 3=anthesis, 4=silk, and 5=ear.

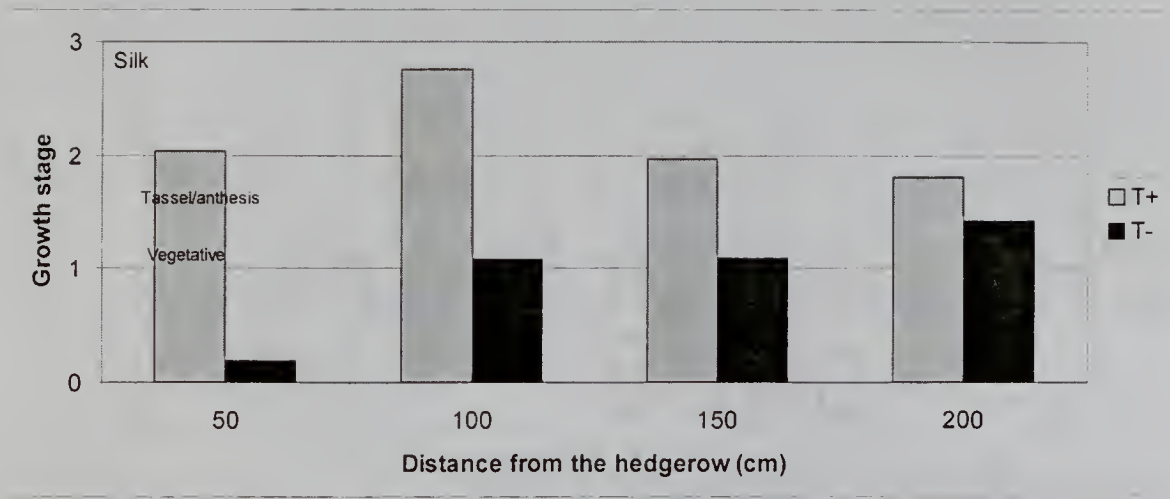


Figure 5-18: Trenched and nontrenched maize growth stage at four distances from the hedgerow, 68 DAS; Spring 1995.

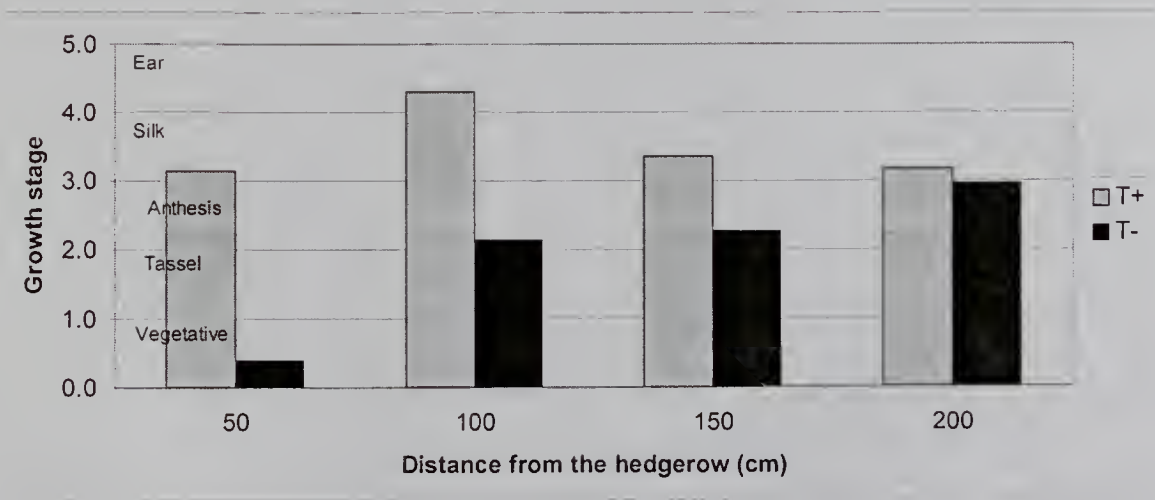


Figure 5-19: Trenched and nontrenched maize growth stage at four distances from the hedgerow, 75 DAS; Spring 1995.

As was the case with maize biomass production, growth stage changed with distance from the hedgerows differently for plants in trenched plots than for those in nontrenched plots. Plants in trenched plots were most advanced at 100 cm from the hedgerows, and identical at the other three distances. There was no retardation in the 50 cm row, and conditions for maize development appear to have been enhanced at 100 cm due to the presence of hedgerows. Maize plants in the nontrenched plots were least developed in the 50 cm row, and progressively more developed as distance increased.

Soil water content. The complete ANOVA models for soil water at 26 and 61 DAS did not produce significant p-values for trenching, fertilizer, or distance from the hedgerow. Only depth was significant ($p < .001$) on both dates. ANOVAs run separately for each distance and depth were also not significant for trenching or fertilizer, with the exception of a significant p-value (.016) for fertilizer at 150 cm distance, 15-30 cm depth at 26 DAS. The nonfertilized plots in that position had only 0.5% more soil water than did fertilized plots, so this difference is probably meaningless. Figures 5-20 and 5-21 show the percent soil water for the various positions in the trenched plots, with the difference between trenched and nontrenched plots in parentheses. None of these differences were significant.

When ANOVAs were run separately for trenched and nontrenched plots for each depth, there were no significant differences in soil water between distances from the hedgerow for either trenched or nontrenched plots, with one exception. At 61 DAS in the nontrenched plots in the 0-15 cm depth, the 50 cm distance had about 1.5% more soil water than the other three more distant positions ($p = .002$). Soil water increased with depth for both trenched and nontrenched plots at all distances from the hedgerows, at both observation periods (Table 5-16).

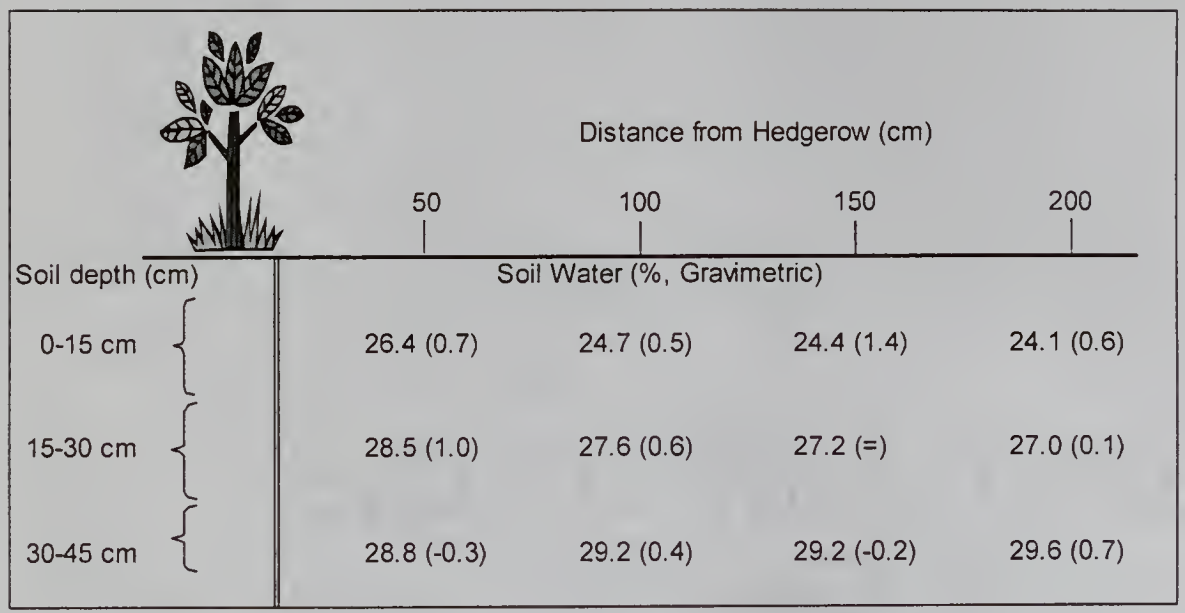


Figure 5-20: Soil water percent in trenched plots (and difference between T+ and T- plots) at 26 DAS, Spring 1995.

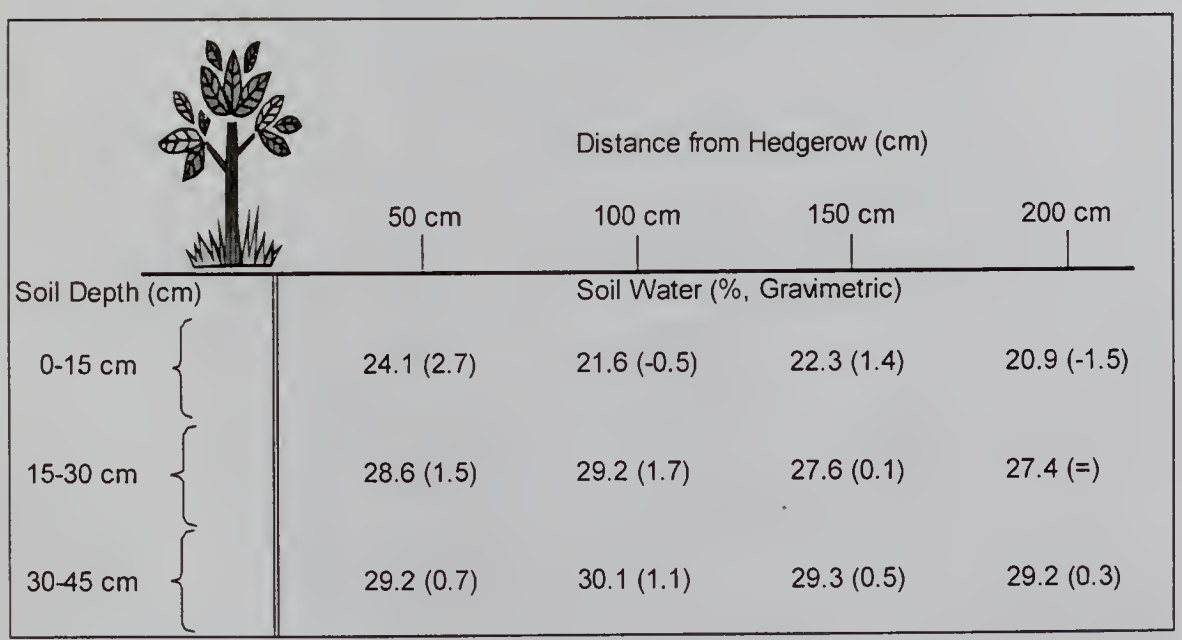


Figure 5-21: Soil water percent in trenched plots (and difference between T+ and T- plots) at 61 DAS, Spring 1995.

Table 5-16: Soil water in trenched and nontrenched plots by depth and distance from the hedgerow, 26 and 61 DAS; Spring 1995.

		26 DAS		61 DAS	
Distance (cm)	**Depth (cm)**	**T+ (%)**	**T- (%)**	**T+ (%)**	**T- (%)**
	0-15	24.1 a	21.4 a	26.4	25.7 a
50	15-30	28.6 b	27.1 b	28.5	27.5 b
	30-45	29.2 b	28.5 c	28.8	29.1 c
	p-value	.044	<.001	.371	<.001
	0-15	21.6 a	22.1 a	24.7 a	24.2 a
100	15-30	29.2 b	27.5 b	27.6 b	27.0 b
	30-45	30.1 b	29.0 b	29.2 c	28.8 c
	p-value	<.001	<.001	<.001	<.001
	0-15	22.3 a	20.9 a	24.4 a	23.0 a
150	15-30	27.6 b	27.5 b	27.2 b	27.2 b
	30-45	29.3 c	28.8 b	29.2 c	29.4 c
	p-value	<.001	<.001	<.001	.001
	0-15	20.9 a	22.4 a	24.1 a	23.5 a
200	15-30	27.4 b	27.4 b	27.0 b	26.9 b
	30-45	29.2 c	28.9 b	29.6 c	28.9 c
	p-value	<.001	<.001	<.001	<.001

Maize yield. Trenching during this season showed a clear advantage in maize production over nontrenched hedgerow plots, and reflected the relationships observed earlier in maize height, biomass production, and growth stage. This advantage extended through 100 cm from the hedgerows, and for number of maize plants and ears as well as grain weight. ANOVAs using the complete model produced very significant p-values (.002 or better) for trenching, distance from the hedgerow, and the trenching by distance interaction (Appendix C). The effect of fertilizer was not significant.

Figures 5-22, 5-23, and 5-24 show the results of the ANOVAs done separately for grain weight, number of surviving plants, and number of ears, respectively, at each distance. P-values for the effect of trenching for all three were <.001 at the 50 cm distance, and .045 or better at the 100 cm distance. Fertilizer made no significant difference at any distance for grain weight, but there were suggestive p-values for the

effect of fertilizer on number of plants (p = .074) and number of ears (p = .068) at the 50 cm distance only. In both cases, the fertilized plots had lower numbers, which would indicate a depressing effect of fertilizer of 1,750 plants per hectare and of 2,250 ears per hectare due to the reduction in the 50 cm rows.

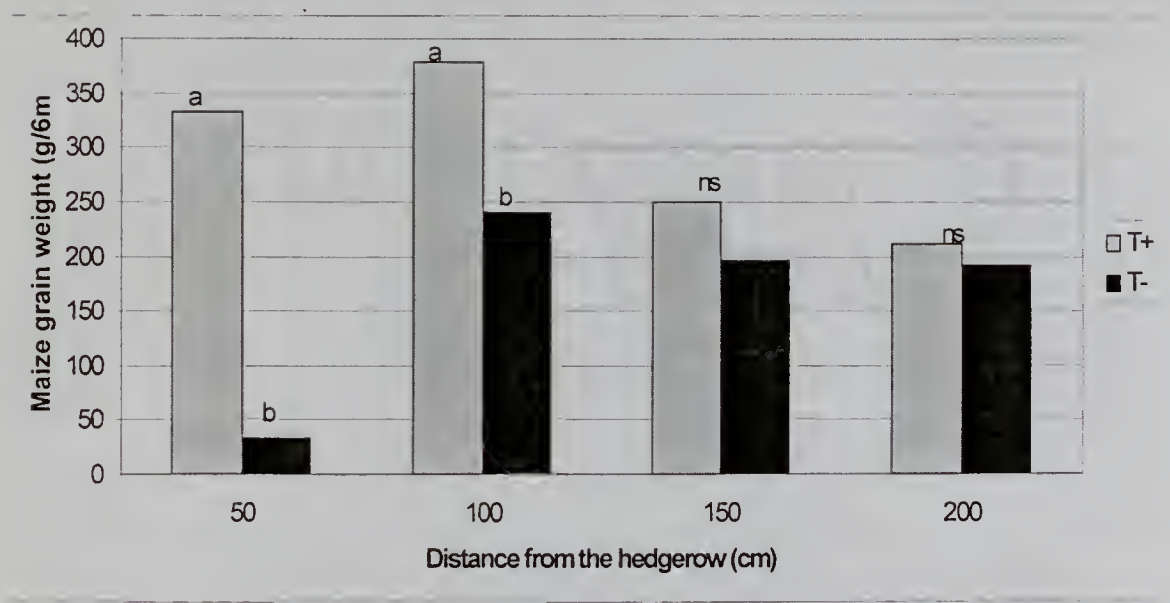


Figure 5-22: Maize grain weight from trenched and nontrenched plots at four distances from the hedgerows, 131 DAS; Spring 1995.

ANOVAs run separately for trenched and nontrenched plots showed that distance from the hedgerow significantly influenced yield in both cases (Table 5-17). In the nontrenched plots, yield in the 50 cm rows was less than in the more distant rows, but there were no significant differences in yield among the rows at 100, 150, and 200 cm distances. In both nontrenched and trenched plots, the numerical maxima occurred at 100 cm, then decreased with distance, but this pattern was significant only in trenched plots. Grain weight, number of plants, and number of ears produced in the trenched plot 100 cm rows were always significantly greater than those produced in the 200 cm rows.

Figure 5-23: Number of maize plants from trenched and nontrenched plots at four distances from the hedgerows, 131 DAS; Spring 1995.

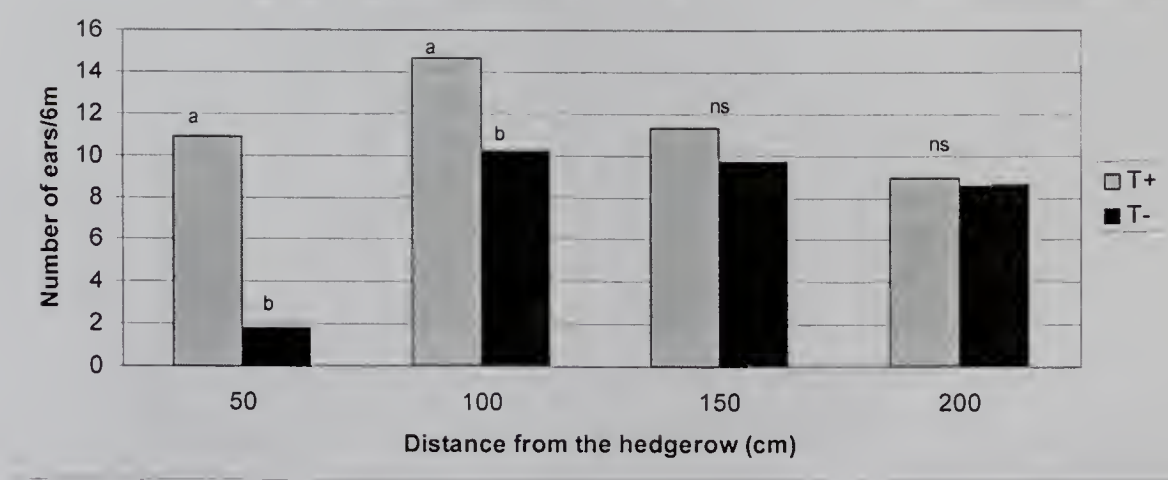


Figure 5-24: Number of ears from trenched and nontrenched plots at four distances from the hedgerows, 131 DAS; Spring 1995.

Table 5-17: Maize grain weight, number of plants, and number of ears at four distances from the hedgerows and as a total per hectare, with p-values for the differences between distances; Spring 1995.

Distance (cm)	Grain (kg/ha)		No. plants/ha		No. ears/ha	
	T+	T-	T+	T-	T+	T-
50	249.0 ab	25.3 a	6,750 ab	1,375 a	8,188 a	1,375 a
100	284.3 a	180.1 b	7,875 b	5,938 b	11,000 b	7,625 b
150	187.7 bc	146.7 b	6,625 ab	5,250 b	8,500 a	7,313 b
200	158.1 c	144.0 b	5,125 a	5,313 b	6,688 a	6,438 b
Total/ha	879	496	26,375	17,875	34,375	22,750
P-value	.019	<.001	.040	<.001	.007	<.001

The quantity of maize produced during this season was intermediate between the spring 1994 and fall 1994 seasons, however the influence of trenching on maize production was stronger. If the increased grain weight is considered only in the 50 and 100 cm rows, where there were significant differences between trenching treatments, then the increased maize grain due to trenching was 328 kg/ha, or a 66% increase over nontrenched plots. If the differences at all four distances are considered the advantage is 383 kg/ha, a 77% increase over nontrenched plots. The difference was due to higher maize mortality, lower grain weight per plant, and lower grain weight per ear in nontrenched plots, especially in the 50 cm row but extending through 100 cm.

Leucaena biomass—production and height

While the effect of trenching on maize production was very strong during the last season, its effects on *Leucaena* growth appears to have been mitigated by root re-growth for the final three harvests. There were no significant effects of trenching or fertilizer on *Leucaena* small stem and leaf biomass (Table 5-18). *Leucaena* height does show a

significant p-value for the effect of trenching at the 57 DAS harvest, with hedgerow trees in trenched plots being about 25 cm taller than those in nontrenched plots (Table 5-19).

Table 5-18: Stem and leaf biomass harvests and daily growth increments of *Leucaena* hedgerows at 19, 57, and 130 DAS; Spring 1995.

	10 Jun. 95		18 Jul. 95		29 Sep. 95	
	Biomass (kg/m)	Increment (g/m/d)	Biomass (kg/m)	Increment (g/m/d)	Biomass (kg/m)	Increment (g/m/d)
T+F+	0.4	10.9	0.3	6.8	0.4	5.0
T+F-	0.4	10.3	0.2	6.4	0.4	5.3
T-F+	0.4	11.0	0.2	5.8	0.4	6.2
T-F-	0.4	11.3	0.2	6.2	0.4	6.1
p-value T	.246		.213		.164	
p-value F	.833		.984		.924	
p-value TxF	.478		.310		.840	
DSPH	35		38		72	
RSPH (mm)	39		81		90	
DAS	19		57		130	

Table 5-19: Height above a 50 cm stump and daily growth increments of *Leucaena* hedgerows at 19, 57, and 130 DAS; Spring 1995.

	10 Jun. 95		18 Jul. 95		29 Sep. 95	
	Height (m)	Increment (cm/d)	Height (m)	Increment (cm/d)	Height (m)	Increment (cm/d)
T+F+	1.1	3.1	1.3	3.4	1.4	1.9
T+F-	1.2	3.4	1.4	3.7	1.3	1.8
T-F+	1.2	3.4	1.1	2.9	1.4	1.9
T-F-	1.2	3.4	1.1	2.9	1.7	2.4
p-value T	.418		.041		.092	
p-value F	.156		.553		.664	
p-value TxF	.945		.520		.112	
DSPH	35		38		72	
RSPH (mm)	39		81		90	
DAS	19		57		130	

These results indicate that, 10 months after trenching, the trees in the hedgerows no longer suffered a production penalty, while the effect of trenching on maize production in adjacent plots remained strong.

Leucaena root distribution in trenched and nontrenched plots

Figures 5-25, 5-26, 5-27, and 5-28 show distinct differences in the number of root intersections found in trenched plots and nontrenched plots 105 days after the final maize harvest. Where the numbers in parentheses are positive, trenched plots had that many more intersections than nontrenched plots; where the numbers are negative, they had that many less intersections than nontrenched plots. Taking only the positions where the differences were statistically different (indicated in the figures by solid or dashed lines around the cells), a pattern can be observed. Trenched plots have more large (>10 mm) roots 20 cm from the hedgerows in the 90-100 cm layer; more medium (5-10 mm) roots 20 cm from the hedgerows in the 40-60 cm layer; more fine (2-5 mm) roots 50 cm from the hedgerows in the 40-50 cm layer; and more very fine (<2 mm) roots 200 cm from the hedgerows in the 30-60 cm layer. It appears as though, because of the barriers, roots in trenched plots have developed below the barriers and produced more very fine roots at the 200 cm distance.

Trenched plots have fewer large and medium roots 20 to 50 cm from the hedgerows in the 0-30 cm layer, fewer medium roots 100 to 200 cm from the hedgerows in the 20-30 cm layer, fewer fine roots 20 to 50 cm from the hedgerows in 0-10 cm layer, 100 cm from the hedgerows in the 20-70 cm layer, and 150 cm from the hedgerows in the 30-40 cm layer; and fewer very fine roots 100 cm from the hedgerows in the 30-40 cm layer. Root barriers have clearly reduced the numbers of root intersections of all diameter classes, especially near the hedgerows and in the surface layers of soil through 150 cm from the hedgerows, but particularly at 100 cm from the hedgerows.

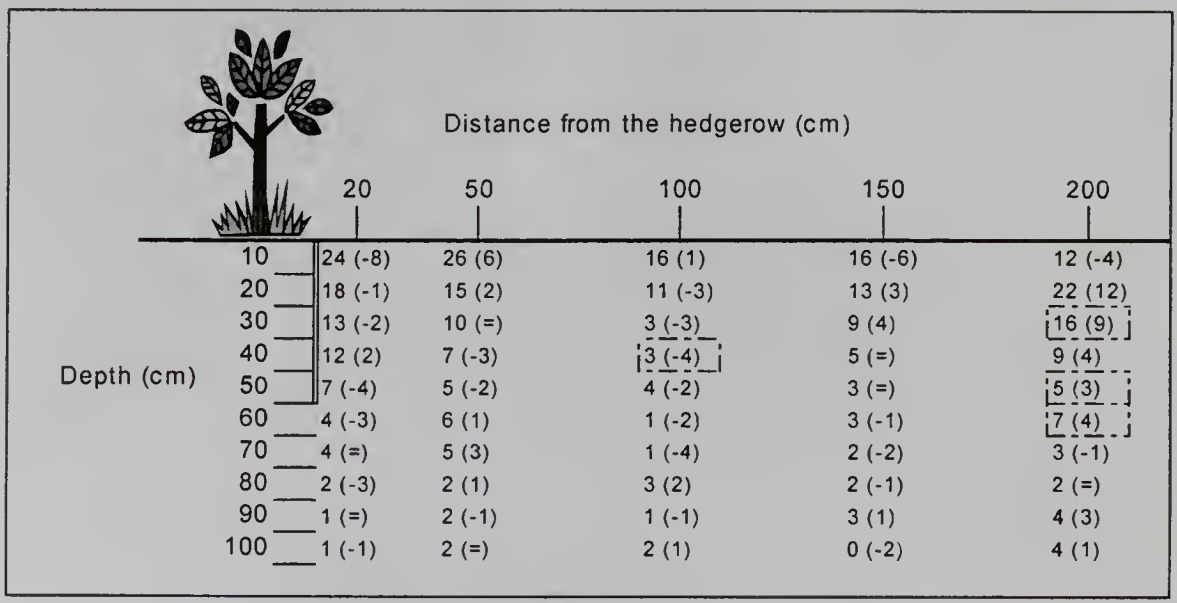


Figure 5-25: Number of very fine root (<2mm) intersections with a 10 by 100 cm plane parallel to the trenched hedgerows at five distances and 10 depths, with the difference between the trenched and nontrenched hedgerows shown in parentheses. The double vertical line represents the plastic root barrier. Numbers enclosed by dashed lines indicate statistical difference between trenched and nontrenched plots at α=.10.

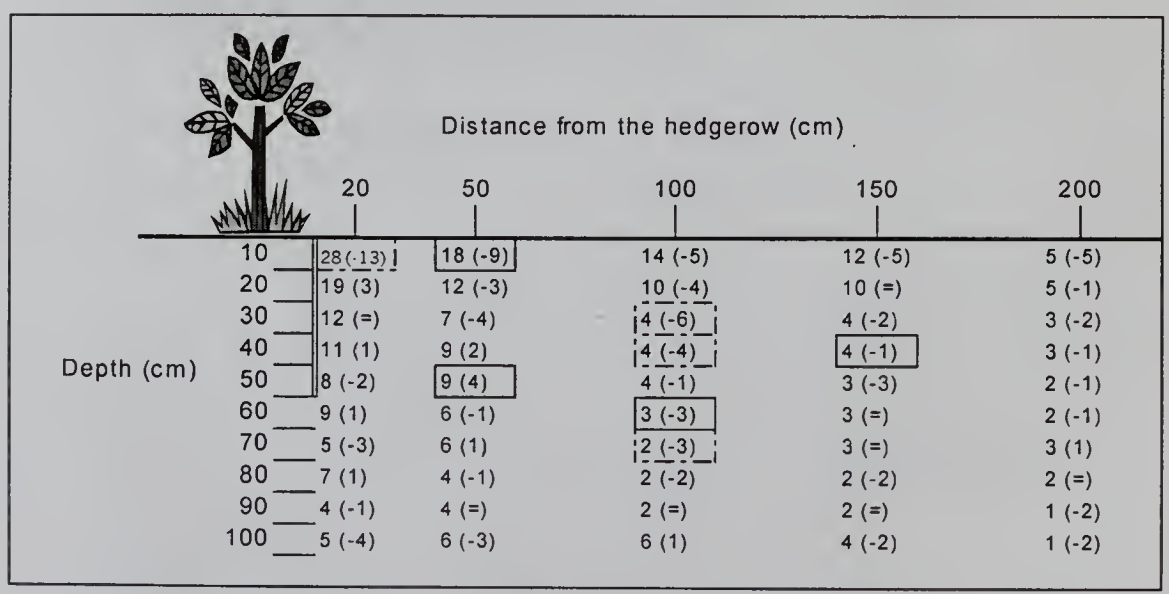


Figure 5-26: Number of fine root (2-5 mm) intersections with a 10 by 100 cm plane parallel to the trenched hedgerows at five distances and 10 depths, with the difference between the trenched and nontrenched hedgerows shown in parentheses. The double vertical line represents the plastic root barrier. Numbers enclosed by solid lines indicate statistical difference at α=.05, dashed lines at α=.10.

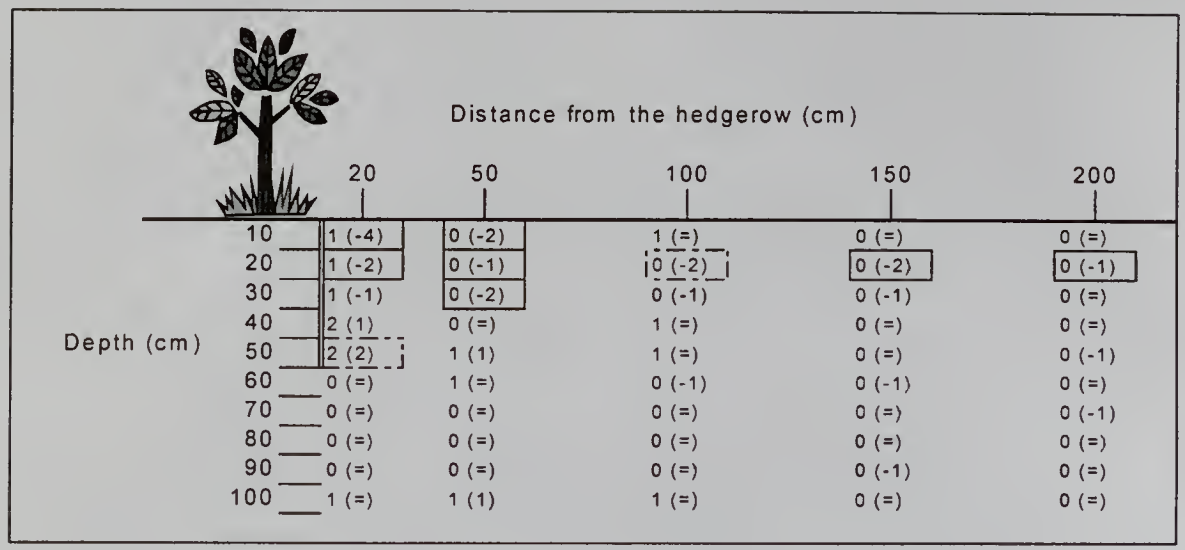


Figure 5-27: Number of medium root (5-10 mm) intersections with a 10 by 100 cm plane parallel to the trenched hedgerows at five distances and 10 depths, with the difference between the trenched and nontrenched hedgerows shown in parentheses. The double vertical line represents the plastic root. barrier. Numbers enclosed by solid lines indicate statistical difference at α=.05, dashed lines at α=.10.

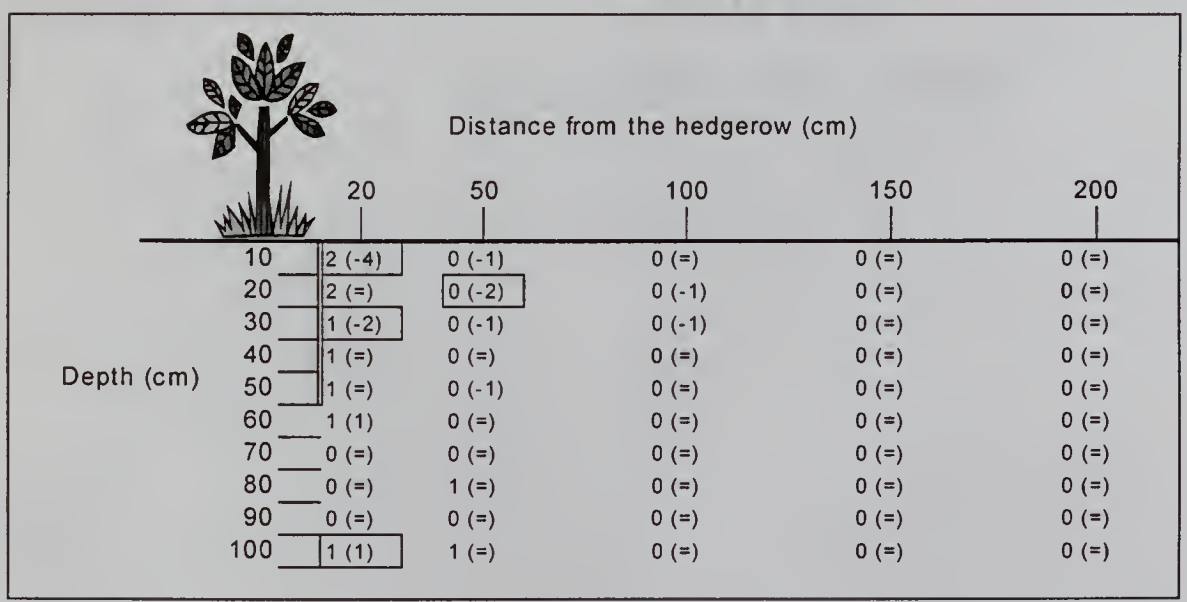


Figure 5-28: Number of large root (>10 mm) intersections with a 10 by 100 cm plane parallel to the trenched hedgerows at five distances and 10 depths, with the difference between the trenched and nontrenched hedgerows shown in parentheses. The double vertical line represents the plastic root barrier. Numbers enclosed by solid lines indicate statistical difference at α=.05.

General Discussion

Summary by season

Spring 1994. This was a season of poor rainfall and poorly functioning root barriers. The root barriers were three years old at the time the maize was planted. In addition, the root systems of the *Leucaena* hedgerows were allowed to develop unhindered during a two-year period from 1991 to 1993 when the tops were not pruned, allowing *Leucaena* roots to re-grow into the alleys over and under the old 30 cm plastic barriers. Based on field observations of soil cracks and leaf wilt, maize plants were under water stress during the flowering period. There was no rainfall from 21 DAS until 67 DAS. Drought stress was severe during flowering, which began about 42 DAS. The soil water content of 22% to 24% from 15 cm to 45 cm depth taken at 56 and 70 DAS correspond to leaf water potentials of 20 bars to 12 bars in this soil (Appendix A). Maize is severely stressed at 16 to 18 bars leaf water potential (Herrero and Johnson 1981). Drought during flowering causes severe decrease in maize yield (de Geus 1973). There were no significant effects of trenching or fertilization on maize growth and yield, or on soil water content. A residual effect of the old root barriers was seen only in the maize biomass harvests at 42 DAS and 63 DAS, when more maize biomass was produced in trenched plots at 50 cm from the hedgerows. Distance from the hedgerow was significant for all maize measurements and soil water content. Maize growth (biomass taken during the season, growth stage, grain weight, number of plants, number of ears) was always lowest at the 50 cm distance and most commonly highest at the 150 cm distance. In three cases (the 49 DAS biomass, grain weight, and number of ears), there was a decline from the 150 cm distance to the 200 cm distance. Overall maize grain yield was only 182 kg/ha. There may have been some competition for light between

hedgerows and trees since the *Leucaena* were taller than the maize until 33 DAS when the hedgerows were pruned, but the principal limitation on maize growth this season was water. Neither trenching nor fertilizer application in the maize plots had any effect on *Leucaena* biomass or height.

Fall 1994. This season saw very good rainfall and newly re-established root barriers to 50 cm depth. Maize was taller than the Leucaena after the 28 DAS hedgerow pruning, most of the maize was in tassel and silk at 65 DAS. At 42 DAS, maize leaf water potential was less in trenched than in nontrenched plots at the 50 cm distance, and there was more soil water close to hedgerows in trenched plots. The maize was able to take advantage of the extra soil water, because at 78 DAS more maize biomass was produced in trenched plots than in nontrenched plots at the 50 cm distance. In the nontrenched plots, maize biomass at the 50 cm distance was significantly less than that produced farther from the trees, but there was no difference by distance in the trenched plots. Since both trenched and nontrenched plots experienced the same shade conditions, this difference in biomass production was apparently due to water competition from the hedgerows. The increased grain yields at the 50 and 100 cm distance in trenched plots correspond to the other measurements made earlier in the growing season. Differences in maize yield over distance were muted by the abundant rainfall. Although the maize biomass in nontrenched plots at 78 DAS did produce the lowest value at 50 cm from the hedgerows, there was no difference in grain weight, number of plants, or number of ears between distances from the hedgerow for either trenched or nontrenched plots. Grain yield in trenched plots was 2,382 kg/ha, an increase of 18% over the nontrenched plots. Some of these findings are consistent with reduced numbers of roots in trenched plots close to the hedgerows. Soil water percent was highest at 50 cm from the hedgerows and

lowest 150-200 cm from the hedgerows in the trenched plots, corresponding to lowest maize leaf water pressure at the 50 cm distance (both measurements taken at 42 DAS). Maize biomass at 78 DAS and grain weight at final harvest were both greater in trenched plots than in nontrenched plots at the 50 cm distance. The recent re-trenching reduced *Leucaena* biomass production by 1,561 kg/ha over the four pruning operations carried out during this period compared to nontrenched hedgerows.

Spring 1995. This season's rainfall was about the same as that of spring 1994, but the distribution was much better. Maize was taller than *Leucaena* only after the 57 DAS pruning, and there was poor maize survival in the 50 cm row of the nontrenched plots. The root barriers were apparently effective. All maize growth and yield parameters were significantly greater in trenched plots than in nontrenched plots at the 50 cm distance from the hedgerows, and all but one at the 100 cm distance. In addition, all growth and yield measurements in nontrenched plots were lowest at the 50 cm distance and peaked at the 150-200 cm distance. In the trenched plots, the highest values were most often found at the 100 cm distance, with a decline at the 150 or 200 cm distance. Grain yield was 879 kg/ha in the trenched plots, an increase of 77% over the nontrenched plots. These findings are consistent with the decreased number of root intersections at the 20-100 cm distance and the increased number of very fine root intersections at the 200 cm distance in trenched plots. Soil water content measured at 21 and 61 DAS was not significantly different between trenching treatments or by distance from the hedgerows, but only by depth. Trenched and nontrenched plots both increased in soil water content with depth, but the amount of soil water present did not represent a condition of severe water stress for the maize plants, according to the relationship established in the pot study (Appendix A). A soil water percent above 25% would be approximately equivalent to 10 bars of leaf water pressure, above which maize begins to

experience water stress (Herrero and Johnson 1981). At soil depths below 15 cm, all positions had more than that amount of water at both observations. The effects of trenching on *Leucaena* biomass production were no longer apparent during this season.

Impact of trenching on *Leucaena*

Trenching has a short-term impact on *Leucaena* growth, primarily on small stem and leaf biomass and to a much lesser extent on height. Figure 5-29 shows the results of 15 harvests from 1991 through 1995. The initial trenching to 30 cm was done in April 1991, just before the first harvest shown in Figure 5-29. Trenched plots always produced less biomass (α=.05) than nontrenched plots during the four subsequent harvests in 1991, for a total loss of 940 kg during seven months. Since no *Leucaena* harvests were taken for the next two years, it is not possible to know how long the effect of the first trenching lasted. In September 1993, after a prolonged absence from the site, the overgrown hedgerow trees (many with a diameter >10 cm at 10 cm from ground level) were cut back to 50 cm stumps. The next four harvests produced no significant differences in *Leucaena* biomass between trenched and nontrenched plots, presumably because the tree roots in the trenched plots had re-grown into a new configuration that exploited a sufficient soil volume. The plots were re-trenched to 50 cm in late August 1994. The loss of small stem and leaf biomass due to the effect of trenching over the next four harvests during a seven-month period was 1,561 kg per hectare (α=.05). The only time trenching affected height growth of *Leucaena* was during the first two harvests after the second trenching, when stems cut from trenched plots were about 10 cm shorter than those cut from nontrenched plots. By June 1995, the trenched trees had again recovered and there were no significant differences during the final three harvests.

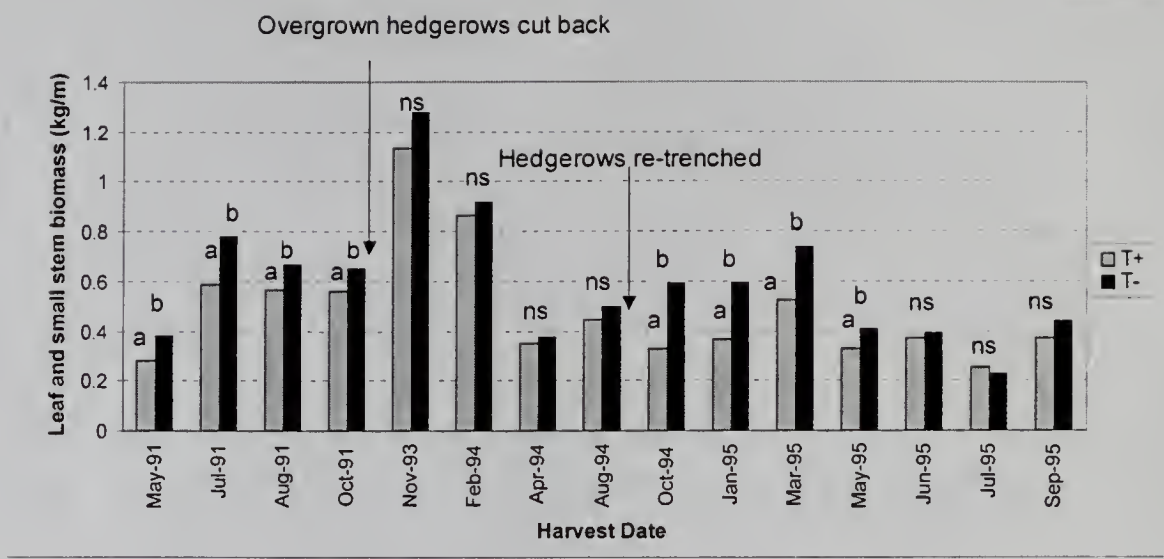


Figure 5-29: *Leucaena* small stem and leaf biomass from trenched and nontrenched plots, May 1991 through September 1995.

Conclusions

Installation of root barriers appeared to mitigate soil water competition between *Leucaena* hedgerows and adjacent maize under certain circumstances, thereby increasing grain yield compared with nontrenched hedgerows. Installation of the barriers also decreased *Leucaena* biomass production. However, the effects of barriers on hedgerow biomass production and on maize grain yield were temporary.

Amount and distribution of rainfall and the time elapsed since the installation of root barriers influenced maize growth and yield and the relative impact of trenching during the three seasons discussed here. Root barriers were not effective during the fall 1994 season, and there were no differences in maize or *Leucaena* yield. Adequate rainfall, as seen in the fall 1994 season, tended to dampen the advantage gained by trenching. Trenched plots yielded an extra 360 kg/ha maize grain over nontrenched plots that season, an increase of 18%; *Leucaena* biomass yield decreased by 1651 kg/ha for

that period. During the final season having lower rainfall, but still effective barriers, maize yield in trenched plots increased by 383 kg/ha (77%) over nontrenched plots. There were no longer any *Leucaena* yield losses due to trenching. At Machakos, Kenya, Ong and Leakey (1999) noted that when rainfall was below 250 mm, maize and hedgerow trees (*Gliricidia sepium* and *Senna spectabilis*) competed with maize for soil water, but when rainfall exceeded 650 mm the trees and crop used water from the same profile without decreasing crop yield.

Maize plants in nontrenched plots were fewer in number, shorter, produced fewer ears, and produced less grain weight per ear than maize in trenched plots. This is consistent with the effect of water stress during flowering (Olson 1988). Corlett et al. (1992a) found that flowering of millet next to nontrenched *Leucaena* hedgerow was delayed compared to sole cropped millet.

Maize yield was usually depressed closest to the hedgerows, a phenomenon noted in several studies (Govindarajan et al. 1996, Kamasho 1994, Mugendi et al. 1999). The causes of maize yield depression, or lack thereof, cannot be determined with certainty, but were probably due mainly to increased soil water available near trenched hedgerows. The pruning height of *Leucaena* was the same for both trenched and nontrenched plots, hedge prunings were removed from both trenching treatments, and fertilizer application was the same for both. However, increased soil water availability also means increased nutrient supply, which promotes increased height growth near hedgerows resulting in improved access to light. Yield depression still occurred in the 50 cm row in the trenched hedgerows, so shading probably influenced yield to some degree at that distance.

Maize yield increased steadily with distance from hedgerows in nontrenched plots, but in the trenched plots it increased with distance to 100 or 150 cm, then

decreased at the 200 cm distance. This could be partially explained by the re-distribution of *Leucaena* roots in the alleys in trenched plots, which were fewer in number than those in nontrenched plots through 150 cm, then increased at the 200 cm distance. Ong et al. (1991) found that barriers next to hedgerows changed *Leucaena* root distribution in a similar way.

The results of this experiment confirm that *Leucaena* hedgerows compete for soil water to the detriment of adjacent maize and cast doubt on the utility of root barriers as a management practice. Their beneficial effect is temporary, and the additional maize grain realized would probably not pay for the cost of installing the barriers. If farmers perceive soil water competition to be a major problem it would be worthwhile to look for a cost efficient replacement for barriers or a less competitive hedgerow species. These issues are discussed in Chapter 6.

On-Farm Study: Maize Growth at Varying Distances from Hedgerows

Introduction and Objectives

The conclusions drawn from the on-station studies in the previous section of this chapter are that *Leucaena* trees in hedgerows reduce grain yield in maize growing in the adjacent one meter area, that permanent root barriers can temporarily mitigate the loss of maize grain yield by reducing soil water competition between the hedges and the maize, but that within a couple of years *Leucaena* roots will grow under the barriers and eliminate their favorable effect on maize yield.

An appropriate next question would be are these results of any use to Haitian farmers, whose plots are mainly on steeply sloping hillsides? This is both a technical and a socioeconomic question; the socioeconomic issues will be discussed in Chapter 6. Before that, the present section of this chapter will address mainly the technical ones and serve as a bridge between the on-station and on-farm work.

The objective of the research supporting this section is limited to showing the development of maize growth and yield on some sloping hedgerow gardens built by Haitian farmers participating in the PLUS project. The logical design to complement the on-station work should have been to install barriers on hillside farms between hedgerows and adjacent maize to investigate whether this practice would economically increase maize yield to farmers. However, such an attempt was not successful.[2] Instead, data were collected from an on-farm trial comparing three different types of soil conservation structures with traditional cultivation to examine how competitive interactions between trees and crops differ between vegetative and nonvegetative soil conservation practices on sloping land. The objective was to determine if plant development was affected in maize rows adjacent to soil conservation structures on sloping land, in plots where farmers were doing the cultivation.

Study Site

The four farm plots, referred to as gardens (*jaden*), from which the measurements were taken are located in the lower central plateau near the town of Lascahobas, about 55 km north and east of Port au Prince and 23 km west of the border between Haiti and the Dominican Republic. These gardens had been part of a larger national study being carried out by SECID and PADF under the PLUS project to compare yields of crops grown in various kinds of soil conservation structures. The national study was abandoned in 1996 because of funding problems, but the four gardens in Lascahobas still contained the treatments intact in spring 1997 when this research was done. The soils are

[2] The research as originally planned included a series of *Leucaena* hedgerow/maize water competition experiments on 30 farms in the south of Haiti as a complement to the on-station trials. This proved infeasible due to political and logistic problems, and was terminated. However, a group of eleven farms in the south of Haiti participated in preliminary work in the spring of 1991 and some of the information gathered from it is used in this section.

calcareous, with slopes ranging between 20 to 45 percent. Three of the plots were one hectare in size; the fourth was 1.3 hectares. The treated portion of the gardens occupied between 12 to 25 percent of the total garden areas. Rainfall in this area is bimodal, falling mainly in spring and fall. In 1997, rainfall during May through August at the nearest rain gauge was 723 mm, with rain falling on 48 days during that period.

Methods

The study was a complete randomized block design with three kinds of soil conservation structures as treatments, plus a control without soil conservation. The subplot treatments were *Leucaena* hedgerows; crop bands constructed of sugarcane, pineapple, and cassava; and rock wall barriers. The control plot had no soil conservation structures, and represented traditional maize cultivation practice for this area. The three soil conservation structures and control plot occupied adjacent subplots, assigned randomly. Each of the four gardens was considered a block. The gardens were rented from the owners, and PADF technicians supervised installation of the structures and collected all data. The owners planted and managed crops in the alleys and kept the harvest. Treated subplots contained four rows built on the contour in April 1993 at a distance of 10 m between rows, each row being 10 m in length. In two of the gardens the contour rows were oriented in north-south direction, and in the other two in east-west direction. A local maize variety was planted in mid-May 1997. The *Leucaena* hedgerows were pruned to a height of 50 cm on 28 April, two weeks before the maize was planted. It was not pruned again before final maize harvest, when it had attained a height of about 1.5 to 2 m. The sugarcane was the tallest component of the crop bands, and remained at a height of about 1.5 m during the maize growing season.

Observations were made on the growth stage of the maize on four dates during the growing season: 43, 49, 56, and 67 DAS. Each stage of growth was assigned a

numerical value as follows: vegetative = 1, tassel = 2, anthesis = 3, silk = 4, and ear = 5. A line transect of observations was taken through the three alleys, perpendicular to the contour rows, from top to bottom at the midpoint of each subplot. One maize plant was observed at specific positions along each transect: 1 m below the uphill structures, mid-way between structures, and 1 m above the downhill structures. Although the control subplots had no soil conservation structures, maize growth stage observations were taken at corresponding positions to those in the treated subplots.

Final harvest was taken in mid-September, about 116 DAS. Whole maize plants were harvested in transects 5 m wide by 25, 26, or 28 m long through the middle of each subplot passing through, and perpendicular to, three alleys and the corresponding position in the control plot. Technicians did not record final harvest data by position on the slope or within the alleys, as was done for the growth stage observations. Weights were taken in the field on suspended spring scales. All weights were field dry and maize grain was not corrected to a standard moisture percent, as no drying ovens or grain moisture meters were available. Analysis of variance was done using SPSS version 9.0.

Results

Maize development was different among soil conservation treatments, but not among slope positions or within-alley positions. The maize growing in the rock wall and control plots developed more rapidly than that in the hedgerow and crop band plots at 43 and 49 DAS (Figure 5-30). Maize grown in hedgerows developed less rapidly than that grown in all other plots at 56 and 67 DAS. The difference in growth stage between maize in hedgerows and maize in the control plot increased through 56 DAS, and then decreased between 56 and 67 DAS.

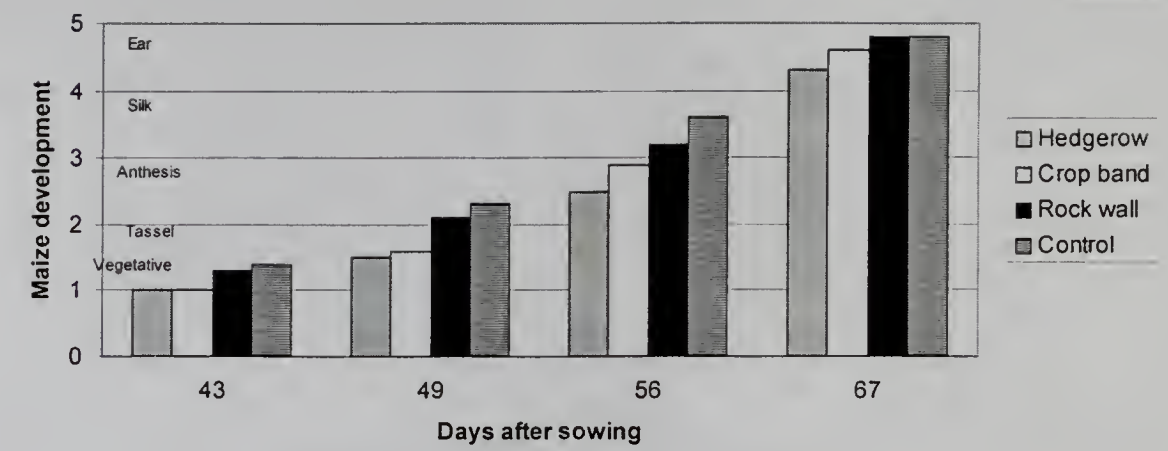


Figure 5-30: Maize development in three soil conservation practices and control at four times during the growing season on four farms during Spring 1997.

The differences in the pattern of maize development among soil conservation structures did not result in statistically significant differences in yield (Table 5-22). There were, however, some relatively large numerical differences. There was a wide variation in maize plant density, which was highest in crop band plots and lowest in control plots. Stover weight was greatest in rock wall plots, as was yield of maize grain. Grain yield was least in the control plot. Harvest indexes calculated with field dry weights were: hedgerows, 0.25; crop bands, 0.38; rock walls, 0.30, and control, 0.15.

Discussion

The pattern of maize development in the alleys between hedgerows and crop bands did not reflect the yield curve caused by soil scouring and hedgerow/crop competition as described by Garrity (1996), even though soil scouring due to hoe tillage is commonly observed in Haiti in the upper parts of hedgerows. Three row-by-row sorghum and maize harvests on sloped farms done as preliminary work by the author in 1991 also produced no clear pattern of yield variations with respect to alley position in *Leucaena* hedgerows. However, the overall development of maize in the soil

conservation structures built of plants, i.e., hedgerows and crop bands, was slower than that in rock walls and in the control plots. This could be due to competition between hedgerow plants and adjacent maize. The differences in maize development between the four treatments diminished over the growing season.

Table 5-20: Maize yield in three soil conservation practices and control at 116 DAS on four farms, spring 1997

	Hills (no/ha)	Plants (no/ha)	Stover (kg/ha)	Ears (no/ha)	Ears (kg/ha)	Grain (kg/ha)
Hedgerow	6,745	13,700	714	9,944	287	200
Crop Band	7,446	15,893	546	9,318	255	222
Rock Wall	7,774	13,399	902	9,893	325	286
Control	6,572	12,426	783	6,994	148	121
P-value	.913	.714	.591	.694	.110	.206

Grain yield was overall poor by the standards of Haitian farmers, but not entirely out of range. Farmers in two regions of the country estimated they should harvest 40 to 80 *marmites* (roughly a gallon measure weighing about 2.6 kg) of field dry maize grain for every *marmite* planted (Swanson et al. 1993a, 1993e). With one marmite seeding about 0.32 hectares (at an initial density of 62,500 plants/ha) (Swanson et al. 1993e), this is equivalent to 325 to 650 kg/ha expected yield. This would be the standard for the control plot, but since the presence of soil conservation structures every 10 m removes 10% of the available cropping space, farmers' expectations would be 293 to 585 kg/ha of maize on plots having hedgerows or rock walls. Taking the lower expected return of 325 kg/ha for a plot without soil conservation (Swanson et al. 1993e), the control plot reached 37%, hedgerows 68%, crop bands 76%, and rock walls 98% of expectations. Although the differences among treatments were not significant ($p = .206$), it is tempting to speculate that maize yield in the control was least because it had the least amount of soil

water. Soil water stress reduces harvest index (HI) in maize (Shaw 1988), and the control plots had the lowest HI. Rock walls produced the highest yield because that treatment harvested water but did not compete for light, nutrients or water with maize. Crop bands and hedgerows were in the middle because they harvested water, but did compete for resources with maize.

Better yield from rock wall terraces compared to hedgerows has precedent in Haiti, but gradually the biomass contributed by trees changes the yield ranking in favor of hedgerows. An on-station experiment on 17 to 21% slopes (Isaac et al. 1995) reported that rock wall plots produced greater maize yields than hedgerows in the first year after establishment, equaled the hedgerow treatments during the second year, then yields steadily declined in rock walls but remained steady in hedgerows. Isaac et al. (1996b) reported that during two years and four maize harvests there was a slight increase in yield in all *Leucaena* hedgerows, and a steady decrease in all other treatments, including rock walls. Increased yield in farmer-managed sloping hedgerow plots has also been shown. Lea (1995e) reported 40% greater sorghum yields in hedgerow plots compared to untreated control plots in experiments done in two regions of Haiti, including farms close to those reported on here. In other regions having different soils and rainfall distribution, hedgerow plots did not show improved yield over traditional cultivation (Lea 1995e).

However, on-farm experimental results can be complicated by management factors outside the intended experimental design. An on-farm study in the same region as the plots in this experiment that reported 70% higher sorghum yields from rock wall terraces compared to control plots without soil conservation (J.D. Lea, personal communication, Sept. 1995), was followed up by this author. The follow up showed that the sorghum harvest had been measured correctly by technicians, but the farmers who owned the plots had managed the protected plots differently than the control plots, which

were not physically adjacent or always physically the same as the treated plots. It was found that the rock walls served to stop sorghum seed from washing out of the plots during heavy rainfall. These seeds sprouted above the structures and the farmers later transplanted the seedlings back into the alleys, resulting in a higher plant density compared to the control plots. In addition, farmers practiced better, deeper, tillage on rock wall plots in some cases, tended to weed them earlier than control plots and were more likely to thin hills (planted 10 to 15 seeds/hill) after germination in the rock wall plots, resulting in larger panicles. This points out a major difference between farmer-managed on-farm trials and researcher-managed on-farm trials, at least for treatments involving relatively complex inputs such as soil conservation structures. Farmers adjust their management intensity according to their investment in the gardens and the economic potential of the gardens, whereas in researcher-managed trials this difference is eliminated.

Conclusions

Conclusions based on these data are limited to differences in the pattern of maize plant development among soil conservation treatments. There was a greater variation in the pattern of maize development between type of soil conservation structure than in relative nearness to the structure or to position of the alley on the slope. Lack of competition between plants serving as the structural components of hedgerows (*Leucaena*) and crop bands (sugarcane and pineapple) is the probable cause of faster maize development in rock wall terraces and untreated control plots. The numerically smaller yield in the control plots compared to the plots having soil conservation structures, although not statistically different, is probably due to the water harvesting effect of the contour structures. A much larger sample size and row by row harvest over several years would be required to draw clearer conclusions regarding the effect of slope position within alleys in plots with such great variability in soil type, soil fertility, soil depth, and rainfall regime.

CHAPTER 6
LAND AND HOUSEHOLD CHARACTERISTICS IN RELATION TO ADOPTION AND MANAGEMENT OF HEDGEROWS

Introduction and Objectives

The two previous chapters described research regarding competition between trees in hedgerows and adjacent crops, with a focus on soil water. If soil water competition were an important factor in reducing crop yield in hedgerows, then farmers might consider it in their adoption and management decisions on farm. Results from the on-station research described in Chapter 4 showed that soil water competition between hedgerow trees and maize can reduce maize yield under certain rainfall conditions. The on-farm research in Chapter 5 was not able to show the same phenomenon at work under the highly variable environmental conditions found in hillside farm plots, but did show differences in maize growth between different types of soil conservation structures. Those differences in maize development may have been due to differences in the way soil conservation structures exerted competitive pressures on the crop.

The research described in this chapter focuses on how farmers adjust their adoption and management decisions based on the technical aspects of soil conservation structures, the land and human resources available to the adopting household, physical and tenure characteristics of the plot, and farmers perceptions of potential benefits and problems associated with the soil conservation practices. The links between the work described in this chapter and the on-station and on-farm studies are: (1) hedgerows remain the principal focus of the research, and (2) farmers were asked their opinion regarding the severity of

tree/crop water competition in hedgerows to explore whether the degree of that perception was correlated with management practices. However, the adoption and management questions explored here included farmers' responses to other soil conservation structures as well as hedgerows, and this proved to be useful in revealing differences in farmers' decision-making strategies. The hypotheses tested in this chapter are

- Farmer household characteristics and farm resources influence the adoption and management of hedgerow intercropping.
- Plot characteristics influence the adoption and management of hedgerow intercropping.
- Problems and benefits with hedgerow intercropping as perceived by the adopting farmer influence management quality.

This study seeks to discover relationships between farmers' decision to install an agroforestry intervention and three groups of variables: (1) characteristics of the technology, represented by the decision to install either hedgerows or other agroforestry practices (crop bands, rock walls, gully plugs, or trees) with different characteristics; (2) farm household characteristics representing wealth, education, and household size; and (3) physical characteristics of the plot and the mode of access through which the farmer worked it. Having installed a particular practice on a plot, some measures of management quality of the soil conservation practices are compared to the same three groups of variables. Finally, hedgerow management quality is compared to farmers' opinions regarding the benefits and problems associated with the practice.

Studies on the adoption of soil conservation technologies began in the 1950s (Ervin and Ervin 1982). Study results predict whether farmers adopt, the rate at which they adopt, or identify the characteristics of adopters compared to non-adopters. This

information is used to design interventions (Bonnard and Scherr 1994), evaluate policy or adjust extension messages (Earle et al. 1979, Murray 1980), or to report on and evaluate extension projects (Pierre et al. 1995, Scherr 1994, Shultz et al. 1997, Smucker 1988, Sunderlin 1997, Swanson 1993, White 1992a).

Adoption studies generally followed the model described by Rogers (1995), that diffusion of adoptions is a process having four components: (1) the innovation, (2) the social system in which the innovation is being adopted, (3) channels of communication (the ways that adopters pass on information about an innovation), and (4) the time over which a social system adopts an innovation. Initially adoption models were static, with the underlying assumptions that the adoption decision is binary; there is a fixed, finite ceiling on adoption; the rate and degree of diffusion through a population is fixed; the innovation is not modified once it is introduced and its diffusion is not affected by other innovations; there is one adoption per adopting unit; and the geographical boundaries of the adopting social system stays constant over the diffusion process (Knudson 1991). However, some of these assumptions are not useful in understanding the adoption of a complex technology such as hedgerows. Adoption researchers began to recommend dynamic models that separated determinations of diffusion over time as the technology being investigated was affected by other technologies and as the adopting population changed in various ways (Knudson 1991), and to integrate physical, economic, and other factors (Fernandez-Cornejo et al. 1994).

Feder et al. (1985) defined final adoption of agricultural technology, at the level of the individual farmer, as the degree of use of a new technology in long-run equilibrium when the farmer has full information about the new technology and its potential. They recommended studying both the extent and intensity of use of the new

technology throughout the adoption process to allow for changes in parameters affecting farmers' decisions. Specifically for hedgerow adoption studies, Dvorák (1991) suggested dividing hedgerow adoption into three phases (establishment, maintenance, and productive) to avoid pronouncements of success or failure based only on the initial establishment.

Some agroforestry adoption studies are regional overviews based on cost/benefit analysis (Current and Scherr 1995), but most are based on case studies using combinations of farmer interviews and plot monitoring (David 1995, Dvorák 1991, Fujisaka et al. 1995, Murray 1980, Neef et al. 1996, Smucker 1988, Wiersum 1994) or questionnaire surveys (Kessey and O'Kting'ati 1994, Lea 1994, Pierre et al. 1995, Singhai and Kumar 1997, Swanson 1993, Vaval et al. 1997). Usually more than one method of data collection is required to interpret the meaning of adoption (Dvorák 1991, Sunderlin 1997, White 1992a). Once the data is collected, analysis methods vary from multiple regression (Ervin and Ervin 1982), logistic regression (McNamara et al. 1991, Norris and Batie 1987, Sureshwaran et al. 1996), ethnographic interpretation (Murray 1980, Smucker 1988, Swanson 1993), or cost/benefit analysis (Nelson et al. 1997). Adaptability analysis is another methodology specifically developed to incorporate the wide diversity of biophysical and socioeconomic conditions found on developing country farms. It uses regression techniques, but has a focus on finding technology solutions for multiple environments rather than simply defining and describing adopters and non-adopters (Hildebrand and Russell 1996).

Variables Used to Predict Adoption

The dependent variables used to represent adoption of soil conservation practices are commonly the binary decision to adopt or not adopt, the number of practices adopted,

and estimated rates of erosion (Ervin and Ervin 1982). The author did not encounter any studies that used the quality of management of soil conservation structures as a dependent variable. The independent variables used to make the predictions/descriptions can be economic characteristics of the technology (Byerlee and Hesse de Polanco 1986, Jarvis 1981, Stark 1996), socioeconomic characteristics of the farm or farm household (Earle et al. 1979, Harper et al. 1990, Kessey and O'Kting'ati 1994, Shultz et al. 1997, Singhai and Kumar 1997, Stark 1996, Sunderlin 1997, Sureshwaran et al. 1996, Vaval et al. 1997, White 1992a), physical or tenure characteristics of the plot (Smucker 1988, Sureshwaran et al. 1996, Vaval et al. 1997, White 1992a), or farmer attitudes regarding actual or potential benefits or problems associated with a technology (David 1995, Earle et al. 1979, Fujisaka et al. 1995, McNamara et al. 1991, Norris and Batie 1987, Wiersum 1994). A combination of these is the norm. Findings from studies using these categories of variables are discussed below.

Technology Characteristics

Farming technologies differ in several ways, including complexity, adaptability, cost of installation and management, potential return from the investment, timing of the return, and the inputs (land, farmer knowledge, labor, chemicals, seed) involved. Some technologies are simple, relatively low in initial cost, and have a short return on investment (e.g., a new variety of crop). Others are complex, involve relatively high investments in installation and management, and can take several years before benefits are realized (e.g., hedgerows). The success of some technologies depends on the adoption of others.

A study of an improved barley variety and attendant inputs in Mexico found that farmers rarely adopted complete technology packages, but adopted them in sequence

based on predictions of profitability and riskiness. Most adopted one component at a time, those giving the highest return on capital were adopted earliest (Byerlee and Hesse de Polanco 1986).

In Kenya a study of 3,000 farmers found they decreased risk associated with new agroforestry practices through incremental adoption and adaptation, and cost and risk-reducing modifications to the technology design (Scherr 1995). The authors noted that farmers adopt agroforestry practices only when they bring economic gain. This is a widely noted, and hardly surprising, observation. Soil conservation programs in developing countries have not had much success because they are often too costly to implement and maintain, so only the better-off farmers are be able to adopt the best practices, poor farmers have to modify them to reduce the cost (Napier 1991). In Rwanda, where a high population of farmers intensely crop marginal soils on steep slopes, soil conservation practices proposed to them were not attractive because of the time lag between initial investment and return (Steiner and Scheidegger 1994). Successful alley cropping adoption in Sri Lanka depended on profitability, time to profit, labor requirement and seasonal availability (Nuberg and Evans 1993).

Farmer Household Characteristics

Household characteristics are labor, land, and knowledge resources that influence adoption of technologies. These characteristics are not consistent in the way they influence adoption, but vary according to the technology. Problems occasionally arise because the correlations between some household variables can be influenced by other variables so that the correlation includes the spurious effect of the others (Feder *et al* 1985). In Africa, where larger farm size and greater extension contact were important to adoption of alley cropping, both were highly correlated to level of education (Tripathi

and Psychas 1992). Ervin and Ervin (1982) rejected farmer age as a household variable in a study of adoption of soil conservation in Missouri, USA, because of a high correlation with other independent variables.

A study of an integrated pest management (IPM) practice in Florida, Michigan, and Texas in the US found a significant and positive relationship between adoption and farm size and availability of family labor; a significant and negative correlation between adoption and the importance of livestock (Fernandez-Cornejo et al. 1994). Farm size and income had a significant and positive impact on soil conservation expenditures in Virginia; off-farm employment, debt level, and tenure had significant and negative impacts (Norris and Batie 1987). In a soil conservation project in El Salvador, adoption of soil conservation and agroforestry practices was greater among younger than older farmers, among land owners than tenants, and increased with more extension visits (Shultz et al. 1997). A model based on a survey predicted intention toward soil conservation to be stronger as farm size, family income, and education level increased (Earle et al. 1979). A study of adoption of sweep nets (IPM) in the US found that higher education was correlated with lower adoption, but farm size was not a significant factor (Harper et al. 1990).

A study of agroforestry adoption (tree and grass associations) in Tanzania found farm size, household size, number of animals, and distance traveled in fuelwood collection, were significantly correlated with adoption. Number of days used for fodder collection was not significant (Kessey and O'Kting'ati 1994). Farm size, household size, and total number of animals were positively correlated with adoption of silvopastoral associations in the Garhwal Himalaya region of India. Age of head of household and

distance traveled for fuelwood collection were negatively correlated with adoption (Singhai and Kumar 1997).

A survey in the Philippines found the main constraint to hedgerow adoption was high labor demand for installation and maintenance. As the number of persons per household decreased and the percentage of female members increased, adoption decreased; women did not usually help in hedgerow establishment (Stark 1996). A model of hedgerow-based soil conservation adoption in the Philippines suggested that government assistance, land size, farmer age, land intensity, and tenure impacted adoption, but income and education did not (Sureshwaran *et al* 1996).

Plot Characteristics

A commonly held opinion is that farmers will invest more resources on a plot of land that is held under a secure form of tenure. It has been recommended in some areas that alley cropping should be targeted first to farmers who own inherited or purchased land (Tonye et al. 1994). Other researchers note that tenure insecurity, but not lack of title itself, could be a disincentive to adoption of agroforestry practices (Current et al. 1995). Apparent effects of tenancy, however, could be caused by indirect relationships between tenure and access to credit or other inputs (Feder et al. 1985). In West Africa tenure plays a significant role in adoption of alley cropping, land tenure security is favorable to it (Lawry et al. 1994). In Benin, tenants, the landless, and most women are worse off than landowners in their ability to adopt agroforestry practices because of tenure insecurity among other reasons (Neef and Heidhues 1994). In the US, land tenure was found to be not significant to IPM adoption because it was an investment in human capital, not in the land (Fernandez-Cornejo et al. 1994)—so the impact of tenure depends on the kind of technology.

Physical characteristics of the plot sometimes impact adoption by themselves, but they usually interact with other characteristics. Size of the farm holding could be a surrogate for other factors, such as access to credit, information or wealth (Feder et al. 1985). In Benin, there was a significant difference between owned and leased fields with regard to distance from the compound (Neef et al. 1996). An adoption study in Indonesia found that non-adopters had significantly less area in sloping land than adopters, but the slope percent of the sloping land was not significant (Fujisaka et al. 1995). Another study in Benin found the key parameters determining adoption of farming technology included the function and history of the field, tenure, and the field's position with regard to fertility flows in the farming system (Koudokpon et al. 1994).

Farmer Attitudes Regarding Problems and Benefits of the Technology

Perceived problems and benefits are sometimes reported as observations and sometimes used as independent variables in adoption models. However, it can be difficult to reconcile expressed attitudes with farmer actions. Dvorák (1991) reported in her survey farmer responses about alley cropping were generally favorable, but in no case had a farmer, household member or neighbors extended an alley or planted a new alley farm. She noted that two apparently enthusiastic farmers even uprooted the alley trees, and concluded this reflected the difficulty in using a one-time survey to evaluate a complex system (Dvorák 1991).

Nevertheless, farmer attitudes can help understand adoption. Farmers' expressed benefits of hedgerows in Indonesia were decreased erosion, flattening alleys for cropping, and ability to use fertilizers without loss; drawbacks were animal damage. Most important reasons for non-adoption were work demands on lowland plots, high labor in the hedgerows, off-farm work opportunities, lack of draft animals, and lack of

capital for labor and inputs (Fujisaka et al. 1995). A model based on survey data predicted intention toward soil conservation was stronger as perception of soil erosion as a problem increased (Earle et al. 1979). Perception of erosion did have a significant and positive impact on soil conservation expenditures in Virginia (Norris and Batie 1987).

Farmer attitudes may be contrary to the expectations of researchers. After 12 years of extension education in Georgia with peanut farmers showing increased income and environmental benefits, only 31% of farmers adopted IPM. The study found promoting the environmental impact of IPM did not affect adoption (McNamara et al. 1991). In Rwanda, small farmers rarely mentioned erosion as an important production constraint (Steiner and Scheidegger 1994). In a risky production environment in Kenya, where crop yields fluctuate constantly with the amount of rainfall, soil fertility was not an urgent concern to farmers (David 1995). Study of hedgerow adoption in Indonesia noted that some farmers adopted not because of its productive benefits, but as a means to gain access to land or credit, or to demonstrate allegiances to social networks (Wiersum 1994).

Findings from Adoption Studies in Haiti

The independent variables used in this study, and others that were not included, have been used by other researchers in Haiti. Smucker (1988) found that farmers planting tree seedlings distributed by a project were older, more protestant, more often married, and better schooled; had larger households and more children; were more involved in wood-related occupations and more likely to own large animals; hired more labor and sold their own labor less; and had more land and more securely-held land, and had more land in fallow than did nonplanters. White (1992a) found that religion, age,

and wealth were not significant to participation in group soil conservation practices in Haiti, but that group membership and cooperative labor tendencies were very important.

Both White (1992a) and Vaval et al. (1997) studied soil conservation and hedgerow adoption in the Maissade region of Haiti and found that land tenure of plots was not important to participation in cooperative watershed management or soil conservation adoption. There were, however, differences of plot tenure among farmers of different economic levels within adopters and non-adopters (Vaval et al. 1997).

Haitian farmers' perceived problems and benefits associated with hedgerows have been surveyed in several studies. The most frequently cited problem was animals destroying the hedgerows, especially during the period after crop harvest when goats are let free to forage (Pierre et al. 1995, Swanson et al. 1993a, Swanson et al. 1993b, Villanueva 1993). Animal problems and mode of access to the plot can be related. Farmers in the northwest of Haiti reported to Swanson et al. (1993a) that, on inherited-undivided plots, they often tie animals nearby their hedgerows to permit direct grazing because other family members will do so in any case. Plot characteristics and labor required to install hedgerows are also cited as problems. White (1992b) reported that 39% of farmers not adopting hedgerows and other soil conservation practices cited lack of time as the reason, 21% said it was due to not owning land, 17% said they owned inappropriate land. A study following up a terminated soil conservation project in the south of Haiti cited farmers as saying hedgerows were too difficult to manage, and that they could not extend them because it was too expensive and took too much time and labor to repair them (Villanueva 1993). Only one study reported farmers' perceived benefits. Over 80% of 105 farmers interviewed in the south of Haiti said that hedgerows increased crop production by 25 to 50%, and some said they felt more secure in their

access to the plots because of the positive reaction of the landlords to hedgerow construction (Pierre et al. 1995).

This literature review has shown that variables representing characteristics of the technology, farm household resources, plot characteristics, and farmer attitudes toward the technology are sometimes useful in predicting adoption. However, the predictive utility of each variable is case specific. A variable might be useful in predicting adoption in one case but not another, or the influence of the variable might be positive to adoption in one case and negative in another. The most consistent variables influencing adoption of hedgerows appear to be economic gain and lag to profit, and threshold cost of installation, especially labor cost. Farmers are more likely to adopt when it makes economic sense to do so.

The studies done on adoption of soil conservation in Haiti included mode of access to the land as a variable. In some cases the conclusion appeared to be that land tenure was important, but that it was not in other cases. This apparent contradiction probably means that it was not important to a farmer's participation, in some form, in a project, because at least one of the farmer's plots is likely to be suitable for some activity that counts as participation. However, tenure could be important in deciding what technology to adopt on a particular plot. It is noted that no other studies were discovered that used management quality of installed agroforestry practices as a dependent variable.

Materials and Methods

A survey of farmers participating in the PADF PLUS project was carried out in spring 1996. The objectives of the survey beyond those of interest to this research were explained in Chapter 4. Sampled farmers were those who had first participated in the project before 1 January 1995, and who, therefore, had been working with the project for

at least 16 months at the time of the survey. In each of the four project regions (*Camp Perrin* in the southwest, *Marigot/Palmiste à Vin* in the southeast, *Cap Haitien* in the north, *Mirebalais* in the lower central plateau), we selected 35 participating farmers from the geographic areas of responsibility of eleven PADF agronomist technicians by using a random number list to pull farmer dossiers from the regional files. The technicians visited 1,540 farmers, 5.6% of all eligible farmers. During the whole period of data collection, other project staff carried out a continuous check of the technicians' work, rotating among the four PADF/PLUS field regions. Data cleaning was performed by sorting variables in the database, and checking suspect data with original questionnaires.

The Household Questionnaire

The survey data were recorded on two questionnaires, one completed in the home of the sampled farmer and one in the garden plots. Technicians completed a two-page household questionnaire recording a description of all plots owned and cultivated by the household during 1995, and a description of all the members of the household (Appendix D). Plot information recorded included distance from the residence (home garden, nearby, or distant), topographic position (top of slope, mid-slope, foot of slope, or plain), and slope steepness (flat, sloping, very steep). The size of the plot and the mode of access (purchased, inherited and separated among siblings, inherited and unseparated, share-cropped, rented from a private party, rented from the state) under which the plot was held were also recorded. For each individual member of the household, age, sex, highest level of education, kinds of PLUS project participation, and kinds of economic activities participated in were recorded. Finally, the head of household was asked whether he or she was originally from the locality, and if not, when did he arrive there. The farmer being interviewed defined the composition of the household and identified

who was the head of the household. The information recorded on the household questionnaire was collected during an in-home interview.

The Plot Questionnaire

During the home interview, the farmer was asked to indicate in which of the plots listed on the household questionnaire he or she had installed PLUS-inspired agroforestry practices. The farmer and the technician then visited those plots. A total of 2,295 plots were visited, an average of 1.5 plots per farm. The technician recorded information on the physical properties of the plots, the yield of crops during the previous twelve months and the average yield before soil conservation structures were built, and management and attitude information for each of the PLUS agroforestry interventions in the plots (Appendix E). Data collected about the physical characteristics of the plot included the fallow status of the plot, slope (taken by the technician with a plumb line clinometer attached to a clipboard), slope aspect, an estimate of the elevation of the plot to within 100 m, the number of erosion gullies greater than 20 cm depth, parent material of the soil (basaltic or calcareous), and the local name for the soil type on the plot. The number of trees per hectare (of any species from any source) whose trunk diameter was greater than 10 cm at 1.3 meters from ground level (DBH = diameter at breast height) was recorded. These trees were counted by the technician conducting the interview, using a plywood caliper with a 10 cm opening to define countable trees. The distance in minutes from the interviewed farmer's house to the plot was estimated. The farmer was then asked four qualitative questions about the soil on the plot; the answers were recorded as a number between one and five. These were regarding soil fertility (1 = infertile, 5 = fertile), soil

depth (1 = shallow, 5 = deep), the "hotness" or "coldness" of the soil[1] (1 = hot, 5 = cold), and the degree of erosion on the plot (1 = no erosion, 5 = severe erosion).

The farmers' qualitative analyses of soil fertility were followed up with a laboratory analysis. Soil samples were taken from 175 gardens selected at random from all gardens visited, 35 each from gardens having fertility classes 1 through 5. The samples were taken by technicians using a machete from the 0-20 cm layer; a composite of four positions for each sample. They were put into ziplock bags and labeled, then transported to the University of Florida for laboratory analysis. Complete methodology and results for the soil analysis are discussed in Appendix F.

Farmers were asked about the yield of the principal crops they harvested during 1995 and an average yield of the same crops before soil conservation structures were installed on the plot. This information was analyzed by SECID for reporting on PLUS project impact to USAID, and so was not used by the author in this study. Questions about the number of family members working on the plot, number of person days of labor from outside the family used on the plot, and the kinds of agroforestry and soil conservation structures installed on the plot completed the general questions. Then followed a separate page of questions for each of seven possible kinds of PLUS project activities installed on the plot: hedgerows, crop bands, rock walls, gully plugs, trees planted on the plot during 1995, top-grafted fruit trees, and vegetable gardens. The appropriate page was used according to the types of structures or techniques used on the plot. The questions asked on these pages varied with the technique. For the soil

[1]Most writers agree that "hot" soils (*CHO*) are dry, well-drained soils and "cold" soils (*FWET*) have more soil water available for plants. Other concepts are integrated into this system as well, including soil parent material, slope, orientation, and vegetative cover (McClain and Stienbarger 1988, Murray 1981). Some crops grow better in hot soils, some in cold, but in general cold soils are preferred (Smucker 1981).

conservation practices they included: the amount present as measured by the technician (number of rows and total length of each row), qualitative assessments (1 to 5 scale) by the farmer of the importance of a series of potential benefits and problems associated with the practice, who of the household participated in the construction and repair of the practice, the number of breaches in the structures over a specified size, whether or not the breaches were repaired, and a row-by-row rating by the technician of well-managed, adequately-managed, or poorly-managed. The management ratings integrated the technicians' opinion about hedgerow plant vigor, pruning height, density, and number of breaches.

Agroforestry Practices Compared on the Plots

Farmers participating in the PLUS project are asked to protect at least one plot of land with an agroforestry practice before they gain access to crop seed banks operated by their community-based organization (CBO) with PLUS assistance. The practices are discussed during training sessions with PADF technicians and CBO extension agents. The farmer decides what practice to install, and where to install it. It is noted that this project requirement is probably complied with, in many cases, only to gain access to crop seeds and tools. Some hedgerows, therefore, have been installed only to satisfy this rule, by farmers who judged the value of the seed and tool credit to be greater than the cost of trying the new technology.

Although the central focus of this study was the hedgerow, several other agroforestry practices were included in the analysis to contrast how farmers change their installation and management strategies to accommodate characteristics of the technology. The agroforestry practices vary in their general types. Hedgerows, crop bands, and rock wall terraces are built across the slope in contour rows. The area between rows, the

interspaces or alleys, is planted to field crops. Gully plugs are confined, obviously, to ravines or gullies. Trees may be planted anywhere. The usual planting configurations are perimeter plantings, small woodlots, or in widely spaced rows in farmed plots. Top grafting is done on existing fruit trees, planted before the PLUS project began.

Hedgerows

Hedgerows were defined in Chapter 3. They consist of a single or double row of densely planted trees (e.g., *Leucaena leucocephala*, *Gliricidia sepium*), perennial food crops (e.g., sugar cane, pineapple), or other perennial (e.g., perennial cotton, castor bean) planted on the contour as a physical barrier to soil erosion, as a soil fertility enrichment structure, and a source of diverse products of economic interest to farmers. Annual crops are planted in the alleys between hedgerows.

Crop bands (*bann manje*)

These evolved from hedgerows built from sugar cane and pineapple. They are similar to hedgerows in that they are installed as contour rows of perennial vegetation in a farmed plot, leaving room for field crops in the alleys between rows, with the goal of producing useful vegetation and holding soil and water on the plot. The differences are: 1) crop bands have a larger dimension—they are a band of one or two meters width as opposed to a single or double row of plants found in hedgerows, 2) the perennial plants that serve as structural components are food crops, such as sugar cane, pineapple, and plantain, and 3) annual crops are also planted in the band, such as yams and sweet potatoes. While differences between hedgerows and crop bands are not always clear—hedgerows can be made with sugar cane or pineapple, for instance, and often have an annual crop planted on the uphill side of the hedgerow that differs from the field crops planted in the alleys—crop bands are wider, contain a greater number of crop species,

and usually do not contain a woody perennial. The number of crop bands is still small (4.4% of PLUS plots had them in 1995), but farmers are interested and the practice is growing.

Rock walls

Rock walls are constructed of fieldstones place in rows across the slope contour. Two general kinds are built. The most common has a footing dug into the soil, and the stones are stacked carefully with flat sides and top (*mi sek*). The other kind requires less skill; the stones are simply piled in rows along the contour without preparing a footing (*kodon pyè*).

Gully plugs

These are constructed across narrow, actively eroding ravines. They are built from rocks where available (*sèy woch*), but also from stakes cut from trees, interwoven with smaller branches (*kleyonaj. fasinaj*). If they are built strongly, they will accumulate a considerable amount of eroded soil in a short time. The soil trapped by the gully plug is quite valuable, because it is deep, well drained, and collects water from adjacent slopes during rainfall. The usual practice is to plant high-value crops uphill from the structures, often plantains and taro, as soon as enough soil accumulates. They can be costly to install and maintain, but the income from the crops can be high and a well-protected ravine does less damage to the farmer's property.

Trees

Two kinds of trees are referred to in the analysis: those planted on the plot as seedlings by a farmer during 1995 as a project activity, or mature trees of any species or source over 10 cm in diameter at breast height.

Top-grafted fruit trees

These are mature low-value mango or citrus that were grafted, either by the farmer or by a project extension agent, with high-value buds.

Statistical Analysis

Data transformation and statistical analyses were done using SPSS version 9. Statistical tests were considered significant at the 95% level of probability. Because the distribution of most of the variables recorded on the questionnaires was not normal and because variables having several factor levels usually had great differences in the numbers of observations among the factor levels, nonparametric analysis was performed on the questionnaire data. The Kruskal Wallis test of mean ranks was used instead of analysis of variance. Because SPSS version 9 is not able to do mean separation after a significant Kruskal Wallis result, Mann-Whitney comparisons were done on the ranked mean pairs, followed by a Bonferroni correction (the p-value of the Mann-Whitney tests were multiplied by the number of factor levels, R. Littel, personal communication, September 1999) (Ott 1992, Zar 1984). Cross tabulations were tested with Pearson chi-square; bivariate correlations were tested with Spearman's rho.

Limitations of the Analyses

The regions where the PLUS project was working were selected because they are smallholder hillside farming areas with above-average agricultural potential. Because only farmers participating in the PLUS project were used as the sample population, conclusions based on the data produced by the survey may not apply to Haiti generally, and they may not apply to farmers not participating in PLUS. It is also noted that the information regarding participation of household members in PLUS agroforestry activities and other economic activities was given by one person, usually a male head of

household, and may therefore be biased. The analysis presented here is limited in that no plots were sampled that 1) were controlled by PLUS participants but had no agroforestry practices installed, 2) were controlled by farmers not participating in the project, or 3) had PLUS-inspired practices installed by secondary adopters (farmers not receiving PLUS extension visits or subsidies).

Results and Discussion

Results are presented in three sections. The first section describes the household members and all the garden plots under household control during 1995 based on the in-home interview questionnaires, and then the 2,295 plots visited by PADF technicians during the survey. The plots visited by the technicians were those where interviewed farmers had installed at least one project-sponsored agroforestry practice.

The second section addresses the decision to install hedgerows and other related agroforestry practices. Several types of household resources bearing on land, education, and labor are compared between households that installed and households that did not install particular agroforestry practices. Physical characteristics of plots having the practice are then compared to those of the plots where that practice was not installed.

The third section discusses the relationships between the quality of management applied to agroforestry practices on the plots, and three categories of independent variables: 1) household resources, 2) plot physical characteristics, and 3) problems and benefits associated with hedgerows as perceived by the farmer.

Characteristics of the Household and Household Plots

Numbers of family members by gender

The 1,540 households interviewed reported a total of 8,584 members, of which 52 percent were male and 48 percent female. The mean number of people per household

was 5.6. Table 6-1 shows the percent of household members by gender in seven age classes. Males and females have about the same distributions among the age classes.

Heads of household

Eighty-five percent of heads of household were male; fifteen percent were female. The mean age of male heads of household was 46 years, and 50 years for female heads of household. Eighty-four percent of heads of household reported that they were from the area where they now lived, and sixteen percent moved into the locality from outside. There was a small but significant age difference between local (46 years) and immigrant (49 years) heads of household. A higher percent of females (18.6%) than males (15.6%) were immigrants, but the difference was not statistically significant. The number of years of schooling for heads of household was 2.7, but it was not distributed normally. About half of them had no schooling whatsoever; the median number of years was zero. There was a significant difference in schooling between female and male heads of household, the mean number of years for females was 1.2, and for males 3.0.

Table 6-1: Age distribution by gender of members of 1,540 farm households interviewed in the four PADF/PLUS project areas in Haiti, 1996.

	Female		Male	
Age class (yrs.)	**N**	**Percent**	**N**	**Percent**
36529	561	13.7	587	13.1
36686	631	15.4	613	13.7
36844	510	12.4	627	14.0
16-20	471	11.5	558	12.5
21-60	1646	40.2	1763	39.4
61-70	197	4.8	232	5.2
>70	81	2.0	99	2.2
Total	4,097	48	4,479	52

Years of school for household members

Increased education could facilitate access to extension material, or increase the likelihood that a farmer might be selected as a project extension agent, and thereby increase his probability of adopting an agroforestry technology. The mean total combined number of years of school for all members of the household was 16 (median = 12). The average male household member had gone to school for 3.3 years, significantly more than the average female household member, who had 2.6 years of school. The distribution of years of education is better understood when broken down by age, as shown in Table 6-2.

Table 6-2: Number of years of school by gender in seven age classes of 1,540 households participating in the PADF/PLUS project, 1996

	Female		Male	
Age class (yrs.)	**N**	**Years**	**N**	**Years**
36529	509	0.3 e[a]	524	0.2 e
36686	610	2.0 c	593	1.9 c
36844	502	3.9 b	615	4.0 b
16-20	455	6.1 a	547	5.9 a
21-60	1534	2.5 d	1652	4.0 b
61-70	178	0.7 e	213	1.8 d
>70	73	0.0 f	89	1.8 d

[a] Numbers followed by the same letter are not significantly different (α=0.05)

For both females and males, there were significant differences among age classes. For both sexes, the number of years of school increased as age increased until it peaked in the 16-20 year age class, and then decreased as age increased. When comparisons were done by gender within each age class, it was shown that females and males through 20 years received the same amount of education. Above 20 years, however, males had attended school longer than females. The data seem to indicate that, in the past, men

received more education than women did, but that has apparently changed for the sampled population and now there is no difference.

Participation of household members in economic activities

The interviewers asked PLUS farmers if each household member participated in economic activities other than PLUS soil conservation, tree culture, and crop improvement practices. A list of categories of activity was produced from the results, but this list does not include normal agricultural work, childcare, cooking, or home maintenance. The mean number of economic activities was three per household. Table 6-3 shows the percent of female and male household members engaged in various categories of economic activity. Small businesses include furniture construction, tailoring, plowing fields, and other activities requiring specialized training or equipment. Local official positions include persons elected to government posts and schoolteachers. Two categories, fishing and factory work, are not shown because they included less than 0.5 percent of household members.

Table 6-3: Percent of female and male members of 1,540 project households who participated in various economic activities during 1995-1996.

	% of Members Participating	
Activity	**Female**	**Male**
Animal raising	6	25
Marketing agr. products	6	0
Marketing other products	20	3
Small businesses	2	9
Handicrafts	1	1
Agricultural day labor	0.5	1
Charcoal or lime production	0	2
Local official position	1	1
Leaf doctor	0	1
Sawyer	0	2
Other day labor	0	1
Sample size	4097	4479

Table 6-3 confirms the commonly made observation that women are more involved in marketing (Murray 1981) and men in animal raising. The percent of women involved in marketing, men selling charcoal, and men selling agricultural day labor appears to be very low. This might be an indication that sampled farmers, being project participants, were wealthier than average. Table 6-4 presents the same information by age class. The two youngest age classes are not included because of very low participation. Only 2 percent of the 6-10 year old boys and 1 percent of the 6-10 year old girls were active in raising animals.

Table 6-4: Percent of female and male members of 1,540 project households who participated in various economic activities during 1995-1996, by age class.

	Age classes (years)									
	319		16-20		21-60		61-70		>70	
Activity	F	M	F	M	F	M	F	M	F	M
Animal raising	3	9	3	21	12	43	17	56	7	40
Marketing agr. products	0	0	4	0	13	1	7	0	1	1
Marketing other products	2	0	11	0	42	6	34	5	17	1
Nonagr. professions	0	1	0	4	5	18	2	12	0	12
Handicrafts	0	1	1	1	2	2	2	3	0	5
Agricultural day labor	0	1	0	1	1	2	1	3	1	3
Charcoal or lime production	0	0	0	1	0	4	0	3	0	2
Local official position	0	0	0	1	1	3	1	1	0	1
Leaf doctor	0	0	0	0	0	2	2	3	0	5
Sawyer	0	0	0	0	0	5	0	3	0	1
Other day labor	0	0	0	0	1	1	1	2	0	1
Sample size	510	627	471	558	1646	1763	197	232	81	99

Table 6-4 shows percent participation within each age class (i.e., the column percents). When percent participation within each activity was considered (i.e., the row percents, which are not shown), it was noted that most of the activities (usually more than 80%) are done by persons in the 21-60 years age class. Animal raising, however, spreads

more into the younger and older age classes, especially for males. Table 6-4 confirms that more boys than girls participate in animal raising, and likewise more old men participate than do older women. The counterpart activity for women is marketing. They begin this activity at an earlier age and continue it longer into older age than do men, and more women than men work in marketing. Men are more active in small businesses, charcoal and lime production, and sawing wood than are women.

Participation of household members in PLUS agroforestry practices

A greater percent of males than females participate in the installation and management of agroforestry practices. The PADF field staff commonly report that mainly females participate in vegetable gardens, but Table 6-5 shows that males are equally involved.

As in the case of other economic activities, persons in the 21 to 60 year age class (usually over 70% of those participating) do most of the agroforestry work. However, the highest percent participation within an age class is seen in the 61 to 70 year olds, where 79% of the males and 36% of the females participate in soil conservation structures on slopes (Table 6-6).

Table 6-5: Percent of female and male members of 1,540 households who participated in PLUS project activities during 1995-1996.

Activity	Female	Male
Soil conservation on slopes	15	39
Gully plugs	2	7
Vegetable gardens	4	5
Fruit tree grafting	1	3
Tree planting	7	20
Sample size	4097	4480

Table 6-6: Percent of female and male members of 1,540 project households who participated in PLUS project activities during 1995-1996, by age class.

	Age classes (years)									
	11-15		16-20		21-60		61-70		>70	
Activity	F	M	F	M	F	M	F	M	F	M
Soil conservation on slopes	4	9	3	25	28	72	36	79	25	68
Gully plugs	0	1	0	5	3	13	3	16	6	9
Vegetable gardens	4	3	3	3	6	9	4	7	3	8
Fruit tree grafting	0	0	0	0	2	7	5	8	1	7
Tree planting	1	3	2	10	13	37	20	48	7	32
Sample size	510	627	471	558	1646	1763	197	232	81	99

Number and area of total household plots

The mean number of plots that the household worked or owned during 1995 was 3.7, normally distributed. The minimum number of plots was one; the maximum was twelve. The mean total area of all family plots was 1.7 hectares. Plot area data are skewed, with a small number of farmers having a large number of hectares. The minimum total size of all plots taken together was .08 hectares, the maximum was 20.7 hectares per family.

Farmers were asked to describe each plot, with respect to distance from the house, as a home plot, a near plot, or a distant plot. These are qualitative categories as defined by the farmers. The total number of hectares per household in each type of plot is shown in Table 6-7. The areas are summed for all plots of a particular type controlled by the household.

The home plot area was smallest, with more land being held in nearby plots, and the most in plots further from the residence. The sum of the means in Table 6-7 is larger than the mean value of 1.7 hectares of total household plot area because the distributions

of the sizes of each plot type, considered separately, are skewed, so the means are not good predictors of the average value. Each distribution has a number of extreme values (plots much larger than average). The sum of the median values (1.5 ha) is close to the 1.3-hectare median value for the total household plot area. The average size of each type of plot (as opposed to the total amount of land area in all plots of each type as shown in Table 6-7) is shown in Table 6-8.

Table 6-7: Average total area of three categories of plots held by 1,540 project households based on the relative distance from the plots to the residence.

	Mean (ha)	Median (ha)
Home plots, total area	.45	.32
Near plots, total area	.78	.49
Distant plots, total area	1.12	.71

Table 6-8: Mean plot area of three categories of plots held by 1,540 project households during 1995, based on the relative distance from the plots to the residence.

	Mean (ha)	Median (ha)	N
Home plot	.42a	.32	1173
Near plots	.40a	.32	2134
Distant plots	.53b	.32	2349

Distant plots were significantly larger than home plot or near plots. A previous study (McLain and Stienbarger 1988) had shown that farmer estimates of plot areas in Haiti were inaccurate and showed a poor relationship between the estimates and actual plot size. Therefore, size of each plot type was computed for each PADF region separately (Table 6-9). The same relationship between plot size and distance from the residence was found in the subsets of plot size data for three of the four regions. Therefore, the hypothesis that farmers are able to estimate plot size relatively, if not

absolutely, is strengthened. The distant plots were significantly larger than the other two plot types in Regions 1, 3, and 4. In Region 2, the mean area of the near plots was smaller than that of the other plot types.

Table 6-9: Mean plot area of three categories of plots held by 1,540 project households during 1995 in four PLUS project regions, based on the relative distance from the plots to the residence.

	Region 1		Region 2		Region 3		Region 4	
	ha.	**N**	**ha.**	**N**	**ha.**	**N**	**ha.**	**N**
Home	.34a	298	.37b	238	.41a	310	.55a	327
Near	.36a	467	.31a	595	.41a	629	.58a	443
Distant	.50b	509	.36b	364	.47b	861	.74b	615

Tenure of plots

The particular aspect of tenure of interest to this analysis is the level of confidence farmers feel regarding their ability to work and eventually harvest agricultural produce from the plot over time. This is referred to as tenure "security," although there is no consistent relationship between different tenure conditions and levels of security. Tenure categories used in the survey are: purchased by the farmer, inherited and divided (legally or otherwise) among siblings, inherited and undivided, sharecropped by the farmer surveyed, rented by the farmer from a private landowner, rented by the farmer from the state, and plots on which the farmer acts as a caretaker for the landowner. This study hypothesizes that purchased and inherited-divided tenure categories are generally more secure than other types.

There are differences in tenure condition among the three types of plots according to distance from the residence, as shown in Table 6-10. Cell values are percents of the row totals. There are statistically significant differences among the cell values.

Table 6-10: Percent of three categories of plots held by 1,540 project households during 1995 under various modes of access.

	Purch	Divid	Undiv	Share	Rent	State	Caretak.	Other	N
Home	48.9	17.2	23.7	2.0	6.5	0.1	1.1	0.6	1174
Near	35.0	13.9	20.9	12.4	15.0	0.3	1.5	1.0	2134
Dist.	36.6	14.1	19.8	11.8	13.4	2.0	0.9	1.4	2350
All	38.5	14.7	21.0	10.0	12.6	1.0	1.2	1.1	5658

The most common mode of access for all three types of plot is purchased, followed by inherited undivided. The home plot, however, is more likely than the others to be on purchased or inherited land. It is much less likely than the other two types to be sharecropped or rented. A plot rented from the state is most likely to be a distant plot. Overall, 74% of plots are held in primary access mode (purchased or inherited), with home plots having the highest proportion in primary access (90%) and near plots having the lowest (70%). The finding that fewer nearby plots than distant plots are held under primary access may be due to farmers' having property located too far from the homestead, and therefore adopting a strategy of leasing distant plots to someone and renting land closer for their own production (Bloch et al. 1987). Tenure relates to plot area, topographic position, and slope, as shown in Tables 6-11, 6-12, and 6-13.

Tenure and plot area. Table 6-11 shows land area by land tenure category taken from the household database of all plots worked during 1995. Numbers followed by the same letter are not statistically different. Numbers of gardens in each tenure category appear in the "N" column. The mean area of purchased plots is greater than the mean area of inherited, separated plots. The area of plots rented from the state is greater than all other plot types except plots where the farmer is acting as a caretaker, which have the largest area.

Table 6-11: Area of 5,660 plots held by 1,540 households during 1995, by mode of access.

	Mean plot area (ha)	N
Rented, state	0.90 a	55
Caretaker	1.22 ab	66
Purchased	0.53 b	2,183
Rented, private	0.42 bc	712
Inherited, unseparated	0.41 c	1,189
Sharecropped	0.39 c	565
Other	0.38 c	61
Inherited, separated	0.36 c	829
All		5,660

Tenure and topographic position. A cross tabulation of land tenure by topographic position of the plot shows similar frequencies for all tenure types except for plots on land rented from the state and plots where the planter acts as caretaker (Table 6-12). State land is much more likely to be in the top slope position than all other tenure types, and much less likely to be on the foot slope or plain position. The opposite is true for caretaker plots, that are much less likely to be on the top of slope position, and more likely to be on a plain. Units are percents of row totals.

Table 6-12: Percent of plots held by 1,540 households during 1995 in eight mode of access categories by slope position.

	Top slope	Mid slope	Foot slope	Plain	N
Purchased	12.7	43.8	25.5	18.0	2180
Inh, sep	14.3	46.6	24.4	14.8	827
Inh, unsep	14.0	46.3	22.9	16.7	1190
Sharecrp	13.1	42.7	26.7	17.5	565
Rent,priv	13.1	42.7	24.3	19.9	712
Rent,state	40.0	45.5	12.7	1.8	55
Caretaker	9.1	40.9	25.8	24.2	66
Other	11.5	36.1	36.1	16.4	61
Total	13.5	44.4	24.8	17.4	5656

Tenure and slope class. A cross tabulation of land tenure by slope class shows results similar to those for topographic position, as it should since topographic position and slope are related (Table 6-13). Land rented from the state is much less likely to be flat, and much more likely to be very steep than other tenure types. Again, the opposite is true for caretaker plots, which are less likely to be on very steep land than are other tenure types.

Table 6-13: Percent of all plots held by 1,540 households during 1995 in eight modes of access categories by slope steepness .

	Flat	Steep	Very Steep	N
Purchased	18.8[a]	56.1	25.2	2178
Inh, sep	16.2	58.4	25.4	826
Inh, unsep	17.1	57.7	25.3	1188
Sharecrp	19.3	59.5	21.2	565
Rent,priv	22.2	54.9	22.9	712
Rent,state	3.6	38.2	58.2	55
Caretaker	23.7	57.6	15.2	66
Other	21.3	49.2	29.5	61
Total	18.5	56.7	24.8	5651

[a] Units are percent of row totals.

Characteristics of the plots having agroforestry practices

All plots having PLUS practices were visited by PADF technicians, quantitative data were noted from them. Of the 5,651 plots described as being in their control during 1995, farmers had installed PLUS-inspired agroforestry practices on 2,295 (41%) of them. On the average, out of the 3.7 total plots controlled by a household during 1995, 1.5 had PLUS interventions. Furthermore, among an average of three PLUS interventions that a household had on its total plot area, two were soil conservation

practices. If we consider only the plots having PLUS practices, each plot had two agroforestry interventions, one of which was a soil conservation structure.

Distance from the residence. There were small but statistically significant differences in distance between the residence and the plot, measured in minutes, among tenure classes[2] (Table 6-14).

Table 6-14: Distance from residence of plots having project agroforestry practices held by 1,540 households during 1995 in the five most common mode of access categories

	Mean distance (minutes)	N
Sharecropped	16 a	189
Rented, private	14 ab	284
Inherited, unseparated	13 b	481
Purchased	13 b	948
Inherited, separated	12 b	324

From the data in Table 6-10, we might have expected purchased plots to be significantly nearer the residence than plots of other tenure types. This was the case; rented and sharecropped plots were more distant than purchased or inherited plots. However, the range of distances is so small that the result is not important. The seven plots in the sample that were rented from the state averaged 25 minutes away from the residence.

Tenure and size of plot. Comparison of tenure category by plot area done only on the plots having PLUS interventions (Table 6-15) agreed with the analysis done on all plots controlled by the household (Table 6-11). Purchased plots were again significantly larger than the other tenure types. Inherited, separated plots were the smallest.

[2] Three tenure classes having very few observations (State land, 7; Caretaker, 32; Other, 29) are eliminated from statistical analyses of PLUS plots.

Table 6-15: Area of plots having project agroforestry practices held by 1,540 households during 1995 in the five most common mode of access categories

	Mean plot area (ha)	N
Inherited, separated	0.36a	324
Rented, private	0.41a	284
Inherited, unseparated	0.41a	482
Sharecropped	0.42a	189
Purchased	0.54b	948

Tenure and elevation. We estimated elevation within plus or minus 100 meters above sea level for the PLUS subset of plots (Table 6-16). Elevation did not correspond to relative topographic position as described by farmers in Table 6-12 (for example, it is possible to have a high elevation plain), but the results were similar. There were no significant differences in elevation among tenure categories. This might indicate that the technician's estimates were not accurate enough, that farmers' plots tend to be found within 100 meters of each other, or a combination of both. Although elevation of plots rented from the state was significantly higher, there were only seven plots in that category. State land in PLUS areas was more commonly found in higher elevations.

Table 6-16: Elevation of plots having project agroforestry practices held by 1,540 households during 1995 in seven mode of access categories

	Elevation (m)	N
Purchased	339	948
Inherited, separated	340	324
Inherited, unseparated	341	481
Sharecropped	348	189
Caretaker	355	32
Rented, private	363	284
Other	439	29
Rented, state	743	7

Tenure and slope. Slope percents measured by technicians on the subset of plots with PLUS interventions (Table 6-17) shows caretaker plots as having the gentlest slopes. State land, however, is also shown as being on gentler slopes, which is contrary to the finding in the cross tabulation done for all household plots (Table 6-13).

Table 6-17: Slope of plots having project agroforestry practices held by 1,540 households during 1995 in seven mode of access categories

	Slope (%)	N
Caretaker	22a	31
Rented, state	26b	7
Inherited, separated	31b	324
Purchased	32b	947
Rented, private	33b	284
Inherited, unseparated	33b	482
Sharecropped	34b	189
Other	34b	29

The Decision to Install Agroforestry Practices

This section considers the 2,295 plots where the 1,540 surveyed households had installed at least one project agroforestry practice. These plots are referred to as "PLUS" plots, meaning the practices were installed under the auspices of the PLUS project. The characteristics of all PLUS plots having a given agroforestry practice were compared to those of all PLUS plots not having that practice. The plots excluded from consideration are the 3,356 plots accessed by the households during 1995 that did not have at least one agroforestry practice installed. Using all household plots in the comparison would have been preferable, as it would have given a better idea of how farmers make decisions based on plot criteria, but technicians visited and collected data only from PLUS plots.

However, it is still possible to see differences in plot characteristics using only the PLUS plot data.

Household resources and the decision to install

The independent variables of interest in this section pertain to the amount and security of access of the land controlled by the household (number of plots, total plot area, number of purchased or inherited-separated plots, total plot area of purchased or inherited-separated plots); the number of family members available as labor (total number of household members, total number of household members of ages of 21 to 60, number of females of ages 21 to 60, number of males of ages 21 to 60); level of education (total years of education for all household members, years of education of the head of household); and the amount of labor used on the plot of interest during 1995 (person-days of agricultural labor purchased in the plot, number of household members working in the plot).

The reasons for including these variables were that the probability of adoption might increase as the amount of total land and land under secure tenure increased and as the number of family members available to work the land increased. Farmers with more land and labor might be more able to risk land for new technologies and with a lower cash outlay for labor if family members were available. Level of education was of interest because more education could allow a farmer easier access to extension material or increase the likelihood that he or she be selected as an officer in the farmer group or as an extension agent. Either of these outcomes could increase the probability of adoption.

Households that had installed a particular practice (hedgerow, crop band, rock wall, gully plug, project trees planted during 1995, top-grafted fruit trees) on at least one of the visited plots were compared to those who had not installed that practice. Very few

of the comparisons between adopting and nonadopting households were significant, and those that were did not have very large numerical differences. In spite of the small differences, interesting trends were revealed:

Hedgerows. Households installing hedgerows had 0.3 ha less total plot area than those not installing ($p = .012$), and had 0.2 fewer family members working on the plot during 1995 ($p < .001$). Both of these findings might appear to be counter intuitive, since less land and labor available to a household should decrease the likelihood of adoption. However, the comparisons were made only within the population of project participants, all of whom installed at least one soil conservation practice. Since hedgerows were the least expensive of the structures to install, it is possible the poorest participants installed hedgerows.

Crop bands. Households installing crop bands had 0.7 more plots ($p < .001$), 0.6 more secure plots ($p = .005$), 0.27 ha more area in secure plots ($p = .011$), but heads of household having 0.9 fewer years of school ($p = .011$) than did households not installing crop bands. This indicates that households adopting crop bands were better off compared to nonadopters. Crop bands are more expensive to install that hedgerows because they require large quantities of perennial crop cultures (e.g., sugar can, pineapple) and they take up more space in the plot than hedgerows.

Rock walls. Households installing rock walls had 0.3 more household members ($p = .001$), 2 years less of total schooling ($p = .006$), and 0.2 more family members working on the plot in 1995 ($p < .001$) than did households not installing rock walls. Rock wall adopters apparently have more labor available than non-adopters, but no difference in amount of land. Rock walls are costly to install, but the cost is exclusively

in labor as no crop germplasm is used. Returns to labor are seen more quickly than for hedgerows, since rock walls function immediately to slow erosion and collect water.

Gully plugs. Households installing gully plugs had 0.5 more plots ($p < .001$), 0.5 more total hectares ($p < .001$), and purchased 4 more person-days of labor to work in the plot during 1995 ($p = .001$) than did households not installing gully plugs. This appears to indicate that better-off farmers built gully plugs. Gully plugs built of stone can be costly to install, but they often create new agricultural land (because they collect sediment on the uphill side) where water accumulates from the side slopes. This can happen quickly (within one rainy season), especially in sandy, basaltic soils. Farmers typically plant plantains and taro in these microsites. As for the installation, getting the crop germplasm can be expensive but the profit can be substantial.

PLUS project tree seedlings. Households planting PLUS project tree seedlings on at least one plot during 1995 had 0.2 more plots ($p = .012$), 2.2 more total years of school ($p = .005$), and 0.2 more family members working on the plot during 1995 ($p = .004$) than did households not planting project tree seedlings.

Top-grafting. Households having top-grafted fruit trees on at least one plot had 0.5 more plots ($p = .001$), 0.4 more hectares ($p = .012$), and 3.4 more total years of school ($p = .006$) than did households not having top-grafted fruit trees. It is interesting that households planting project tree seedlings and those grafting fruit trees had more total years of school than households not engaging in those activities. This was not true for any of the other agroforestry practices. These findings are similar to those found by Smucker (1988), but the reasons for it are not clear. Tree seedlings are either provided free or grown by the farmer, and the first four grafts are also either done by the farmer or the extension agent without charge, so costs of adoption are minimal.

The small number of significant results and the small numerical differences, even when significant, between households having and not having the indicated practices means there were small household resource differences in the sampled population. This was probably because nonproject farmers were not included in the sample. However small the differences, though, it appears that

- households installing hedgerows had less land than households installing crop bands and gully plugs or top grafting;
- households installing crop bands had more land in secure tenure than other households;
- households installing gully plugs invested more in purchased labor on the plot; and
- households planting project trees or top-grafting attended more years of school than other households.

These associations appear to make sense based on the costs of installation of the agroforestry technologies, as explained above.

Plot characteristics and the decision to install

The plot characteristics of interest were tenure security, soil fertility, slope, and distance from the plot to the residence. The assumption was that these influence the probability that farmers adopt agroforestry practices in various ways. Land held under secure modes of access would be more likely to be used when the practice is expensive to install and potential returns are high and extend over time. Plots having fertile soil would be used for practices that could provide a quick return to that resource. In contrast, plots having infertile soil might be used for practices that were previously unknown to the farmer and looked risky. Slope might influence adoption in a similar way to soil

fertility—the best (less sloped) plots would be used for practices requiring larger investment, steeper slopes for untried practices. Distance from the residence might be an issue if theft of potential products (e.g., trees, fruit) was likely.

Direct measurements or observations were used to determine tenure, slope, and distance. Purchased plots and inherited divided plots are referred to as "secure". Farmers assessed soil fertility on a qualitative scale, with the soils rated as 4 and 5 on that scale referred to as "fertile." Analyses showed there was a correspondence between farmers' ratings and laboratory tests: soils rated as fertile had a lower pH, more potassium, and more organic carbon (Appendix F). Plot characteristics for six agroforestry practices were considered in the 2,295 gardens visited during the survey: hedgerows, found in 60% of the gardens; crop bands, found in 4%, rock walls, found in 30%; gully plugs, found in 17%; tree seedlings, found in 46%; and grafted trees, found in 9%.

The importance of tenure security and soil fertility on the decision to install a practice is shown in Tables 6-18 to 6-21. These tables present two-by-two cross tabulations comparing tenure security (Tables 6-18 and 6-19) and soil fertility (Tables 6-21 and 6-21) of plots having the indicated practice to those not having the practice. Three kinds of results were seen. A lower percentage of plots with hedgerows were in secure tenure (52%) compared to plots without hedgerows (61%). However, a higher percentage of plots with crop bands, tree seedlings, and tree grafting were in secure tenure compared to plots without those practices. Tenure status of plots did not differ for rock walls or gully plugs.

Table 6-18: Percent of 2,295 surveyed plots with and without three kinds of agroforestry practice held under secure (purchased or inherited/divided) or not secure (all other) tenure

	Hedgerows		Crop bands		Rock walls	
	with	without	with	without	with	without
% of plots having secure tenure	52	61	66	55	54	56
% of plots not having secure tenure	48	39	34	45	46	44
Number of plots	1,365	930	100	2,195	686	1,609
2-by-2 chi-square P-value	<.001		.030		.349	

Table 6-19: Percent of 2,295 surveyed plots with and without three kinds of agroforestry practice held under secure (purchased or inherited/divided) or not secure (all other) tenure

	Gully plugs		Tree seedlings		Tree grafting	
	with	without	with	without	with	without
% of plots having secure tenure	57	55	64	48	69	54
% of plots not having secure tenure	43	45	36	52	31	46
Number of plots	385	1,910	1,050	1,245	207	2,088
2-by-2 chi-square P-value	.604		<.001		<.001	

All cross tabulations for the effect of soil fertility on adoption showed significant differences from the expected cell values. A lower percent of plots with hedgerows had fertile soil (41%) compared to plots without hedgerows (51%). The opposite was true for all other practices, where a higher percent of the plots with them were rated as having fertile soil compared to plots without them.

Table 6-20: Percent of 2,295 surveyed plots with and without three kinds of agroforestry practice having fertile or not fertile soil

	Hedgerows		Crop bands		Rock walls	
	with	without	with	without	with	without
% of plots having fertile soil	41	51	58	44	50	43
% of plots not having fertile soil	59	49	42	56	50	57
Number of plots	1,365	930	100	2,195	686	1,609
2-by-2 chi-square P-value	<.001		.007		.001	

Table 6-21: Percent of 2,295 surveyed plots with and without three kinds of agroforestry practice having fertile or not fertile soil

	Gully plugs		Tree seedlings		Tree grafting	
	with	**without**	**with**	**without**	**with**	**without**
% of plots having fertile soil	50	44	47	43	58	44
% of plots not having fertile soil	50	56	53	57	42	56
Number of plots	385	1,910	1,050	1,245	207	2,088
2-by-2 chi-square P-value	.026		.036		<.001	

Two observations can be drawn from these results: 1) assignment of agroforestry practices to plots is not random and 2) hedgerows seem to be assigned to plots of less secure tenure and lower fertility. However, the hedgerows found in the sampled plots were not uniform. They were composed of various tree, crop, and grass species. There were sixteen different tree species represented in the sample, the most common being *Leucaena leucocephala*. There were also hedgerows whose components included pineapple, sugar cane, plantain, pigeon pea, and cassava, as well as five kinds of forage grasses. If each type of hedgerow is analyzed separately, quite different sets of results are obtained that strengthen the findings in Tables 6-18 to 6-21. These results are shown in Tables 6-22 and 6-23. Tree-based hedgerow plots contained only tree species; crop-based hedgerow plots contained at least one food crop species, but may also have contained trees and grasses; and grass-based hedgerow plots were made exclusively of forage grasses. The characteristics of each kind of hedgerow plot were compared to the same characteristics of all other plots in the sample of 2,295 PLUS plots, as above.

Table 6-22: Percent of 2,295 surveyed plots with and without three kinds of hedgerows held under secure (purchased or inherited/divided) or not secure (all other) tenure

	Tree-based		Crop-based		Grass-based	
	with	without	with	without	with	without
% of plots having secure tenure	49	59	54	56	48	56
% of plots not having secure tenure	51	41	46	44	52	44
Number of plots	701	1,594	507	1,788	44	2,251
2-by-2 chi-square P-value	<.001		.543		.300	

Table 6-23: Percent of 2,295 surveyed plots with and without three kinds of hedgerows having fertile or not fertile soil

	Tree-based		Crop-based		Grass-based	
	with	without	with	without	with	without
% of plots having fertile soil	34	50	51	43	43	45
% of plots not having fertile soil	66	50	49	57	57	55
Number of plots	701	1,549	507	1,788	44	2,251
2-by-2 chi-square P-value	<.001		.001		.810	

The results for tree-based hedgerows were the same as for hedgerows in general—a lower percent of plots where they were installed were in secure tenure and fertile soil compared to plots where they were not installed. However, when perennial crops were added as structural components of hedgerows the results were similar to those for crop bands, with a higher percent of plots having crop-based hedgerows in fertile soil compared to plots without them. Tenure security was not significant for crop-based hedgerows; neither tenure security nor soil fertility were significant for grass-based hedgerows.

There were statistically significant differences ($\alpha = 0.05$) in the slope of plots having agroforestry practices compared with those not without them, but the differences were numerically small. Hedgerows (34% vs. 30%) and crop bands (37% vs. 32%) were

on plots having steeper slopes compared to plots without those practices. Rock walls (31% vs. 33%) and grafted trees (26% vs. 33%) were on plots having less steep slopes compared to plots without those practices. There were no differences in slope for gully plugs or tree seedlings. The differences in distance from the residence to the plots having agroforestry practices and those without them were also statistically different ($\alpha = 0.05$), but the numerical differences were only from one to three minutes, except for grafted trees. Grafted trees were found on plots averaging seven minutes walk from the residence, while plots without grafted trees were fourteen minutes distant.

It is possible to gain additional insights on the relationship between plot characteristics and the decision to invest in agroforestry practices by considering all trees on the plot whose trunk diameter is greater than 10 cm DBH. These trees may or may not have been planted in association with PADF projects, and may be either fruit or hardwood species. There were a significantly greater number of mature trees on purchased plots, and on inherited but separated plots, than on inherited unseparated, sharecropped, or on rented land (Table 6-24). More (but not statistically different) trees were found on inherited separated land than on purchased land, probably because the inherited land had been held longer by the household than the purchased land.

Table 6-24: Number of all trees larger than 10 cm diameter on PLUS plots, by plot tenure

	Mean no. of trees/ha[a]	**No. of plots**
Inherited, separated	103a	324
Purchased	88 a	946
Inherited, unseparated	69 b	481
Sharecropped	61 b	189
Rented, private	56 b	283

[a]Kruskall-Wallis p-value <.001

A similar analysis showed that more mature trees were found on plots having fertile soil (Table 6-25).

Table 6-25: Number of all trees larger than 10 cm diameter on PLUS plots, by soil fertility

Qualitative fertility classes	Mean no. of trees/ha[a]	No. of Plots
Very fertile	98 a	274
Above average fertility	90 a	758
Moderate fertility	73 b	893
Less than average fertility	60 b	308
Infertile	58 b	58

a: Kruskall-Wallis p-value <.001

Management Quality of Agroforestry Practices

The hypotheses for this section are that the quality of management a farmer gives to an agroforestry practice is better in households with more labor resources are available, in plots having physical resources (slope, soil fertility) that potentially would provide a better chance of return to management investment, and in households that have a greater expectation (based on experience or demonstration) of benefits from the technology.

Management quality variables were recorded by PADF technicians during the site visit. Four variables are used as indicators of management quality: percent of rows/gully plugs judged to be well managed, percent poorly managed, number of breaches larger than 25 cm in the structures, and whether the farmer repairs the breaches. Each row of hedges, crop bands, or rock wall, and each gully plug, was judged separately by the technician as being well managed, medium managed, or poorly managed based on plant vigor, pruning practice, plant density, and number of breaches (holes) in the structure. The numbers of breaches were counted by the technician. The technician determined

whether the farmer repaired breaches by observation and by asking the farmer, since this kind of repair is normally done just before crops are planted and might not have been done yet at the time of the visit. As for the decision to install tests, the four management quality indicators were tested against plot slope, distance from the residence in minutes, mode of tenure/access to the plot, and farmers' qualitative estimates of soil fertility.

Household resources and management quality

The statistical tests used in this section were bivariate correlations (percent well managed, percent poorly managed, number of breaches) and t-tests without the assumption of uniform variances (whether breaches were repaired). Similar to the section on household resources and the decision to install, there were statistically significant correlations and t-tests, but the correlation coefficients and differences between means were small.

Hedgerows. The percent of well-managed hedgerows decreased as the number of plots held by the household ($p = .004$) and the number of plots in secure tenure ($p = .054$) increased. The percent of well-managed hedgerows increased as the number of males of age 21-60 ($p = .003$), the number of household members of age 21-60 ($p = .016$), and the number of person-days of labor purchased in the plot during 1995 ($p = .050$) increased. The number of breaches in the hedgerows decreased as the number of plots in secure tenure ($p < .001$), number of hectares in secure tenure ($p < .001$), number of person-days of labor purchased in the plot during 1995 ($p = .012$), and the number of family members working in the plot ($p = .002$) increased. Households repairing breaches in hedgerows had 0.3 more family members working in the plot than did households not repairing breaches ($p = .002$).

Crop bands. The percent of well-managed crop bands increased as the number of years of school attended by the head of household increased ($p = .043$). The number of breaches in crop bands decreased as the number of secure plots ($p = .036$), the number of person-days of labor purchased in the plot during 1995 ($p = .017$), and the number of years of school attended by the head of household increased ($p = .027$). Households repairing breaches in crop bands purchased 19 person-days of labor in the plot, households not repairing breaches bought 10 person-days ($p = .012$).

Rock walls. The percent of poorly managed rock walls decreased as the number of females of age 21-60 increased ($p = .021$). The number of breaches in rock walls increased as the number of plots per household increased ($p = .034$). Households repairing breaches bought four more person-days of labor in the plot ($p = .049$) and had 0.3 hectares less total plot area ($p = .037$) than households not repairing breaches.

Gully plugs. The percent of well managed gully plugs increased as the number of secure plots ($p = .025$), the number of hectares in secure tenure ($p = .041$), the number of household members ($p = .004$), the number of females age 21-60 ($p = .002$), and the number of household members age 21-60 ($p = .006$) decreased. The number of poorly-managed gully plugs increased as the number of females age 21-60 ($p = .012$) and the number of household members age 21-60 ($p = .039$) increased.

Plot characteristics and management quality

Although plot tenure security appears to have been an important factor in farmers' decisions to install agroforestry practices on a plot, it was not related to the quality of management of the practices. None of the tests of land tenure status against management quality (percent well-managed, percent poorly-managed, number of breaches, repairs breaches) were significant for any agroforestry practice.

Hedgerows. Hedgerows were installed on plots having less-secure tenure compared to other practices (Table 6-18), but, once installed, the best management of the hedgerow was practiced on plots having the most fertile soil (Table 6-26). Note that the very fertile category appears to have poorer management (fewer percent well-managed rows and more breaches) than the above average category. This kind of anomaly in the order of soil fertility categories is found in many of the analyses, and is probably due to the inexact and qualitative nature of this variable. Table 6-26 indicates that the best-managed hedgerows were found on the most fertile soil, the worst managed hedgerows were found on the most infertile soils, and that farmers were more likely to repair breaches on more fertile soils.

Table 6-26: Soil fertility and hedgerow management quality.

Qualitative soil fertility classes	Percent well managed rows	Percent poorly managed rows	No. of breaches per 100 m	Repairing (%) Yes	No
infertile	24 b[b]	33a	19a	37	63
less than average	24 b	32a	18a	34	66
moderate fertility	37ab	22ab	18a	46	54
above average	43a	20b	17a	52	48
very fertile	40ab	29ab	13b	44	56
P-value[a]	<.001	.003	<.001	.001	

[a] P-values in first three columns are for Kruskal-Wallis tests; last column for 2 by 5 cross-tabulation

[b] numbers within columns followed by the same letter are not significantly different (α=.05).

Percent slope of the garden was not an important factor in management quality except in the case of number of breaches. There was a significant negative correlation between slope and the number of breaches ($p = .002$), that is, there were fewer breaches on steeper slopes, more on gentler slopes. A negative correlation was also found for

distance between the house and the plot; there are more breaches in hedgerow plots closer to the house ($p < .001$). These results seem contradictory. It seems reasonable to suppose steeper slopes would have more breaches because it is harder to establish hedgerow trees on steeper slopes, and more difficult to work at repairing them. The case of more breaches in closer more gently sloping plots might be explained by more foot traffic closer to the house cutting paths through the hedgerows, and the possibility that animals might be picketed in plots close to the house.

When the three kinds of hedgerows are tested separately, as they were in the previous section discussing farmers' decisions to install practices, we find a similar but weaker result (as compared to the aggregated hedgerow results in Table 6-26) regarding management quality and soil fertility. For tree-based hedgerows, the soil fertility vs. management quality Kruskal-Wallis tests (percent well managed rows, percent poorly managed rows, number of breaches, and whether or not the breaches were repaired) showed significant and similar differences in management quality as all hedgerows combined—better management on more fertile soil. However, the mean separation tests were either not significant or did not produce a rank order that could be interpreted. Crop-based hedgerows were better managed in plots having fertile soils. The percent well- and percent-poorly-managed variables increased and decreased in the same order as soil fertility ratings increased ($p = .006$) and decreased ($p < .001$), respectively. Again, however, mean separation was not significant in the case of percent well managed. Slope was not an important factor in management quality in tree-based hedgerows, but significant correlations were found for crop-based hedgerows. The percent of well-

managed rows increased as slope became steeper ($p = .009$), and the number of breaches decreased as slope became steeper ($p < .001$). The mean slope of repaired crop-based hedgerows was slightly, but significantly ($p = .007$), steeper (36%) than the slope of unrepaired ones (32%). In only two cases was distance from plot to residence significant. Number of breaches decreased with increasing distance for both tree-based ($p = .003$) and crop-based ($p = .009$) hedgerows. No differences were found in any of the tests of management quality for grass-based hedgerows.

Differences in hedgerow management quality among PADF field regions were at least as important as differences among plot characteristics (Table 6-27).

Table 6-27: PADF/PLUS field region and hedgerow management quality.

PADF/PLUS Field Region	Percent well managed rows	Percent poorly managed rows	No. of breaches per 100 m	Repairing (%)	
				Yes	No
1: Les Cayes	41ab[b]	21bc	19b	48	52
2: Jacmel	15c	31a	24a	33	67
3: Cap Haitien	45a	28ab	9c	54	46
4: Mirebalais	35b	19c	22ab	40	60
P-value[a]	<.001	<.001	<.001	<.001	

[a] P-values in first three columns are for Kruskal-Wallis tests; last column for 2 by 5 cross-tabulation

[b] Numbers within columns followed by the same letter are not significantly different (α=.05).

Overall, there were more well managed hedgerows than poorly managed ones, but there were significant differences among regions. Region 2 had a much lower percentage of well-managed hedgerows, a higher number of breaches, and a lower percent of farmers repairing breaches than do the other three teams. Most of the hedgerows in region 2 were built by farmers in areas where the soils are poor and steep.

Crop bands. The small number of crop band gardens in the survey (about 100) made it necessary to recode the soil fertility ratings into three categories instead of five. Even so, only five crop band plots were in the infertile category. Farmers apparently eliminated infertile plots during the installation, leaving few to be analyzed for differences in management quality. Table 6-28 indicates that very fertile plots had fewer breaches and a larger percent of farmers repairing breaches. The test for percent of rows well managed and soil fertility was significant, but mean separation tests were not.

Table 6-28: Soil fertility and crop band management quality.

Qualitative soil fertility classes	Percent well managed rows	Percent poorly managed rows	No. of breaches per 100 m	Repairing (%)	
				Yes	No
infertile	13	40	48a[b]	20	80
moderate fertility	30	11	15a	50	50
very fertile	68	7	6b	87	13
P-value[a]	.005	.250	.001	<.001	

[a] P-values in first three columns are for Kruskal-Wallis tests; last column for 2 by 3 cross-tabulation

[b] Numbers within columns followed by the same letter are not significantly different (α=.05).

Slope percent of the plot was important to crop band management quality only for the percent of well-managed rows, where there was a significant negative correlation (p = .013). The percent of well-managed rows increased as the slope became gentler. Distance from the house to the plot, and the tenure category of the plot were not important to management quality.

Table 6-29 shows the differences in crop band management quality among PADF field regions. There were only six crop band plots in the Team 4 region, so it was not

included in the table. All other teams had more than 30 crop band plots each, but because of missing data for some of the variables, not all of the plots were included in the analyses.

Table 6-29: PADF/PLUS field region and crop band management quality.

PADF/PLUS Field Region	Percent well managed rows	Percent poorly managed rows	No. of breaches per 100 m	Repairing (%) Yes	No
1: Les Cayes	46b[b]	15	22a	44	56
2: Jacmel	9ab	0	3ab	60	40
3: Cap Haitien	73a	8	4b	89	11
P-value[a]	.011	.165	<.001	<.001	

[a] P-values in first three columns are for Kruskal-Wallis tests; last column for 2 by 3 cross-tabulation

[b] Numbers within columns followed by the same letter are not significantly different (α=.05).

Crop bands in region 3 were the best managed. Crop bands were first installed in the Cap Haitien area, so the region 3 team has more of them and a longer history of working with them.

Rock walls. Soil fertility of rock wall plots is not an obvious characteristic to test for differences in management quality, yet Table 6-30 shows that differences did exist. Better management was found in plots of higher soil fertility and poorer management was found on less fertile plots, even though the differences were not great and the order of the fertility classes (in this case the unfertile class has better management than the less than average class) was inconsistent. A more marked difference was seen in the percent of farmers repairing breaches in rock walls. In plots of moderate to high fertility, repairing farmers outnumbered nonrepairing farmers by a large margin. In the less fertile plots, the reverse was true.

Table 6-30: Soil fertility and rock wall management quality.

Qualitative soil fertility classes	Percent well managed rows	Percent poorly managed rows	No. of breaches per 100 m	Repairing (%) Yes	No
infertile	51ab[b]	15ab	8ab	29	71
less than average	44b	17a	9a	41	59
moderate fertility	59a	6b	6b	66	34
above average	63a	7b	6b	66	34
very fertile	61a	8ab	5b	55	45
P-value[a]	.004	.002	.002	<.001	

[a] P-values in first three columns are for Kruskal-Wallis tests; last column for 2 by 5 cross-tabulation

[b] Numbers within columns followed by the same letter are not significantly different (α=.05).

Slope of the plot was important to management quality of rock walls. A slight but significant effect of slope was found for each of the four management quality indicators, with rock walls found in plots of gentler slope being better managed and having fewer breaches. There was a significant negative correlation between slope and the percent of well managed rows ($p = .023$), and significant positive correlations between slope and the percent of poorly managed rows ($p = .001$), and between slope and the number of breaches per 100 meters ($p = .016$). The average slope of plots where farmers repaired rock walls (30%) was slightly, but significantly ($p < .001$), less than the average slope of plots where farmers did not repair (33%). Distance between the plot and the house was a factor for only one management indicator. There was a slight but significant negative correlation between the percent of poorly managed rows and distance from the house ($p = .020$), that is, rock walls closer to the house were less well managed. The reason for this is not obvious, but may have to do with the presence of large animals closer to the house.

There is less difference in rock wall management quality among PADF regions than there is for plant-based structures. However, rock walls in regions 1 and 4 appear to be better managed (Table 6-31).

Table 6-31: PADF/PLUS field region and rock wall management quality.

PADF/PLUS Field Region	Percent well managed rows	Percent poorly managed rows	No. of breaches per 100 m	Repairing (%) Yes	No
1: Les Cayes	72a[b]	7ab	4bc	74	26
2: Jacmel	53b	9a	7a	56	44
3: Cap Haitien	52b	11a	5c	58	42
4: Mirebalais	66a	5b	6ab	67	33
P-value[a]	<.001	.010	<.001	.007	

[a] P-values in first three columns are for Kruskal-Wallis tests; last column for 2 by 4 cross-tabulation

[b] Numbers within columns followed by the same letter are not significantly different (α=.05).

Gully plugs. Overall, there were few significant differences in management quality due to plot characteristics for gully plugs. Soil fertility, distance from the house, and tenure category of the plot were not significant factors. There was a slight but significant positive correlation ($p = .043$) between the percent of poorly managed gully plugs on the plot and the slope of the plot. There were not great management quality differences among PADF regions.

Farmers' perceived benefits and problems and hedgerow management quality

Farmers expressed their perception of the importance of several potential benefits and problems associated with hedgerows during the plot interview. A potential benefit thought to be not important would be assigned a value of one or two on a qualitative five-point scale; a potential benefit thought to be very important by the farmer would be assigned a value of four or five. These observations pertain to the 1,362 hedgerow

gardens in which the interviews took place, and were not observations about hedgerows in general. The percentages of ratings falling in each qualitative category for six potential benefits are shown in Table 6-32.

Table 6-32: Percent of 1,362 plots where potential benefits of hedgerows (fuel, charcoal, construction wood, fodder, soil fertility, soil conservation, and crop production) were classified according to importance by farmers on a five-point scale, 1=not important, 5=very important.

Importance	Fuel	Charcoal	Construction	Fodder	Soil Fertility	Soil Conservation	Crop Production
1	65	79	86	22	13	4	40
2	12	10	6	13	15	8	10
3	9	5	3	22	22	24	14
4	7	4	3	22	24	31	17
5	7	2	2	21	27	35	18

Most farmers did not consider fuelwood, charcoal, or construction wood to be important benefits of hedgerows. These three benefits were assigned to the two lowest categories of importance (categories 1 and 2) on 77%, 89%, and 94% of all hedgerow plots, respectively. The importance of other potential benefits was less skewed. The use of hedgerows as a source of animal fodder was highly rated (categories 4 and 5) on 43% of all hedgerow plots. However, the benefits of hedgerows in increasing crop yield were held to be low on 50% of the plots and high in only 35%. A surprising finding was that, on over half of the plots, farmers said that hedgerows' effect on improving soil fertility and soil conservation were very important—in 51% and 66% of the plots these two benefits were placed in the top two categories of importance, respectively. One would have thought a more concrete and immediate benefit (e.g., crop production or fodder) would be given a higher rating, unless farmers were just parroting back the extension message to the technicians conducting the interviews. One way to check this is to

compare stated importance of benefits to how well farmers manage hedgerows, on the theory that hedgerows on a plot where a potential benefit is highly-rated would be better cared for. The results of Kruskal-Wallis tests comparing the mean ranks of the percentage of well-managed hedgerows in gardens where the potential benefits were rated are shown in Table 6-33.

Table 6-33: Percent of hedgerows classified as well-managed by technicians in 1,362 plots where potential benefits of hedgerows (fuel, charcoal, construction wood, fodder, soil fertility, soil conservation, and crop production) were classified according to importance by farmers on a five-point scale, 1=not important, 5=very important.

Importance	Fuel	Charcoal	Construction	Fodder	Soil Fertility	Soil Conservation	Crop Production
1	33a[b]	35a	34a	37b	26ab	19ab	29a
2	37ab	35a	45ab	25a	21a	17a	24a
3	46bc	55b	46ab	33abc	32b	27b	42b
4	41b	51b	56bc	41c	41c	37c	46b
5	55c	41ab	70c	44c	51d	49d	50b
P-value[a]	<.001	<.001	<.001	<.001	<.001	<.001	<.001

[a] P-values are for Kruskal-Wallis tests

[b] Numbers within columns followed by the same letter are not significantly different (α=.05).

All of the tests done on potential hedgerow benefits vs. the percent of well-managed rows in the garden produced significant results (Table 6-33). A greater proportion of hedgerows were well managed in gardens where the farmers said any of the potential benefits were very important. This was true for benefits given top ratings in very few gardens (fuel, charcoal, construction wood) as well as for benefits given top ratings in large numbers of gardens (fodder, crop production). The 69 hedgerow plots where the farmers rated construction wood as being of highest importance (in categories 4 and 5) had the highest percentages of well-managed hedgerows, but these plots were

only 5% of the total. There was apparently some substance to farmers categorizing soil fertility and soil conservation as of highest importance in a large number of gardens, since in those gardens were found substantially greater proportions of well managed hedgerows compared to gardens rated lower for those benefits.

The opposite trend should show up when the same analyses are done for proportion of poorly managed hedgerows and for the number of breaches per 100 m of hedgerow. This is the case, as shown in Tables 6-34 and 6-35. All Kruskal-Wallis tests were significant for percent poorly managed vs. benefit rating, however mean separation for the charcoal benefit was not significant at α=0.05.

Table 6-34: Percent of hedgerows classified as poorly-managed by technicians in 1,362 plots where potential benefits of hedgerows (fuel, charcoal, construction wood, fodder, soil fertility, soil conservation, and crop production) were classified according to importance by farmers on a five-point scale, 1=not important, 5=very important.

Importance	Fuel	Charcoal	Construction	Fodder	Soil Fertility	Soil Conservation	Crop Production
1	27b[b]	26	26b	31b	44b	60e	28b
2	21ab	21	14a	30b	36b	41d	30b
3	19ab	13	16ab	22ab	22a	29c	21ab
4	17ab	16	16ab	19a	16a	21b	19a
5	13a	10	6a	20a	16a	16a	19a
P-value[a]	.022	.013	<.001	<.001	<.001	<.001	<.001

[a] P-values are for Kruskal-Wallis tests

[b] Numbers within columns followed by the same letter are not significantly different (α=.05).

When the number of breaches per 100 m of hedgerow is used as the dependent variable, only four of the benefits showed significant difference among importance ratings (Table 6-35). In general there were fewer breaches in plots where the benefits

were highly rated but the differences are not great and the trend, according to the results of the mean separations, are not always clear.

Table 6-35: Number of breaches per 100 m of hedgerow counted by technicians in 1,362 plots where potential benefits of hedgerows (fuel, charcoal, construction wood, fodder, soil fertility, soil conservation, and crop production) were classified according to importance by farmers on a five-point scale, 1=not important, 5=very important.

Importance	Fuel	Charcoal	Construction	Fodder	Soil Fertility	Soil Conservation	Crop Production
1	17	18	17	17a[b]	22abc	22ab	19c
2	15	16	16	23b	21cd	25b	24c
3	18	17	17	17b	19d	23b	18bc
4	20	20	19	17b	17bcd	16ab	17b
5	18	17	20	15a	13a	13a	11a
P-value[a]	.065	.225	.364	<.001	<.001	<.001	<.001

[a] P-values are for Kruskal-Wallis tests

[b] Numbers within columns followed by the same letter are not significantly different (α=.05).

The final variable tested against the benefit categories was whether the farmer repaired breaches in the hedgerows. Chi-square tests for cross tabulations of all benefits except charcoal were significant (α=0.05), and in general showed that as the benefit was rated higher in importance, farmers repaired breaches in a greater percentage of those hedgerow plots. This trend was shown most strongly for soil fertility, soil conservation, and crop production (Table 6-36).

Very few farmers interviewed said there were problems associated with hedgerows. In more than 90% of hedgerow plots farmers rated shade competition, loss of cropping space, hedgerow/crop water competition, and weediness in the two lowest categories of importance; reduced space for picketing animals and labor cost were not important in more than 70% of hedgerow gardens (Table 6-37).

Table 6-36: Percent of gardens where hedgerow breaches were repaired or not repaired for three potential benefits of hedgerows.

	Soil Fertility		Soil Conservation		Crop Production	
Importance	Yes	No	Yes	No	Yes	No
1	36	64	30	70	37	63
2	34	66	29	71	31	69
3	42	58	31	69	54	46
4	53	47	52	48	55	45
5	52	48	55	45	58	42
Chi^2 P-value	<.001		<.001		<.001	

Table 6-37: Percent of 1,362 plots where potential problems of hedgerows (shade, reduced space, water competition, reduced ability to picket animals, weediness, and labor cost) were classified according to importance by farmers on a five-point scale, 1=not important, 5=very important.

Importance	Shade	Loss of Space	Water Competition	Space for Animals	Weediness	Labor Cost
1	84	78	81	51	90	48
2	12	14	13	25	7	27
3	3	5	4	14	2	15
4	1	3	1	6	1	7
5	0	1	0	4	0	3

Only seven of the possible 18 Kruskal-Wallis tests (percent well managed, percent poorly managed, and number of breaches per 100m for each of the six problems) of hedgerow problems against importance categories were significant (α=0.05). However, for four of the seven no significant differences could be detected between importance categories during the mean separation procedure. For the remaining three tests where mean separation did show significant differences the results were very small or they did not make any sense, and they are not shown here. This was probably due to the skewed distribution of the data—very few of the observations were in the higher importance classes. To reduce this effect in the cross tabulations of hedgerow problems

vs. whether the breaches were repaired, the problem rating categories were reduced from 5 to 3, with the old categories 1 and 2 (the problem is not important) grouped together and old categories 4 and 5 (the problem is very important) grouped together. Only two cross tabulations produced significant results, as shown in Table 6-38. As reduced space for picketing animals in hedgerows and labor cost of maintaining hedgerows became more important, fewer farmers repaired breaches in the hedgerows.

Table 6-38: Percent of gardens where hedgerow breaches were repaired or not repaired for three potential problems of hedgerows.

	Space for Animals		Labor Cost	
Importance	**Yes**	**No**	**Yes**	**No**
1	48	52	48	52
2	40	60	43	57
3	36	64	36	64
Chi^2 P-value	.007		.023	

Summary and General Discussion

Household and Plots

On average, the households sampled in the survey were composed of five to six members, about half of whom had no formal education. Their three or four farm plots totaled about 3.7 hectares and were on slopes ranging from 22 to 34%; just over half of the plots were accessed via purchase or inheritance divided among siblings. Households engaged in an average of three economic activities other than raising food crops. The men mainly kept animals and engaged in various small businesses; the women worked in marketing of both agricultural and non-agricultural products, but also kept animals. Each household had installed one or two soil conservation structures, over half of the households had built hedgerows. About 40% of the men and 15% of the women

participated in some phase of the installation or maintenance of soil conservation structures.

The survey found no significant differences between tenure of plots in terms of elevation, topographic position, or severity of erosion. There were small differences in slope (caretaker plots were less steep, all others were about 33%) and distance from the residence (sharecropped and rented plots were one or two minutes more distant) by tenure category. Purchased plots averaged 0.53 hectares, significantly larger than divided, undivided, and sharecropped plots. There were statistically significant differences in soil fertility (data not shown). A higher percent of purchased plots (49%) were in the high fertility category compared to other plots (42-44%), with rented plots having the lowest percent in high fertility.

Decision to Install Soil Conservation Technologies

There were indications that household resources influenced decisions about what kind of soil conservation practice to install. Households installing hedgerows had smaller farms and fewer family members working on plots than did households not installing hedgerows. Households installing crop bands accessed more plots, had more plots in secure tenure status, and had more land area in secure tenure status than households not installing crop bands. Households installing rock walls had more household members and more family members working on the plots than households not installing rock walls.

There were strong indications that farmers considered plot characteristics in their decision to install hedgerows and other agroforestry practices. Figure 6-1 shows the relative influence of plot characteristics. The numbers for tenure security and soil

fertility are the percent of plots having the indicated practice that are held in secure tenure or that have fertile soil, respectively.

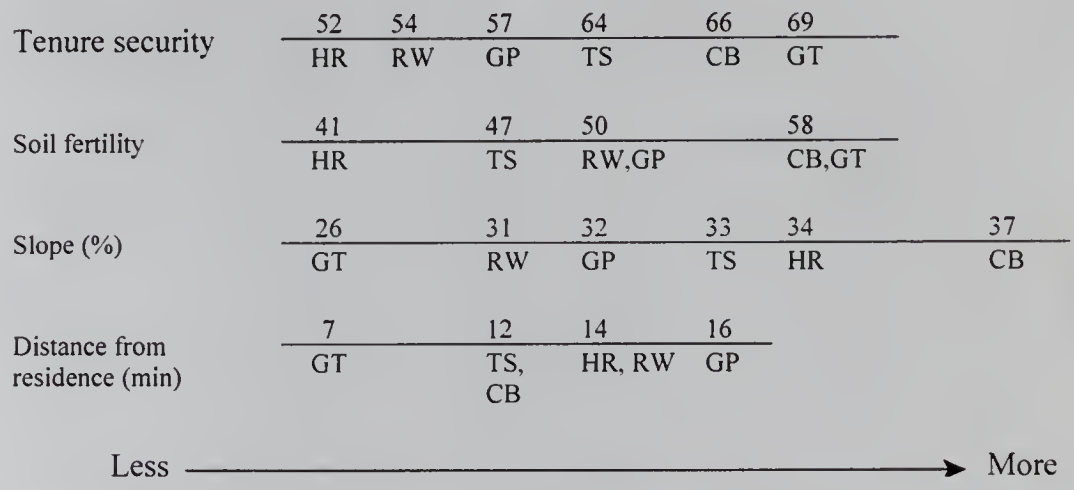


Figure 6-1: Relative importance of four plot characteristics to the decision to install six agroforestry practices (HR = hedgerow, CB = crop band, RW = rock wall, GP = gully plugs, TS = tree seedlings, GT = grafted trees)

In summary,

- Hedgerow were installed on less secure plots having lower soil fertility, steeper slopes, very slightly farther from the residence.
- Plots having hedgerows constructed with at least one perennial crop plant were found on more fertile plots, and there were no differences in tenure status of plots with or without crop-based hedgerows.
- Crop bands were installed on more fertile and more secure plots having steeper slopes, but there was no difference in distance from the residence.
- Rock walls were installed on more fertile, slightly less steep plots slightly more distant from the residence, but there was no difference in tenure security.
- Gully plugs were installed on more fertile plots slightly farther from the residence, but there was no difference in tenure security or slope.
- PLUS project tree seedlings were planted on more secure, more fertile plots slightly closer to the residence, but there was no difference in slope.

- Fruit trees were top-grafted on more secure, more fertile plots of gentler slope, much closer to the residence.

- More mature trees of any species were found on more fertile plots. There were a significantly greater number of mature trees on purchased plots, and on inherited but separated plots, than on inherited-unseparated, sharecropped, or on rented land.

Management Quality

Management quality of agroforestry practices, as defined by the condition of the structures at the time of the survey, was not correlated with level of household resources. The strongest trend noted was that quality of management for hedgerows, crop bands, and rock walls increased as the level of labor employed on the plots increased.

Although tenure security was an important factor in the decision to install an agroforestry practice, it did not influence the quality of management of those practices once they were installed. The management quality of hedgerows, crop bands, and rock walls did not differ according to the tenure of the plots. The most important variable appeared to be soil quality as perceived by the farmer. All soil conservation structures were better managed on plots having better soil fertility. Management quality increased as slope decreased. The effect of distance between the plot and the residence was not strong. These results could not be compared to those from other studies, because no other studies used management quality as a dependent variable.

Most farmers did not consider fuelwood, charcoal, or construction wood to be important benefits of hedgerows. Soil conservation and soil fertility improvement were considered important by substantial numbers of farmers, as were, to a lesser extent, crop yield improvement and fodder. Management quality of hedgerows was significantly better on plots where any of the potential benefits was highly rated. Very few farmers said any of the listed potential drawbacks of hedgerow was important—94% said water

competition between hedgerows and adjacent food crops was not a serious problem. There was little correspondence between opinions regarding severity of hedgerow problems and management quality.

Differences Among Technologies

Differences among technology adoption revealed in the survey are better understood if discussed in the context of investment, risk, and timing of benefits to the farmer. Agroforestry practices have a cost of installation and a cost of management that can be measured in labor and materials. The farmer must compare these costs to the resources commanded by the household, and then to the amount and timing of the anticipated benefits, which must in turn be compared to the needs of the household. All this must be balanced against the risk of failure. Risk might be higher if the farmer or his peers have no previous experience with the practice, or if the practice is sensitive to environmental factors, such as free ranging animals or drought. Risk is diminished when some of the costs are subsidized by projects, or when there is a continuing outreach program. The survey did not provide cost and benefit data, but some general comparisons among practices can be made based on experience of the project staff. In the matrix shown in Table 6-39, the relative costs, benefits, and risks of agroforestry techniques are compared.

The ratings shown in Table 6-39 cannot be fixed exactly, because they change with the length of the farmer's experience, with the available resources and needs of the household, with the stage of development of the practice, and with the degree of project subsidy. For example, tree-based hedgerows are at greater risk of animal damage in the early stages of growth, and are less prone to animal damage if there are perennial crops associated with the trees. In that case, neighboring farmers would be more likely to

contain their animals. Tree seedlings are much more vulnerable to loss due to accidental weeding by paid laborers and by animal damage in the early stages of growth. Crop bands containing sugar cane, pineapple, or plantains could be expensive to install in some areas, unless the plant material is subsidized by a project.

Table 6-39: Estimated relative costs, benefits, and risk of agroforestry practices

AF practice	Cost of installation	Cost of management	Amount of benefits	Timing of benefits	Risk of loss
Hedgerows	low-med.	med.-high	med.-high	med.-long	med.-high
Crop bands	med.-high	med.-high	high	short	med.
Rock walls	high	low	low-med.	short	low
Gully plugs	med.-high	low-med.	med.-high	short-med.	low-med.
PLUS trees	low	low	med.-high	med.-long	low-med.
Grafted trees	low-med.	low-med.	med.-high	med.-long	low-med.

Hedgerows

It is apparent that hedgerows were installed on less-desirable plots. There are several possible reasons for this. Hedgerows are a relatively new agroforestry practice in Haiti, even though there are similar indigenous practices such as trash barriers and living fences, and farmers tend to install new practices on their worst plots (Murray 1979). They are not difficult to install, and the PLUS project sometimes provides the seeds. Hedgerows are a relatively easy way to comply with the PLUS project requirement that participants install soil conservation structures on some part of their holdings in order to get access to crop seed banks operated by their group--about 60% of the sampled PLUS plots had hedgerows. Although the cost of installation is reasonable, hedgerows require regular maintenance in the form of repairing breaches, top-pruning the hedgerow trees, and eliminating invasive hedgerow seedlings from the area between the rows. The

timing and amount of returns to hedgerows depend on the management objective of the farmer. If they are being managed for soil fertility, three to five years may be required to make a noticeable contribution. If they are being managed for animal production, useful amounts of fodder can be taken after the first year.

Tree-based hedgerows exhibited the same plot characteristics (Tables 6-22, 6-23) as all types of hedgerows were considered together (Tables 6-18, 6-20). They were on plots of less security, lower fertility, and steeper slope. Tree-based hedgerows showed no difference in distance from the residence compared with all other plots. The most striking result displayed in Tables 6-22 and 6-23 is that when even one food crop species entered the hedgerow, plot characteristics changed, and became similar to those of the crop band plots: they were installed in plots having soils of higher fertility and slightly steeper slopes. Unlike crop bands, however, crop-based hedgerow plots did not differ in tenure security from other plots, and there was a slight, but significant tendency for crop-based hedgerows to be farther from the residence. The key plot parameter affecting the farmers' decision in this case seems to be soil fertility, since 51% of the plots having crop-based hedgerows had fertile soils, while only 34% of the plots having tree-based hedgerows were rated as fertile.

Crop bands

Because of their larger dimension and greater number of food crops, crop bands are more expensive to install than hedgerows, and need more fertile soils and regular rainfall to flourish. Quite often in the PLUS project, the food crop plants are distributed to new participants in a crop multiplication arrangement. The farmer must return the same amount of plant material to his or her group as was given, and it is then spread to other farmers under the same arrangement. This underwrites the cost of installation, and

reduces risk to the farmer. Crop bands were planted on steeper plots of higher fertility compared to plots having other interventions. Land tenure appears to be a factor in the choice of plots, as it is in the case of hedgerows, except that crop bands are installed on more secure plots. High soil fertility is required to sustain crop growth, and to reduce the risk of losing the investment in valuable crop germplasm. The choice of steeper slopes possibly reflects the extension message that crop bands are a soil conservation technique.

Rock walls

Rock wall terraces are well known to most farmers because they have been promoted for many decades by various projects. They require the most skill and labor to install of all the soil conservation practices promoted by the PLUS project. Once installed, however, they are relatively undemanding in their upkeep. They produce no vegetation to take care of, and they are stable if large animals are kept out of the garden and the slope is not too steep. About 30% of the sampled gardens had rock walls installed. The availability of rocks prevents farmers from constructing rock walls in some areas, especially where the soils are derived from basaltic parent material. Analysis of plots having rock walls show them to be similar in most characteristics compared to others, except they are located on soils of higher fertility. This may reflect a choice of the farmer—since rock walls are an expensive investment they might want to install them on the best soils—or it might be that soils having enough rocks for constructing the terraces are of higher fertility than normal. Although slope of rock wall plots was less steep and distance from the residence was greater compared to other plots, the differences were small. Land tenure was not a factor in choice of plots for rock walls.

Gully plugs

Tenure and slope were the same on plots with and without gully plugs. Soils on gully plug plots were more fertile, but it is not clear whether the farmer was judging the fertility of the soil collected by the structure, or the soil on the plot in general. Gully plug plots were slightly farther from the house than are other plots. It could be that houses are located away from gullies for safety.

Number of mature trees on the plot

There was clearly an association between the number of trees on a plot and the security of tenure. More securely-held plots had greater numbers of trees. There was also a very slight but statistically significant negative correlation between the numbers of trees on a plot and the distance of the plot from the house. There tended to be more trees on plots closer to the house. There was not a significant correlation between slope of the plot and numbers of trees. There was also a significant difference in the numbers of trees found on plots of different soil fertility, as shown in Table 6-25. The number of trees increased with increasing soil fertility. From observation, most trees nurtured by Haitian farmers are fruit trees or trees whose timber is valuable. Valuable trees are planted near the house to avoid theft. Home garden plots were more likely to be in secure tenure categories (Table 6-10). Greater numbers of trees could be found on soil of higher fertility because they survive and grow better there. In addition, animals are often tied under trees near the home, and this, along with the accumulation of tree litter, enriches soil fertility.

Project tree seedlings planted during 1995

Trees planted with project assistance during 1995 exhibited similar plot characteristics as existing large trees (Tables 6-19 and 6-21). They were located on plots

of more secure tenure, slightly greater soil fertility, closer to the house, but with no difference in slope. Overall, more trees were planted and maintained on more fertile, more secure plots close to the residence. Establishment and maintenance cost little, and potential returns are high. These plot characteristics reinforce the idea of trees as a store of value.

Top-grafted fruit trees

The decision to graft fruit trees appears to have been made according to specific plot characteristics. Alternatively, the original decision of the farmer to plant or nurture the low value fruit trees could be reflected in these plot characteristics. All four plot characteristics are significantly different from those of plots not having grafted trees. Grafted trees are found on plots with greater tenure security, more fertile soils, gentler slopes, and much closer to the house. This clearly indicates that grafted trees are mainly found in or near the home garden, the plot where the house is found.

Conclusions

Previous studies found differences in household resources between adopters and non-adopters. These differences were weak in this study, but appeared to indicate that hedgerow adopters were less well off (less land and household members), while crop band adopters were better off (more land and more securely held land). This could have been due to regional differences (most of the crop bands were in the north of the country), or because they are more demanding in their requirements for space, soil fertility, and rainfall. Possibly only better off farmers can make crop bands succeed.

Farmers apparently based their decisions regarding installation of agroforestry practices on characteristics of the plot and the technology. There were differences in the selection of plots between the different agroforestry practices. Overall, the survey

indicated that farmer decisions to adopt new technologies are correlated with several plot characteristics. Tenure appears to influence adoption in five of six technologies surveyed. Trees and grafted fruit trees were more common on purchased and divided inheritance plots. The value of tree products increases over time, so farmers need to protect their rights to harvest. Crop bands and gully plugs are also more common on purchased or divided inheritance plots. This is likely attributable to the high value of perennial food crops in crop contour bands (pineapple, plantain, sugar cane) and the economically important crops planted in soil collected by gully plugs (plantains, taro). Hedgerows are more commonly found on plots with other modes of access. Hedgerows are relatively easy to install, so this may reflect a strategy of risk minimization when trying a new practice or fulfilling project requirements to install soil conservation measures.

Correlation between technology adoption and soil fertility was as important as the relation between adoption and tenure status. This is perhaps to be expected since tenure status and soil fertility were also related (more purchased plots were classified as very fertile); however, farmer assessments of fertility also appear to integrate other productive factors not measured by laboratory analysis of soil nutrient levels.

Tenure and soil fertility were both associated with adoption in parallel fashion. Technologies (crop contour bands, gully plugs, trees, top-grafted fruit trees) more common on purchased and divided inheritance plots were also more common on fertile plots, and conversely (hedgerows). Although overall analysis of the data indicated that mode of access to land was an important variable, the data showed no definitive relationship between tenure status and adoption. The evidence does not allow clear separation of the relative influence of tenure and fertility on adoption; therefore, it is not

possible to determine which is more important in a particular decision to adopt new technology.

The analysis found no association between tenure status and differences in management; but soil fertility was important to management quality, with the best management found on the best soils. Based on these results, an extension program would not need to target technologies towards or away from any particular tenure type. It might, however, want to work with farmers on cost-effective ways to improve soil fertility while simultaneously ensuring a supply of dry-season fodder.

Farmers did not consider soil water competition between hedgerows and adjacent crops to be a problem. Only 16 of the 1,540 farmers considered it to be a serious problem. This could be because there was adequate rainfall in 1995, the success or failure of a crop is dominated by other factors that effect the whole field, such as the timing of the rainfall compared to crop demands, or because very few farmers rated any of the problems on the questionnaire as severe.

This study revealed relationships between plot characteristics and farmers' decision to install various soil conservation structures, and how those structures were managed. However, the findings should be considered as indicative, and not definitive, until follow-up interviews clarify the relationships, for several reasons:

1. Decisions to install various technologies appeared to correlate with both tenure and soil fertility in the same way, the relative contribution cannot be determined from the data in this study.

2. Management quality of soil conservation practices varied significantly between regions of the country at least as much as differences due to soil fertility, but it

is not clear if this was a reflection of differences in regional soil fertility, extension methods, or the length of time since a technology had been introduced into the region.

3. The analysis mixed together farmers just recently installing a practice with those having several years experience. Hedgerows can require several years to show benefits, and they evolve as farmers get more experience with them. Analysis should be separated by age of the practice.

4. The correlations between farmers' expressed problems and benefits regarding hedgerows and the management quality of hedgerows should have been compared as well to their pattern of building or removing hedges after the initial installation. In general, getting good responses to these kind of questions might require a more intensive type of data collection from a much smaller sample of farmers as a complement to the larger survey.

CHAPTER 7
CONCLUSIONS AND RECOMMENDATIONS

The over-arching objective of this series of studies was to produce information that could improve extension and adoption of agroforestry technologies in Haiti, particularly of hedgerow intercropping. The experimental designs employed reflected the range of information needed to understand agroforestry systems, and included on-station and on-farm agronomic studies as well as a large-scale questionnaire-based socioeconomic survey. The objectives of the three studies comprising the dissertation were to determine the importance of soil water competition between hedgerows and adjacent maize on station and on farm, and to examine the factors that influence farmer adoption, adaptation, and management of hedgerow intercropping. These objectives were attained, but with some limitations as indicated in the following discussion based on the hypotheses tested in each study.

The on-station trial showed that soil water competition caused by Leucaena hedgerows could reduce maize yield substantially, however the percent reduction in yield depended on how limiting rainfall was during the season. The mitigating effect of installing root barriers between the maize and the hedgerows was temporary, as Leucaena roots re-grew under the barriers and into the alleys. Severing Leucaena roots during the installation of the barriers resulted in a loss of 1,600 kg/ha Leucaena biomass over a seven-month period. Thereafter, the hedgerow trees recovered and there was no

subsequent difference in biomass yield between plots having root barriers and those without barriers.

The on-farm trial of maize development did not detect any differences at various distances from three types of soil conservation structures and at various positions on the slope. There were differences in maize development between types of soil conservation structures and the untreated control, with the maize growing in plant-based structures (hedgerows and crop bands) developing more slowly than maize in rock wall terraces and plots without soil conservation structures. No statistical differences in maize yield were detected, even though the untreated control plots produced numerically less than the treated plots. The plots having plant-based structures yielded less maize than the rock wall plots, indicating competition between maize and the plants in the hedges, but again the difference was not significant. It is the opinion of the author that differences in maize growth and yield do exist between flat land and sloping land. The failure to show differences was probably due to the small sample size and short duration of the on-farm trials.

No direct recommendation for the use of hedgerow root barriers on farms can be made based on these results. Assuming the increased maize grain yield due to root barriers on station could be realized on farm by a similar technique, say trenching on the uphill side only of the hedgerows before each maize crop, it still might not make economic sense to the farmer. On the station trial, increased maize grain yield due to barriers was about 350 kg/ha. If a typical hillside half-hectare plot would realize an extra 175 kg of maize grain, the cost of installation would be about halfway between the range of prices the extra maize would bring at the farm gate. In addition, the maize crop might fail completely due to poor rain up to 30% of the time, so the risk to the farmer might be

too great for the expected benefit, unless another crop of higher value were planted or the trenches bring some other value to the garden plot, such as increased water harvesting.

The on-farm survey hypotheses were supported by the results, but within a limited range because the sampled farmers were all project participants and therefore similar. Level of household land and labor resources in some cases influenced the choice of technologies and the management quality applied to agroforestry practices. Associations were detected that appeared to confirm that more available labor and land improved management quality, and that farmers with better resources invested in more expensive agroforestry practices. Farmers based their decisions about where to install different soil conservation structures on characteristics of the plots. Mode of access and soil fertility were important in the decision to install contour soil conservation structures (hedgerows, crop bands, rock walls) but their relative influence could not be separated. Farmers' decisions to install hedgerows on plots having relatively poorer soil fertility and less secure tenure could indicate they have not yet seen that practice as one returning sufficient benefits to risk better plots, whereas the short-term benefits taken from the crops bands apparently justify installing them on better plots. Soil fertility appeared to be the most important determinant of management quality of the structures, with the best management occurring on the most fertile plots for all practices. Tenure status of the plot did not affect how well farmers managed hedgerows or any other agroforestry practice. Hedgerow plots where farmers cited any of several potential benefits (wood products, fodder, soil fertility and conservation, improved crop production) as being very important were better managed. However, very few farmers rated wood products as important hedgerow benefits. Over half of the interviewed hedgerow farmers cited soil fertility and soil conservation as being very important hedgerow benefits. Because plots where that

opinion was expressed were significantly better managed, the farmers were probably revealing their true attitudes toward hedgerows, as opposed to parroting an extension message.

The conceptual thread of tree/crop soil water competition was not successfully traced through the three studies described here. This was because the study designs recorded different scales of data from environments of increasing variability. The small-scale phenomenon of soil water competition close to hedgerows seen on the station was not encountered on the four hillside farms comparing different soil conservation techniques in the second study. A larger sample of farmers over several seasons, with yield measured row by row might have picked it up. Farmers claimed that hedgerow/crop soil water competition was a serious problem on less than one percent of hedgerow plots surveyed. From observation, drought over the whole garden causing crop failure probably covers up tree/crop competition for soil water on hillside farms.

These three studies represent components of what should be a broader program of multidisciplinary trials and field exercises to understand the dynamics of hedgerow performance and adoption in Haiti. The results are indicative of some aspects of competition and adoption, and the links between them, but they are by no means complete. It is evident that by focusing on a specific biophysical phenomenon on station, such as soil water competition between hedgerow trees and adjacent maize, one can not necessarily usefully apply those results to a system as complex as Haitian hillside farms. There are three overriding, and interrelated, characteristics of hillside agriculture in Haiti that make that so: complexity, variability, and need for cash.

Complexity is manifested in the number of plots of varying quality worked, the several modes of access through which the plots are worked, numbers of crops

grown/animals raised, numbers of extra-agricultural enterprises undertaken by family members, and the social networks and dependencies nurtured by the family. Great variability is seen in soil quality and other physical properties within and between plots, timing of rainfall compared to the needs of the crops, the quantity and timing of agricultural labor available to the family from year to year, sale price of crops, and the variability of crop yield. The need for cash for both cyclic and cataclysmic expenses in a cash poor economy guides farmer decisions in a complex and highly variable farming system. Complexity can be a response to soil and rainfall variability and the need for cash, as a risk management strategy, such as holding several plots in different microsites under different modes of access. But complexity in a new technology, such as hedgerows, can make it difficult for a farmer to plan investment strategies that allow him to manage it optimally, given his level of family resources and cash constraints. This is because farmers' price expectations from a plot contain both a mean and a cyclical component, and farmers are unlikely to invest in a practice, like hedgerows, unless they perceive it as affecting the mean component. Time of adoption for a given farmer occurs when his or her beliefs about the expected value of profits from the new technology is at least as great as the return from the old technology. But it takes time for farmers know the variance of profits with the new technology. Because of the initial delay in realizing benefits from hedgerows, due to loss of cropping space and time required to establish the hedges, and because this takes place in a highly heterogeneous and variable cropping system, the farmer has difficulty in discerning the mean component from the seasonal variations. Hedgerows are an evolving, complex, relatively expensive agroforestry practice being experimented with by very poor farmers in a highly variable and risky social and agricultural environment. When new technologies are constantly being

modified, adoption equilibrium may never be attained because the parameters affecting farmers' decisions are changing as well.

Methods for studying adoption under these conditions were not completely met by the research undertaken in this study. Additional farmer focus groups to follow up soil water competition on farm and to separate the influence of mode of access on adoption from that of soil fertility would have been useful. Most socioeconomic adoption models have not incorporated the distinctive features of agroforestry, such as multiple outputs, production variability, the economic role of trees, impact of off-farm employment, and the sociocultural context of farmer decision-making. On farm methods of testing dynamic agroforestry technologies have not been adequately tested. However, in spite of the shortcomings of the methodology used in these studies, useful information was developed that might guide future investigations. Some recommendations based on these studies are:

- It is more important to focus on stabilizing the soil and water flow on the garden plot as a whole than to reduce competition at the tree/crop interface. Tree/crop soil water competition was not observed in on-farm trials, nor did farmers consider it to be a problem. It is unlikely that farmers would make large investments to prevent soil water competition at the tree/crop interface. Farmers should be occasionally surveyed to see if tree/crop soil water competition becomes important, and under what conditions.

- Analysis of survey data should compare farmers according to how long they have been using particular agroforestry practices and whether or not they are changing the structure and management of the practice. Non-adopters should be included in surveys to better understand how household resources limit adoption.

- Survey data should be supplemented with other data collection and interpretation methods, such as farmer focus groups or a small number of ethnographic studies of household economics.

- Farmers' assessment of soil fertility appears to be important in the decision to adopt a practice and in how well it is managed. Since improving soil fertility makes agronomic sense, a substantial proportion of farmers with

hedgerows say that soil fertility is a very important benefit of hedgerows, and since farmers expressing that opinion manage their hedgerows better than those who do not, extension programs should put more focus on developing appropriate ways of increasing soil fertility.

APPENDIX A
POT STUDY OF SOIL WATER DEPLETION VS. MAIZE LEAF WATER POTENTIAL

I established a pot study in January 1994 to determine how soil water depletion at the ODH site correlated with plant water stress. I planted 12 pots of maize on 2 January 1994 with soil taken from the top 25 cm at the trial site, one plant per pot. Field capacity of the soil measured at the trial site was about 41%. I stopped watering the maize in the pots on 4 March, 60 DAS. Pre-dawn leaf water stress was measured with a pressure chamber. Figure A-I shows the result of four sets of measurements taken from 3 to 12 days after watering stopped, 63 to 72 DAS. After 72 DAS, the maize leaves were too dry to give pressure chamber readings. Most of the plants were wilted by that time, and some had fired leaves. After the final measurement at 74 DAS, I re-watered six of the pots. Two pots did not recover from the wilting, the other four did. Figure A-I shows the mean values of the 12 pots as they dry from field capacity to just under 25% soil water over the four observation dates.

Figure A-2 shows the regression relationship between leaf water stress and percent soil water. When soil water percent in the root zone decreases below about 25%, leaf water pressure passes below 10 bars. Maize plants begin to suffer drought stress at this point.

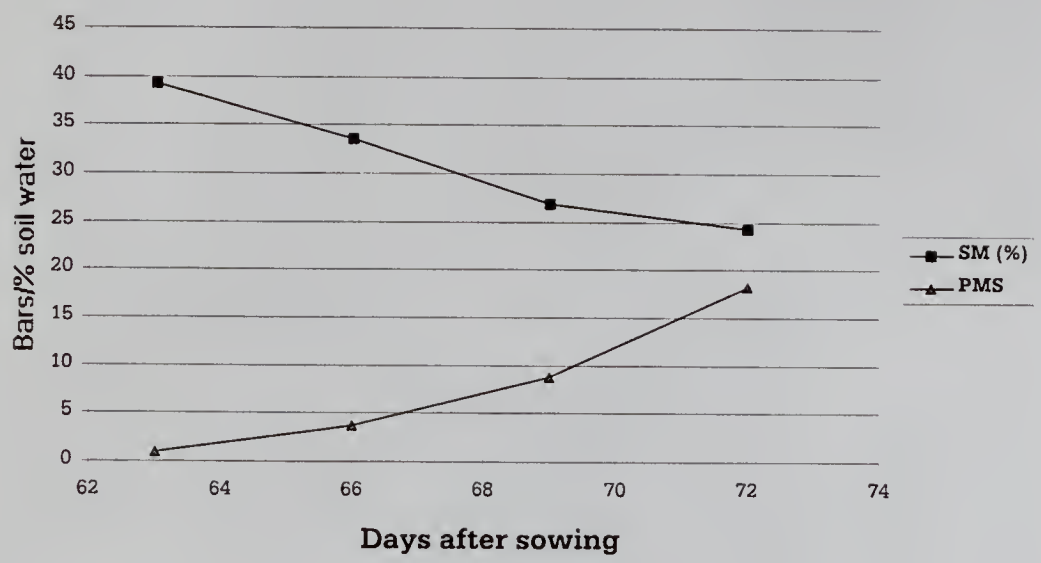


Figure A-1: Changes in maize leaf water pressure as soil water percent decreases, 63 to 72 DAS (n = 12)

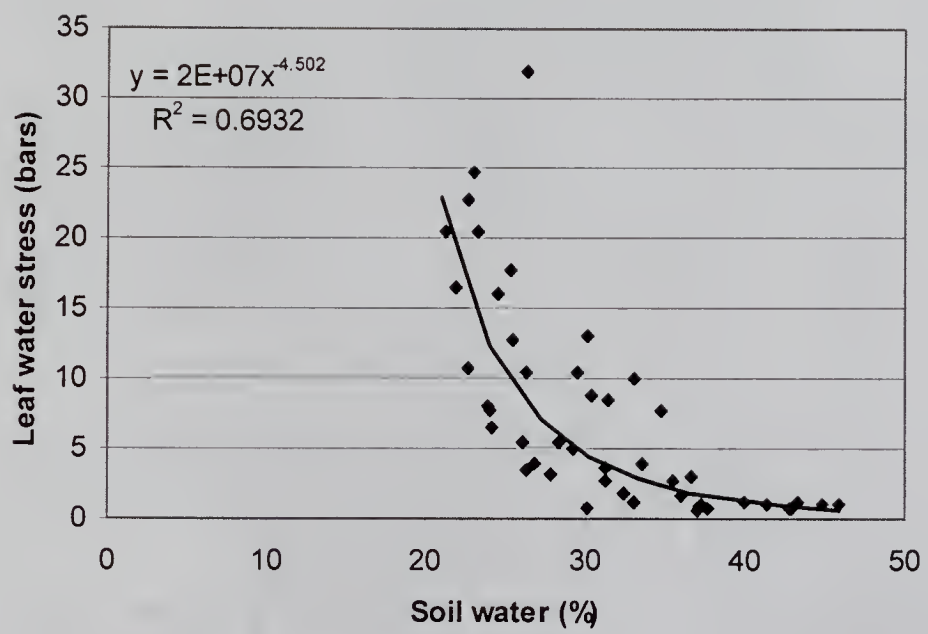


Figure A-2: Pot study regression of soil water percent against maize leaf water potential in soil 25 cm deep taken from the study site.

APPENDIX B
ROOT DISTRIBUTION OF A *LEUCAENA LEUCOCEPHALA* HEDGEROW

This study was done in November 1990 on a nursery/demonstration site owned by a community church group in the town of Mirebalais, located in Haiti's lower central plateau. There were no repetitions (and therefore no statistical analyses), just one transect 3 m long through one *Leaucaena* hedgerow planted on a deep, sandy soil of gentle slope (about 5%) on a river terrace. I mapped eight sections 1.2 m wide by 1 m deep parallel to the hedgerow, beginning 200 cm uphill of the row, cutting through the row of trees, and ending 100 cm downhill. A plexiglass plate inscribed with a 10 by 10 cm grid was pinned to the cut surface. The positions of the roots were drawn on plastic sheets clipped over the Plexiglas plate, a separate symbol was used for each of four diameter classes: very fine (<1mm), fine (1-5 mm), medium (5-10 mm), and large (>10 mm). From 70 to 96% of the very fine roots were found in the top 30 cm of the soil, the lowest percents being found 150 cm and 200 cm uphill from the hedgerow (Figure B-1). A lesser percent of the fine roots were found in the top 30 cm (20 to 83%), with the least (20%) at the 200 cm uphill position. Very few medium and large roots were found, but of those that were, 50% or more were deeper than 30 cm.

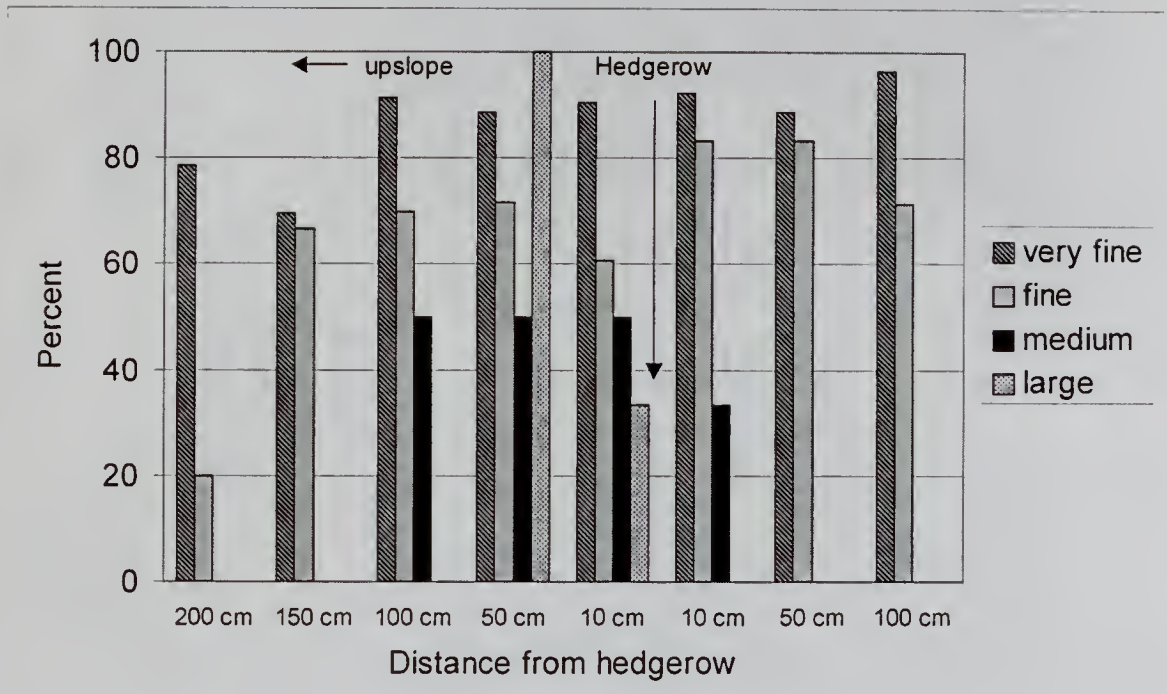


Figure B-1. Percent of very fine (<1mm), fine (1-5 mm), medium (5-10 mm), and large (>10 mm) *Leucaena* root intersections in the 0-30 cm soil layer, Mirebalais.

APPENDIX C
P-VALUES OF ANOVAS PERFORMED ON STATION

Table C-1. P-values for the analyses of variance done on the on-station trial of maize/leueaena soil water competion

Spring 1994	p-values													
test	block	trench	fert	trench*fert	distance	trench *dist	fert*dist	trench *fert*dist	depth	trench* depth	fert* depth	dist* depth	trench *fert* depth	R^2
42 DAS maize biomass	.001	.260	.142	.316	<.001	.780	.577	.172						.904
49 DAS maize biomass	<.001	.189	.156	.340	<.001	.857	<.001	.022						.961
63 DAS maize biomass	.392	.085	.525	.380	<.001	.497	.414	.358						.810
70 DAS maize biomass	.995	.907	.463	.381	<.001	.831	.998	.618						.809
56 DAS soil water	.009	.837	.603	.081	.656	.905	.733	.531	<.001	.663	.456	.940	.183	.935
70 DAS soil water	.013	.504	.362	.105	.178	.020	.007	.477	<.001	.593	.617	.529	.720	.602
Final grain	<.001	.805	.710	.015	<.001	.826	.454	.016						.765
Final # plants	.104	.354	.172	.485	<.001	.721	.898	.088						.691
Final # ears	<.001	.792	.724	.299	<.001	.264	.807	.114						.762
20 Nov. 93 LELE biomass	.002	.074	.358	.198										.659
20 Nov. 93 LELE height	.001	.725	.076	.196										.684
33 DAS LELE biomass	.089	.139	.224	.091										.490
33 DAS LELE height	.506	.462	.840	.329										.274
65 DAS LELE biomass	.124	.300	.187	.994										.421
65 DAS LELE height	.059	.095	.393	.160										.500
20 Aug. 94 LELE biomass	.508	.283	.941	.400										.282
20 Aug. 94 LELE height	.131	.403	.640	.640										.391

Table C-1--continued.

Fall 1994 test	p-values block	trench	fert	trench* fert	distance	trench *dist	fert *dist	trench *fert*dist	depth	trench *depth	fert *depth	dist *depth	trench *fert* depth	R^2
77 DAS maize biomass	<.001	.018	.223	.093	.023	.458	.386	.415						.748
42 DAS pms	.497	.839	.717	.298	.439	.155	.274	.656						.487
42 DAS soil water	.146	.042	.345	1.000	<.001	.071	.855	.487	<.001	.549	.376	.943	.022	.608
Final grain	.031	.009	.385	.798	.076	.627	.441	.051						.497
Final # plants	.953	.488	.939	.067	.464	.157	.647	.256						.349
Final # ears	.494	.975	.187	.638	.571	.619	.074	.017						.477
28 DAS LELE biomass	.168	<.001	.985	.745										.804
28 DAS LELE height	.234	.005	1.000	.471										.471
14 Jan. 95 LELE biomass	.006	.005	.401	.255										.629
14 Jan. 95 LELE height	.007	.038	.945	.331										.592
16 Mar. 95 LELE biomass	.509	<.001	.301	.358										.558
16 Mar. 95 LELE height	.744	.113	.633	.447										.263
6 May 95 LELE biomass	.627	.013	.919	.033										.436
6 May 95 LELE height	.152	.311	.311	.030										.466

Table C-1--continued.

Spring 1995	p-values													
test	block	trench	fert	trench *fert	distance	trench *dist	fert *dist	trench *fert* dist	depth	trench* depth	fert*d epth	dist* depth	trench *fert* depth	R^2
40 DAS maize height	<.001	<.001	.449	.433	<.001	<.001	.652	.847						.512
47 DAS maize biomass	.005	.035	.445	.423	.152	.202	.569	.676						.853
54 DAS maize biomass	.001	.085	.287	.388	.324	.020	.654	.496						.809
26 DAS soil water	<.001	.373	.884	.095	.594	.310	.804	.927	<.001	.859	.663	.514	.871	.914
61 DAS soil water	.080	.344	.152	.386	.134	.996	.459	.994	<.001	.665	.075	.018	.398	.842
Final grain	<.001	.001	.329	.346	.001	<.001	.248	.459						.714
Final # plants	.004	.002	.783	.180	<.001	<.001	.101	.447						.694
Final # ears	.003	.002	.840	.402	<.001	<.001	.066	.513						.715
19 DAS LELE biomass	.003	.246	.833	.478										.594
19 DAS LELE height	.061	.418	.156	.945										.463
57 DAS LELE biomass	<.001	.213	.984	.310										.714
57 DAS LELE height	.334	.041	.553	.520										.387
130 DAS LELE biomass	.376	.164	.924	.840										.318
130 DAS LELE height	.921	.092	.664	.112										.273

Table C-2. P-values for the analyses of variance done on the on-station trial of maize/leucaena soil water competion

	50 cm distance			100 cm distance			150 cm distance			200 cm distance		
	trench	fert	trench* fert	trench	fert	trench* fert	trench	fert	trench* fert	trench	fert	trench* fert
Spring 1994												
42 DAS maize biomass	.039	.508	.126	.913	.231	.765	.229	.987	.090	.870	.307	.155
49 DAS maize biomass	.162	.387	.520	.427	.063	.575	.160	.002	.010	.799	.199	.648
56 DAS growth stage	.439	.491	1.000	.423	.390	.531	.604	.324	.604	.064	.407	.250
63 DAS maize biomass	.039	.384	.805	.311	.371	.200	.514	.215	.331	.767	.625	.547
70 DAS maize biomass	.328	.427	.607	.694	.661	.254	.510	.745	.508	.716	.618	.980
56 DAS soil water, 0-15 cm	.580	.310	.877	.568	.797	.019	.850	.523	.585	.280	.778	.038
56 DAS soil water, 15-30 cm	.884	.703	.713	.293	.177	.218	.386	.910	.890	.704	.522	.394
56 DAS soil water, 30-45 cm	.427	.445	.923	.170	.004	.279	.379	.855	.641	.763	.457	.728
70 DAS soil water, 0-15 cm	.323	.177	.694	.186	.143	.730	.451	.762	.325	.388	.352	.688
70 DAS soil water, 15-30 cm	.590	.643	.058	.804	.428	.646	.995	.731	.451	.231	.027	.176
70 DAS soil water, 30-45 cm	.159	.519	.161	.441	.949	.151	.544	.584	.859	.281	.164	.033
Final grain	.180	.141	.057	.512	.463	.219	.728	.550	.008	.623	.230	.043
Final # plants	.370	.572	.370	.709	.077	.184	.654	.191	.115	.523	.872	.069
Final # ears	.722	.479	.023	.139	.918	.918	.361	.276	.276	.224	.942	.062

Table C-2--continued.

	50 cm distance			100 cm distance			150 cm distance			200 cm distance		
	trench	fert	trench* fert	trench	fert	trench* fert	trench	fert	trench* fert	trench	fert	trench* fert
Fall 1994												
77 DAS maize biomass	.037	.191	.635	.105	.508	.747	.285	.185	.030	.531	.613	.570
42 DAS pms	.081	.242	.775	.103	.471	.175	.829	.524	.829	1.000	.126	.232
42 DAS soil water, 0-15 cm	.666	.514	.306	.259	.110	.912	.402	.630	.981	.240	.465	.384
42 DAS soil water, 15-30 cm	.033	.546	.787	.405	.567	.966	.095	.120	.523	.264	.312	.467
42 DAS soil water, 30-45 cm	.002	.091	.093	.014	.617	.055	.886	.932	.178	.675	.617	.101
Final grain	.071	.467	.330	.068	.209	.043	.398	.272	.318	.177	.522	.163
Final # plants	.895	.362	.037	.020	.865	.865	.436	.602	.793	.883	.659	.310
Final # ears	.389	.160	.070	.617	.065	.176	.643	.360	.443	.939	.939	.159

Table C-2--continued.

	50 cm distance			100 cm distance			150 cm distance			200 cm distance		
	trench	fert	trench* fert	trench	fert	trench* fert	trench	fert	trench* fert	trench	fert	trench* fert
Spring 1995												
40 DAS maize height	<.001	.035	.074	<.001	.536	.141	<.001	.626	.517	<.001	.234	.475
47 DAS maize biomass	.030	.201	.202	.096	.530	.566	.016	.750	.787	.017	.557	.285
54 DAS maize biomass	.072	.241	.260	.103	.484	.538	.111	.302	.950	.464	.019	.049
26 DAS soil water, 0-15 cm	.376	.926	.602	.641	.823	.136	.140	.780	.077	.242	.277	.588
26 DAS soil water, 15-30 cm	.140	.278	.065	.172	.720	.182	.718	.016	.010	.964	.615	.054
26 DAS soil water, 30-45 cm	.370	.562	.196	.429	.985	.309	.298	.112	.122	.412	.611	.006
61 DAS soil water, 0-15 cm	.743	.149	.859	.566	.222	.806	.201	.736	.361	.393	.555	.694
61 DAS soil water, 15-30 cm	.338	.674	.857	.358	.145	.329	.900	.419	.145	.836	.691	.336
61 DAS soil water, 30-45 cm	.724	.411	.233	.219	.571	.049	.678	.973	.720	.289	.884	.365
Final grain	<.001	.102	.211	.039	.286	.346	.333	.475	.594	.659	.543	.370
Final # plants	<.001	.074	.290	.045	.199	.199	.158	.894	.691	.779	.779	.063
Final # ears	<.001	.068	.330	.011	.256	.752	.365	.596	.664	.825	.912	0.197

APPENDIX D
HOUSEHOLD QUESTIONNAIRE

a. Nom chef kay-la:

_____ / _____ Nimewo kod: _____

Sinyati Prenom

b. Si genyen lòt plantè PLUS ak pwòp kod pa-yo, ki nan menm kay, ekri nom ak kod yo isit:

_____ / _____ Nimewo kod: _____

Sinyati Prenom

_____ / _____ Nimewo kod: _____

Sinyati Prenom

c. Lokalite: _____ **d. Seksyon:** _____ **e. Kominn:** _____

f. Ann al fè lis chak mòso tè moun nan kay sa te genyen oubyen te travay nan 12 mwa ki sòt pase:

Jaden	Lokalite	Tip jaden /1	Kantite tè (1/100 cx)	Sistem fonsyè /2	Pozisyon topografik /3	Klas pant /4	Aktivite PLUS ki fet nan jaden /5
1							
2							
3							
4							
5							
6							
7							
8							
9							
10							
11							
12							

Kod: 1 Tip jaden: 1=lakou, 2=pre kay, 3=lwen kay 2 Sistèm fonsyè: 1=tè achte, 2=èritaj deja separe, 3=èritaj poko separe 4=demwatye, 5=anfeme nan men moun, 6=femyè leta 7=jeran, 8= Lot _____

3 Pozisyon topo: 1=tet mònn, 2=flan mònn, 3=pyè mònn, 4=laplenn

4 Klas pant: 1=plat, 2=panche, 3=trè panche

5 Aktivite PLUS: RV=ranp vivan; BM=bann manje; MS=misek; RP=ranp pay; BR=baraj ravinn; PB=pyebwa; JL=jaden legim; DR=danre; KO=konp

g. Anfòmasyon sou moun ki abite nan kay-la:

Nom moun	Laj moun	Seks /6	Nan ki klas lekol li rive?	Ki aktivite PLUS li patisipe ladan /7	Lot aktivite li patisipe ladan ki bay lajan /8
Chef kay la:					

h. Eske chef kay la moun bò isit? ☐ Wi ☐ Non i. Depi konbyen ane chef kay la abite isit? _____ ane

j. Eske plantè PLUS la te patisipe nan AFII? ☐ Wi ☐ Non k. Nom ankètè: _____

l. Depi konbyen ane plantè-a konmanse patisipe ak PLUS? _____ ane

Kod: 6 Seks moun: F=fi G=gason

7 Aktivite PLUS: RV=ranp vivan; BM=bann manje; MS=misek; RP=ranp pay; BR=baraj ravinn; PB=pyebwa; JL=jaden legim; DR=danre; KO=konpos; GR=gr

8 Lot Aktivite: 1=atelye, moulin kann; 2=atizana; 3=dokte fey; 4=elvaj, gadinaj; 5=fe chabon, lacho; 6=fonksyone; 7=jounalye jaden, vann jou 8=jounalye, lot; 9=komes pwodwi agrikol; 10=komes, lot; 11=peche; 12=siye bwa; 13=ti metye; 14=lot aktivite

APPENDIX E
GARDEN PLOT QUESTIONNAIRE

IDNO:_____ **PADF/PLUS ETID EKSTANSIF 1995** EKIP:_____

Data Collection Form for annual large-sample impact survey

I. IDANTIFIKASYON JADEN

a. Nom patisipan PLUS ki travay jaden sa:

_____ / _____ Nimewo kod: _____

Sinyati Prenom

b. Jaden sa se nimewo_____ **nan** _____**jaden PLUS pou fwaye sa.** **c. Jaden sa se nimewo**_____ **nan lis jaden sou Dosye Fwaye.**

d. Depi konbyen ane plantè sa antre nan pwoje PLUS? _____ane **e.Konbyen tan sa pran sòti lakay li rive nan jaden sa?** _____minit

f. Lokalite: _____ **g. Seksyon:** _____ **h. Kominn:** _____

II. DESKRIPSYON JADEN

a. Valè tè nan jaden sa: _____(1/100 cx) **b. Kondisyon fonsyè:** [ ] 1=tè achte, 2=èritaj deja separe, 3=èritaj poko separe 4=demwatye, 5=anfeme nan men moun, 6=femyè leta 7=jeran, 8= Lot _____

c. Eske jaden sa te an jachè pandan 1995? [ ] wi [ ] non **d. Si wi, depi konbyen ane?** _____ane

e. Pant mwayèn: _____% **f. Ekspozisyon pant:** _____ **g. Elèvasyon:** _____mèt

h. Konbyèn pyebwa (dyamèt >10 cm) genyen nan jaden sa?_____ **i. Konbyèn rigòl (>20 cm pwofondè) nan jaden?**_____

j. Sòl: Klasifikasyon lokal:_____ Tip wòch mè: Kalkè [ ] Bazaltik [ ] Lot [ ]

Dapre mèt jaden an, èske tè nan jaden sa fètil:	(1=pòv, 5=fètil)	1	2	3	4	5
Dapre mèt jaden an, èske tè nan jaden sa fon:	(1=mens, 5=fon)	1	2	3	4	5
Eske tè ki ant strikti KSDL montre siy ewozyon:	(1=okenn, 5=anpil)	1	2	3	4	5

Nom Asistan:_____ PADF 11/97 DAT:_____

IDNO:_____ **PADF/PLUS ETID EKSTANSIF 1995** EKIP:_____

III. DANRE NAN JADEN PANDAN 1995

a. Dònezòn danre, pri nan epòk rekolt, ak estimasyon plantè sou gwose rekolt danre ak KSDL vèsis sistèm tradisyonèl

Donezon avan KSDL, rekolt mwayen sistem tradisyonel					Donezon apre KSDL, pandan 1995				
Danre	Kantite Rekolte *	Pri/inite	Inite	Asosye ak lòt?	Danre	Kantite Rekolte *	Pri/inite	Inite	Asosye ak lòt?
1					1				
2					2				
3					3				
4					4				
5					5				
6					6				

b. Tip ak kantite semans danre itilize

Semans avan KSDL				Semans apre KSDL, pandan 1995			
Danre	Kantite plante	% Mòso ki plante	Sous semans	Danre	Kantite plante	% Mòso ki plante	Sous semans
1				1			
2				2			
3				3			
4				4			
5				5			
6				6			

c. Konbyèn jounen (òm jou) yo te peye (an nati oubyen nan kach) pou travay nan jaden sa pandan 1995? _____ òm/jou

d. Konbyen moun ki nan fwaye-a tap travay nan jaden pandan 1995 _____ moun

IV. AKTIVITE PLUS NAN JADEN SA

Kwaze chak ti bwat ki reprezante aktivite PLUS plantè a fè nan jaden sa. Pou chak aktivite, rampli tèy pa-l.

☐ Ramp vivan ☐ Misèk ☐ Ramp pay ☐ Pyebwa ☐ Semans danre amèlyore ☐ Kompòs

☐ Bann manje ☐ Kanal kontou ☐ Baraj ravinn ☐ Grefaj sou gwo bwa ☐ Jaden legim

*** NB: Nan ka plante-a pa kapab ba-w kantite rekolte, sèvi ak kod sa yo:** a=rekolt-la rate okoz move tan b=rekolt-la rate okoz bet c=rekolt-la poko fet

IDNO:_____ **PADF/PLUS ETID EKSTANSIF 1995** EKIP:_____

V. RANP VIVAN

a Depi konbyen ane premyè ramp vivan nan jaden sa te fèt? _____ ane b. Konbyen ranje ki pa sou bon koub nivo? _____ ranje

c. Ki èspès konpoze ranp yo? _____ d. Akimilasyon tè dèvan ramp yo? _____ cm

e Ranje/mèt fèt pandan 1995: _____ ranje _____ mèt f. Ranje/mèt fèt avan 1995: _____ ranje _____ mèt g. Distans ant ranp yo? _____ mèt

h. Konbyen ranje ou we ki tre byen jere? _____ ranje i Konbyen konsi konsa? _____ ranje j. Konbyen move net? _____ ranje

k Konbyen brèch >25 cm genyen nan ranp yo? _____ l. Eske mèt jaden an konn repare brèch yo? ☐ wi ☐ non

m Ensèkle nimewo ki endike anpòtans mèt jaden an bay bènèfis ki sòti nan r 1=pa enpòtan ditou, 5=trezanpòtan

Bwa pou kwit manje	1	2	3	4	5
Bwa pou fè chabon	1	2	3	4	5
Bwa pou konstriksyon	1	2	3	4	5
Fey pou bay bèt manje	1	2	3	4	5
Fey pou enrichi sòl nan jaden	1	2	3	4	5
Baraj pou krèm tè a rète nan jaden	1	2	3	4	5
Danre sòti nan ranp pou manje ak pou vann	1	2	3	4	5

n Ensèkle nimewo ki endike anpòtans mèt jaden an bay pwoblem nan ranp vi 1=pwoblem sa pa anpotan ditou, 5=pwoblem sa trezanpòtan

Eske ranp yo okipe twop espas nan jaden?	1	2	3	4	5
Eske ranp yo bay twop lombraj nan jaden?	1	2	3	4	5
Eske bwa nan ranp yo souse twop dlo nan tè ki fè danre soufri?	1	2	3	4	5
Eske ranp nan jaden bay difikilte pou mare bèt?	1	2	3	4	5
Eske bwa nan ranp yo jete twop semans nan jaden?	1	2	3	4	5
Eske ranp yo pran twop tan pou okipe yo?	1	2	3	4	5

o Konbyen moun te ede konstwi ranp yo? ☐ Mesyè ☐ Medanm ☐ Gran ti moun ☐ Ti moun piti ☐ Lòt

p. Konbyen moun te ede repare ranp yo? ☐ Mesyè ☐ Medanm ☐ Gran ti moun ☐ Ti moun piti ☐ Lòt

q Konbyen moun, ki pat patisipe nan PLUS, aplike teknik sa li te aprann nan men ou? _____ moun

Nom Asistan _____ PADF 11/97 DAT _____

IDNO:_____ PADF/PLUS ETID EKSTANSIF 1995 EKIP:_____

VI. BANN MANJE

a Depi konbyen ane premyè bann manje nan jaden sa te fèt? _____ ane b. Konbyen ranje ki pa sou bon koub nivo? _____ ranje

c. Ranje/mèt fèt pandan 1995: _____ ranje _____ mèt d. Ranje/mèt fèt avan 1995: _____ ranje _____ mèt e. Distans ant bann yo? _____ mèt

f Ki èspès ki konpoze bann manje yo? Pozisyon "A" _____

Pozisyon "B" _____

Pozisyon "C" _____

g Ki danre plantè a rekolte nan bann manje yo pandan 1997? _____

h Ki valè kach li jwenn nan danre ki sòti nan bann manje yo pandan 1995? _____ Gdes

i Konbyen ranje ou we ki tre byen jere? _____ ranje j. Konbyen konsi konsa? _____ ranje k. Konbyen move net? _____ ranje

l Konbyen brèch >25 cm genyen nan bann manje yo? _____ m. Eske mèt jaden an konn repare brèch yo? ☐ wi ☐ non

n Ensèkle nimewo ki endike anpòtans mèt jaden an bay bènèfis ki sòti nan 1=pa enpòtan ditou, 5=trezanpòtan

Bann manje bay li kek nouvo kalite manje nan jaden sa	1	2	3	4	5
Bann manje bay li manje pandan pèryod grangou	1	2	3	4	5
Bann manje pèmèt li vann plis nan mache	1	2	3	4	5
Li sèvi kom baraj pou krèm tè a rète nan jaden	1	2	3	4	5
Bann manje bay fey pou bay bèt manje	1	2	3	4	5

o. Ensèkle nimewo ki endike anpòtans mèt jaden an bay pwoblem nan bann 1=pwoblem sa pa anpotan ditou, 5=pwoblem sa trezanpòtan

Eske bann manje yo okipe twop espas nan jaden?	1	2	3	4	5
Eske bann manje yo bay twop lombraj nan jaden?	1	2	3	4	5
Eske plantil nan ranje yo souse twop dlo nan tè ki fè lòt danre soufri?	1	2	3	4	5
Eske bann manje nan jaden bay difikilte pou mare bèt?	1	2	3	4	5
Eske bann manje yo pran twop tan pou okipe yo?	1	2	3	4	5

p Konbyen moun te ede konstwi bann manje yo? ☐ Mesyè ☐ Medanm ☐ Gran ti moun ☐ Ti moun piti ☐ Lòt

q Konbyen moun te ede repare bann manje yo? ☐ Mesyè ☐ Medanm ☐ Gran ti moun ☐ Ti moun piti ☐ Lòt

r Konbyen moun, ki pat patisipe nan PLUS, aplike teknik sa li te aprann nan men-ou? _____ moun

Nom Asistan._____ PADF 11/97 DAT _____

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VII. MISEK

a. Depi konbyen ane premyè misèk nan jaden sa te fèt?_____ b. Konbyen ranje ki pa sou bon koub nivo?_____

c. Ranje/mèt fèt pandan 1995: ranje mèt d. Ranje/mèt fèt avan 1995: ranje mèt

e. Distans ant misek yo? _____ mèt f. Akimilasyon tè dèvan misek yo? _____ cm

g. Konbyen ranje ou we ki tre byen jere? _____ ranje h. Konbyen konsi konsa? _____ ranje i. Konbyen move net? _____ ranje

j. Konbyen brèch genyen nan misèk yo? _____ k. Eske mèt jaden an konn repare brèch yo? ☐ wi ☐ non

l. Ensèkle nimewo ki endike anpòtans mèt jaden an bay bènèfis ki sòti nan m 1=pa enpòtan ditou, 5=trezanpòtan

Misèk pèmèt tè a vinn pi fasil pou travay	1	2	3	4	5
Misèk kreye plis espas pou fè jaden	1	2	3	4	5
Misèk sèvi kom baraj pou krèm tè a rète nan jaden	1	2	3	4	5
Misèk fè li jwenn plis rekolt danre nan jaden	1	2	3	4	5

m. Ensèkle nimewo ki endike anpòtans mèt jaden an bay pwoblem nan mise 1=pwoblem sa pa anpotan ditou, 5=pwoblem sa trezanpòtan

Eske misek yo okipe twop espas nan jaden?	1	2	3	4	5
Eske misek nan jaden bay difikilte pou mare bèt ?	1	2	3	4	5
Eske misek yo pran twop tan pou okipe yo?	1	2	3	4	5

n. Konbyen moun ki te ede konstwi misek yo? ☐ Mesyè ☐ Medanm ☐ Gran ti moun ☐ Ti moun piti ☐ Lòt

o. Konbyen moun ki te ede repare misek yo? ☐ Mesyè ☐ Medanm ☐ Gran ti moun ☐ Ti moun piti ☐ Lòt

p. Konbyen moun, ki pat patisipe nan PLUS, aplike teknik sa li te aprann nan men-ou? _____ moun

Nom Asistan:_____ PADF 11/97 DAT:_____

VIII. BARAJ RAVINN

a. Konbyèn baraj jaden sa genyen ki te konstwi pandan 1995, ak avan 1995?

Tip Baraj	Pandan 1997	Avan 1997
Kleyonaj		
Fasinaj		
Sey woch		
Sak tè		

b Ki danre met jaden an te plante nan baraj yo pandan 1995? _____

c. Ki danre li rekolte nan baraj pandan 1995? _____

d. Ki valè lajan li jwenn nan danre ki sòti nan baraj yo pandan 1995? _____ Gdes.

e. Konbyen moun nan twaye-a ki te ede konstwi baraj yo? ☐ Mesyè ☐ Medanm ☐ Gran ti moun ☐ Ti moun piti ☐ Lòt

f. Konbyen moun nan twaye-a ki te ede repare baraj yo? ☐ Mesyè ☐ Medanm ☐ Gran ti moun ☐ Ti moun piti ☐ Lòt

g. Konbyen baraj ou we ki tre byen jere? _____ baraj h. Konbyen konsi konsa? _____ baraj i. Konbyen move net? _____ baraj

j. Ensèkle nimewo ki endike repons pou kesyon swivan: **(1= no, pa ditou, 5= wi, anpil)**

Eske konstriksyon baraj yo teknikman korèk?	1	2	3	4	5
Eske kondisyon aktyèl baraj yo bon?	1	2	3	4	5
Eske mèt baraj konn fè reparasyon?	1	2	3	4	5
Eske baraj yo deja kenbe kek tè ewode?	1	2	3	4	5
Eske baraj yo reziste gwo dlo lapli?	1	2	3	4	5
Eske baraj yo pwoteje kay ak tè ki anba monn sa?	1	2	3	4	5

k. Konbyen moun, ki pat patisipe nan PLUS, aplike teknik sa li te aprann nan men-ou? _____ moun

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IX. KANTITE PYEBWA NAN JADEN

a Konbyen pyebwa total ou te plante nan jaden sa avan 1995?_____ b. Ki espès? _____

c. Konbyen pyebwa ou te plante nan jaden sa pandan 1995?_____ d. Ki espès? _____

e. Ki jan ou te pwodwi\plante pyebwa 1995 yo? ☐ Semi direk ☐ Rasinn ni ☐ Rache plante ☐ Sache plastik
☐ Rootrainer ☐ Lòt vèso ☐ Lòt (ekri): _____

f. Ki kote ou te jwenn ti pyebwa sa yo? ☐ PADF ☐ Zanmi plantè ☐ Pepinyè endividyèl ☐ Pepinyè an gwoup ☐ Lot kote

g. Konbyen moun travay nan jesyon ak rekolt pyebwa yo? ☐ Mesyè ☐ Medanm ☐ Gran ti moun ☐ Ti moun piti ☐ Lòt

h. Ensèkle nimewo ki endike jesyon ak devlopman pyebwa ki te plante nan 1995

(1=pa ditou, 5=anpil)

Eske pyebwa yo soufri anba sechres?	1	2	3	4	5
Eske pyebwa yo soufri anba maladi ak ensek?	1	2	3	4	5
Eske pyebwa yo soufri anba zanimo?	1	2	3	4	5
Eske pyebwa yo soufri domaj ki te tèt nan saklaj jaden?	1	2	3	4	5
Eske move zeb domine pyebwa yo?	1	2	3	4	5
Eske lot danre domine pyebwa yo?	1	2	3	4	5

i. Ki espes pyebwa ki pi byen devlope? _____ j. Ki espes pyebwa ki pa byen devlope ditou? _____

k. Nan tout pyebwa nan jaden, ki pwodwi met janden rekolte pandan 1997? ☐ Fwi ☐ Manje bèt ☐ Planch ☐ Poto ☐ Gol
☐ Chabon ☐ Bwa difè ☐ Bwa klisaj ☐ Pye pran ☐ Pikèt

l. Nan tout pyebwa nan jaden, ki valè lanjan met jaden jwenn nan pwodwi li rekolte pandan 1997? _____ Gdes.

m. Konbyen moun, ki pat patisipe nan PLUS, aprann teknik plante pyebwa li te aprann nan men-ou? _____ moun

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X. KANTITE BWA GREFE NAN JADEN

a. Konbyen pyebwa ki te grefe nan jaden sa avan 1995? _____ b. Ki espès?_____

c. Konbyen grefon ki te grefe sou pyebwa sa yo? _____ d. Konbyen grefon te pran? _____

e. Konbyen pyebwa ki te grefe nan jaden sa pandan 1995? _____ f. Ki espès?_____

g. Konbyen grefon ki te grefe sou pyebwa sa yo? _____ h. Konbyen grefon te pran? _____

i. Ki lès moun te fe grefaj pandan 1995? ☐ Teknisyen PADF ☐ Bòs grefè ☐ Ekstansyonis ☐ Plantè a ☐ Lòt moun

j. Konbyen moun te travay nan jesyon fwi grefe yo? ☐ Mesyè ☐ Medanm ☐ Gran ti moun ☐ Ti moun piti ☐ Lòt

k. Konbyen moun te travay nan rekolt fwi grefe yo? ☐ Mesyè ☐ Medanm ☐ Gran ti moun ☐ Ti moun piti ☐ Lòt

l. Pou pyebwa ki te grefe pandan 1995, ki bò ou te jwenn grefon yo? ☐ PADF ☐ Bòs grefè ☐ Lakay mwen ☐ Lot kote

m. Eske met jaden te elimine gouman yo? ☐ Li te fe li korek net ☐ Li te koupe kek landan ☐ Li pa te fe li ditou

n. Eske met jaden rekolte fwi grefe pandan 1995? ☐ Wi ☐ Non

o. Si wi, konbyen ak ki kalite fwi li rekolte?

Kalite Fwi Li Rekolte	Kantite Fwi Li Rekolte

p. Ki sa met jaden an te fe ak fwi yo? ☐ Fanmi li manje yo ☐ Li bay lot moun manje yo ☐ Li vann yo

q. Si li te vann fwi yo, konbyen lajan li jwenn nan vant la? _____ gdes.

r. Konbyen moun, ki pat patisipe nan PLUS, aplike teknik grefe pyebwa li te aprann nan men-ou? _____ mou

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XI. JADEN LEGIM

a Konbyen fwa met jaden an plante legim pandan 1995? _____ fwa b. Ki gwosè jaden legim nan? _____ mèt x _____ mèt

c. Ki kalite legim li te plante? _____

d Konbyen moun te travay nan jaden legim sa pandan 1995? ☐ Mesyè ☐ Medanm ☐ Gran ti moun ☐ Ti moun piti ☐ Lòt

e. Esèkle nimewo ki dekri pwoblem nan jaden sa pandan 1995 (1=pa gen pwoblem sa ditou, 5=pwoblem sa te grav anpil)

Varyete ak kalite semans	1	2	3	4	5
Sechres	1	2	3	4	5
Ensek	1	2	3	4	5
Maladi	1	2	3	4	5
Move zeb	1	2	3	4	5
Zanimo	1	2	3	4	5
Lòt pwoblem _____	1	2	3	4	5

f Esèkle nimewo ki dekri anpòtans benefis plantè a te jwenn nan jaden pand (1=pa anpòtan ditou, 5=benefis sa anpòtan anpil)

Vann legim	1	2	3	4	5
Vann plantil	1	2	3	4	5
Manje legim lakay	1	2	3	4	5
Bay zanmi legim kom kado	1	2	3	4	5
Lòt benefis _____	1	2	3	4	5

g Ki sa met jaden an te mete nan jaden an pou ogmante fetilite? ☐ milch ☐ konpos ☐ poupou bèt ☐ angre chimik

h. Ki sa met jaden an aplike nan jaden an pou kontwole ensek ak mala ☐ Pestisid òganik ☐ pestisid chimik ☐ li kontwole yo a men

i Eske met jaden te resevwa fòmasyon nan pestisid òganik? ☐ wi ☐ non

j Kwaze ti bwat ki endike kalite depans an kach mèt jaden an te fe pandan 1997.

☐ achte semans ☐ achte plantil ☐ Mendèv nan jaden ☐ Pestisid ☐ Angre ☐ Transpò nan mache

k Ki depans total li te fe pou jaden sa pandan 1997? _____ Gdes. l. Ki valè total mèt jadan an reyisi nan jaden sa pandan 1997? _____ Gdes

m. Konbyen moun, ki pat patisipe nan PLUS, aprann teknik jaden legim li te aprann nan men-ou? _____ moun

Nom Asistan _____ PADF 11/97 DAT _____

XII. REMAK JENERAL SOU JADEN SA

APPENDIX F
SOIL NUTRIENTS, ORGANIC CARBON STATUS, AND pH OF 175 HILLSIDE GARDENS

As a part of the interview that took place during the garden visits (n=2,295), technicians asked the farmers to evaluate several soil parameters of the plot. A qualitative scale of 1 to 5 was used. The parameters were soil fertility (1=poor, 5=very fertile), soil depth (1=shallow, 5=deep), an evaluation of the hot/cold scale[1] (1=hot, 5=cold), and signs of soil erosion between the rows of soil conservation structures on the plot (1=none, 5=many). In addition, the farmer was asked to give the local Creole name for the soil type, and the technicians noted the type of parent material (calcareous or basaltic).

The relationship of Haitian indigenous soil classification systems to the western systems is not well understood (McLain and Stienbarger 1988). Since these qualitative opinions about soil were used as independent variables in analyses of farmers' decision to install and manage various agroforestry practices, it is necessary to understand if they relate to measurable fertility parameters.

Method

Cross tabulations of farmers' soil names and ratings were done using information from all 2,295 gardens visited. Soil samples were taken for laboratory analysis from 175

[1]Most writers agree that "hot" soils (*cho*) are dry, well-drained soils and "cold" soils (*fwet*) have more soil water available for plants. Other concepts are integrated into this system as well, including soil parent material, slope, orientation, and vegetative cover (McLain and Stienbarger 1988, Murray 1981). Some crops grow better in hot soils, some in cold, but in general cold soils are preferred (Smucker 1981).

gardens selected at random from all gardens visited, 35 each from gardens having fertility classes 1 through 5. Two samples were mislabeled and could not be used. The samples were taken by technicians using a machete from the 0-20 cm layer; a composite of four positions for each sample. They were put into ziplock bags and labeled, then transported to the University of Florida for laboratory analysis. Inductively coupled argon plasma spectroscopy (ICAP) was used with the Mehlich 3 procedure for Ca, Mg, K, and P. ICAP was also used to determine water extractable pH. Percent organic matter was determined using the Walkley-Black procedure. Statistical analyses were done using SPSS; nonparametric tests (chi-square, Mann-Whitney) because distributions were not normal and numbers of observations were not equal for all factor levels. The 1 to 5 scales were recoded by combining ratings 4 and 5 into one category (the "best" end of the scale) and ratings 1, 2, and 3 into another category (the "worst" end of the scale). The comparisons were therefore fertile vs. not fertile, deep vs. not deep, not eroded vs. eroded, and cold vs. not cold soil.

Results

Farmers used 21 different names for their soils in the 2,279 gardens for which they gave that information. Of these, four are based on color, six refer to parent material or texture, six refer to the fertility, water-holding ability, or other capacity of the soil to produce crops, and five refer to miscellaneous or unknown properties. Table F-1 summarizes these, and gives the percent of each named soil given the top two fertility ratings (categories 4 and 5).

Table F-1: Haitian farmer soil classifications

Group	Creole name	Translation	No. of cases	% fertile
Color	Nwa	Black	578	51
	Wouj	Red	228	38
	Jonn	Yellow	69	52
	Gri	Grey	46	33
Parent material or texture	*Grennen*	Grainy?	256	45
	Sab	Sand	246	40
	Tif	Lime	174	36
	Ajil	Clay	111	65
	Woch	Rock	92	30
	Fen	Fine	13	15
Fertility, water, productive capacity	*Gra*	Fat	167	83
	Cho	Hot	117	14
	Meg	Thin	77	8
	Pat	Paste	55	73
	Dlo	Water	9	89
	Fwet	Cold	5	80
Miscellaneous	*Gro*	Big	17	29
	Ravet	Roach	15	0
	Men	Unknown	2	50
	Si	Sour	1	0
	Grison	Unknown	1	0

It appears that black, yellow, clay, fat, paste, water, and cold soils tend to be fertile, while thin, fine, and hot soils tend towards the infertile end of the scale. However, since farmers were sampled over four large regions of the country from the north to the south, several of these soil names probably refer to the same underlying characteristics. For example, Figure F-1 shows that the distribution of fertility ratings from 1 (very infertile) to 5 (very fertile) is skewed to the left—farmers tend to give their soils high ratings. If hot always meant infertile and cold fertile a corresponding pattern would be expected in the hot/cold scale, but this is not the case. Figure F-2 shows that the distribution of hot/cold soils is skewed to the right, farmers tend to rate their soils as hot more frequently than cold. A cross tabulation of the fertility ratings with the hot/cold

ratings shows that 63% of the 431 gardens given the top two cold ratings are also given the top two fertility ratings. However, 41% of the not cold gardens (n=1,864) are also rated as fertile, so the distinction is not clear-cut.

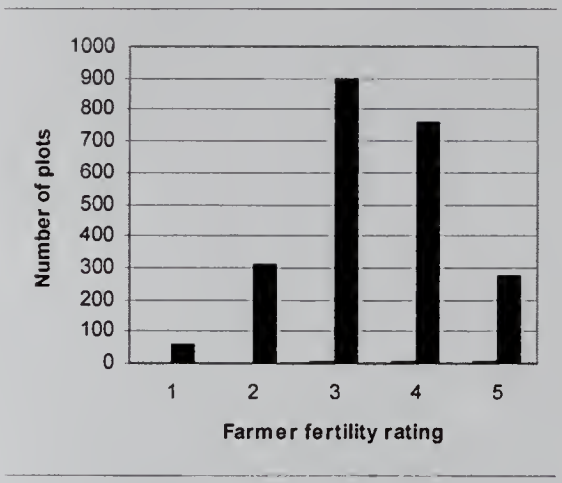

Figure F-1: Distribution of fertility ratings

Figure F-2: Distribution of "hot/cold" ratings

However, if cross tabulations are done using the soil names hot, cold, fat, and thin against soil fertility ratings, stronger correlations are shown: 80% of cold soils (n=5) are rated as fertile, and 86% of hot soils (n=117) are rated as not fertile; 83% of fat soils (n=167) are rated as fertile, and 92% of thin soils (n=77) are rated as not fertile. Because the cold name was used in only five gardens, doubtless the same concept is included in other soil names.

The mean and median pH, nutrient, and organic carbon values for all 173 plots where soil samples were taken are shown in Table F-2. Based on interpretation tables for the Mehlich 3 procedure, the phosphorus level is low for maize, potassium is high, calcium and magnesium are not limiting. Maize planted in soils having these values

would probably respond to phosphorus and nitrogen, and possibly micronutrients (R. Tucker, pers. comm.).[2]

Table F-2: pH, nutrient, and percent organic carbon for 173 gardens

	pH	P (mg/kg)	K (mg/kg)	Mg (mg/kg)	Ca (mg/kg)	% OC
Mean	7.7	5.6	143.6	435.5	14,783	1.7
Median	8.0	3.6	117.0	261.0	13,500	1.5

There were statistically significant differences between soils rated as fertile and those rated as not fertile (Table F-3). Fertile soils had a lower pH, more potassium, and more organic carbon. However, since the difference in pH is very small and potassium is abundant in both classes of soils, the difference in organic carbon is the most interesting result. These differences are indicative, but doubtless do not reveal everything farmers integrate into the concept of fertility.

Table F-3: Nutrients, pH, and % organic carbon for soils rated as fertile and not fertile

		pH	P (mg/kg)	K (mg/kg)	Mg (mg/kg)	Ca (mg/kg)	% OC	n
Fertile	Mean	7.6	6.1	161.2	439.6	13,287	1.9	69
	Median	7.9	3.6	132.0	287.0	12,100	1.6	
Not fertile	Mean	7.8	5.3	131.8	432.7	15,776	1.5	104
	Median	8.1	3.6	104.5	243.5	13,850	1.4	
p-value		.004	.268	.020	.171	.117	.018	

Similar comparisons were made between deep and not deep soils, eroded and not eroded soils, and cold and not cold soils. Each had only one significant difference: deep soils had 21 mg/kg more potassium than not deep soils ($p = .023$), eroded soils had 143

[2]Based on interpretation tables for maize in North Carolina, the southernmost state in the U.S. that uses Mehlich 3.

mg/kg less magnesium than not eroded soils (p = .030), and cold soils had 30.5 mg/kg more potassium than did not cold soils (p = .081). These differences do not appear to be important.

Limestone substrate underlies 80% of the land area in Haiti; the rest is basaltic or alluvial (Ehrlich et al. 1985). The soils found in basaltic areas are visually different than those found in limestone areas, they are of a coarser texture and they erode faster. Only limestone (68%) and basaltic (32%) soils were recorded in this survey. Do farmers' fertility ratings differ between these two categories of soils, and are the differences in fertility shown in Table F-3 reflecting the differences in parent material? A cross tabulation revealed that 72% of fertile soils (n=1032) and 65% of not fertile soils (n=1262) were of limestone origin. This appears to indicate that limestone soils are more likely to be considered fertile. Table F-4 shows the differences as found in laboratory analyses.

Table F-4: Nutrients, pH, and % organic carbon for basaltic and limestone soils

		pH	P (mg/kg)	K (mg/kg)	Mg (mg/kg)	Ca (mg/kg)	% OC	n
Basaltic	Mean	7.5	6.2	112.6	595.9	10,166	1.2	59
	Median	8.0	3.7	90.5	326.0	8,980	0.9	
Limestone	Mean	7.8	5.3	159.6	352.4	17,172	2.0	114
	Median	8.0	3.6	131.0	256.5	15,300	1.7	
p-value		.097	.422	.001	.218	<.001	<.001	

The expected differences in pH and calcium are found, limestone soils having higher values for both. Limestone soils also have significantly more potassium and a higher percentage of organic carbon. The difference in organic carbon between basaltic

and limestone soils is somewhat greater than the difference between soils rated as fertile and not fertile (Table F-3).

Conclusions

Soil fertility ratings as expressed by farmers in the survey appear to be in agreement with opinions expressed in the literature (Murray 1981, McLain and Stienbarger 1988, Smucker 1981), for example the hot/cold fat/thin scales. They also generally conform to laboratory results, but the soil analysis does not completely explain them. The ratings are relative, subjective, and relate to other nearby plots, not to plots over the whole country. Although farmers rate limestone soils as fertile more often, the basaltic soils in the north of the country often produce better crops because rainfall is higher and more regular. Farmers integrate rainfall, regularity of rainfall, slope, water holding capacity and other undiscovered factors into their fertility ratings. However, their ratings as expressed in the survey appear to be well founded enough to be used in analysis of adoption and management choices.

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BIOGRAPHICAL SKETCH

After serving four years in the U.S. Navy, Michael Bannister earned a B.S. and Master of Forestry (M.F.) in forest management from Oregon State University in 1976 and 1981, respectively. Between the two degrees he served as a Peace Corps volunteer in Guatemala, establishing two community pine/oak nurseries and promoting soil conservation. In 1981 he accepted a position working in agroforestry extension in Haiti with the Pan American Development Foundation (PADF). PADF has implemented three USAID-funded agroforestry projects in Haiti from 1981 through 2000. Mr. Bannister worked on all three projects as regional team leader, research and documentation coordinator, and assistant director for agroforestry; the latter position he still holds. Since 1981 he has also done short consultancies for PADF in the Dominican Republic, Honduras, El Salvador, and Panama. Mr. Bannister began his Ph.D. at the University of Florida in 1987, taking three years off from his professional work for required classes. He then returned to Haiti as a full-time employee of PADF while simultaneously doing his field research, analysis, and much of the writing. This process, aggravated by political and civil turmoil in Haiti, has taken 14 years.

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy

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This dissertation was submitted to the Graduate Faculty of the School of Forest Resources and Conservation in the College of Agricultural and Life Sciences and to the Graduate School and was accepted as partial fulfillment of the requirements for the degree of Doctor of Philosophy.

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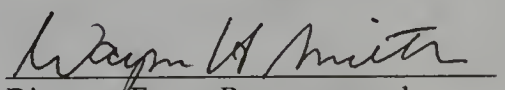

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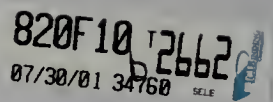
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