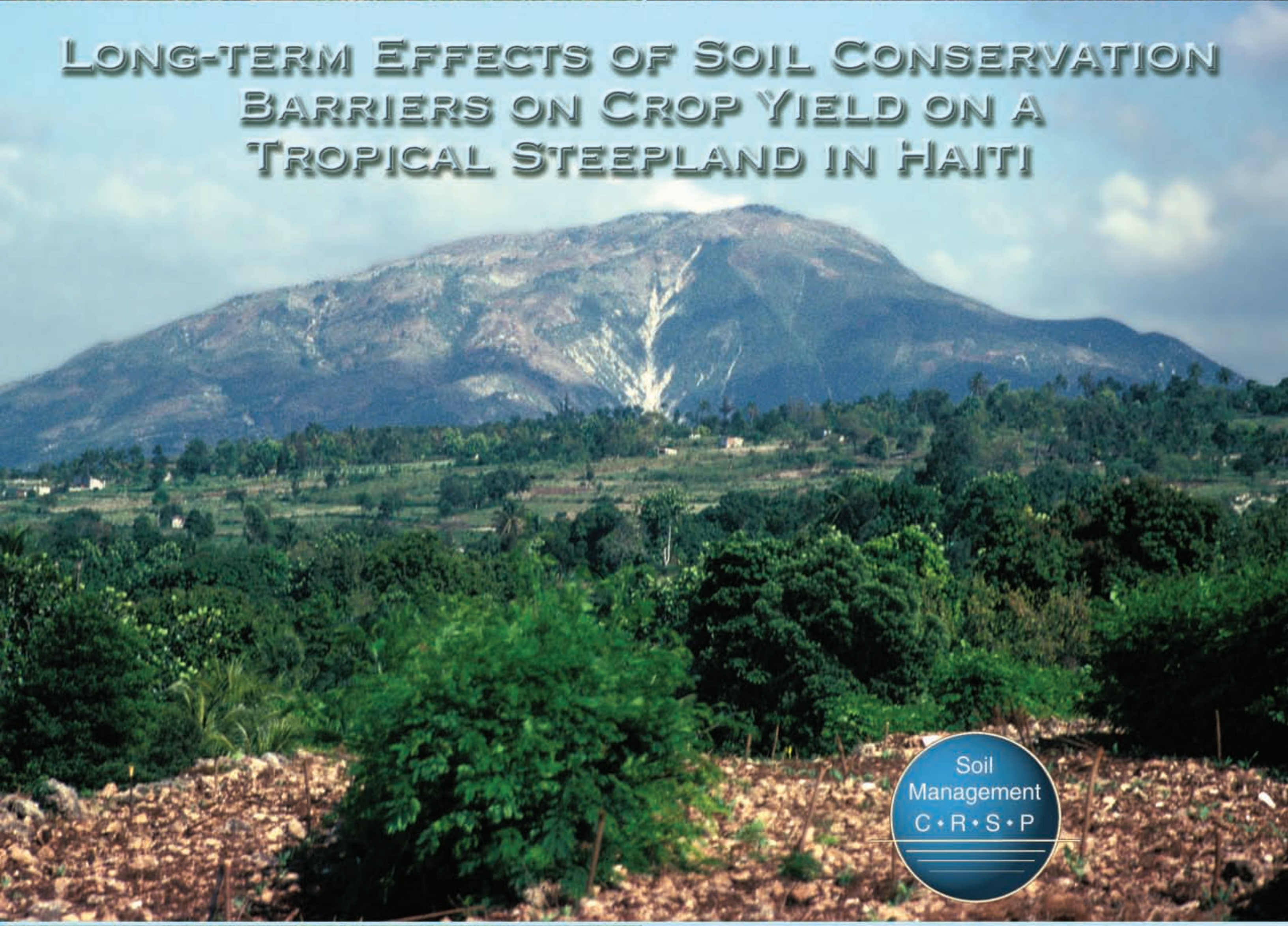
Long-term Effects of Soil Conservation Barriers on Crop Yield on a Tropical Steepland in Haiti



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introduction

Soil erosion and degradation is a problem common to steeplands throughout the tropics. In 1998, devastation caused by hurricanes Mitch and Georges in Central America and the Caribbean renewed the attention of policy makers to the importance of soil conservation on agricultural lands, especially on steep slopes. Lack of soil conservation structures or protective vegetative cover on large areas of cropped land and grazed fallows in the mountains of Honduras, Nicaragua, and Haiti led to loss of valuable topsoil and arable land throughout watersheds, costly destruction and loss of life along waterways and in the lowlands. In Haiti, Hurricane Georges widened streambeds and created new dry streambeds in agricultural fields. Observations in farmers' fields in Honduras in the aftermath of Hurricane Mitch showed that properly constructed and located rock terraces, contour grass rows, and tree fallows were all effective in preventing the landslides that devastated unprotected lands (T. Thurow, personal communication, 1998). On the other hand, mulching with crop residues, although effective in reducing surface runoff during normal storm events, were totally ineffective at preventing landslides under extremely high rainfall. Choice of appropriate soil conservation practices for low-resource farmers on tropical steeplands is thus an important consideration.

Although the primary purpose of soil conservation practices in agriculture is to reduce loss of soil and water in runoff, a soil conservation practice must also be assessed with respect to other aspects of the farming system, such as cost, acceptability, and its long-term effect on agricultural production. Soil erosion control contributes to increased sustainability by arresting loss of organic matter and nutrients needed for crop production. However, simply retaining soil from moving may not be sufficient incentive for low-resource farmers to invest in costly conservation structures. There must also be benefits to the farmer in terms of enhanced and sustained production of crops and/or livestock. In this paper, we consider the long-term effects on crop yield. In future papers, this Steepland Project will consider other factors affecting the choice of soil conservation practices, such as erosion and runoff, acceptability to farmers, and economic assessment.

Context of the Research

The research described in this report was initiated in Haiti under USAID's Agroforestry II Project, in response to perceived needs expressed by the two organizations conducting extension work in the project, CARE International and the Pan American Development Foundation (PADF). However, the issues and trends involved are common to tropical steeplands around the world. A background to soil and water conservation history with respect to USAID-supported activities in Haiti, and nutrient management issues provides the context for the research described here.

Soil Conservation Practices in Haiti

A number of soil and water conservation practices on cropped land are well established in rural Haiti. These include contour ridging, rock walls built without mortar (*murs secs*), rock lines (*cordons de pierre*), residue barriers (*rampes pailles*), grass rows, and more recently, hedgerows (*rampe vivant* or *haie vive*). Contour canals, although promoted by some, have not received much attention, nor have they been widely adopted by farmers. Other practices that may be considered experimental are now finding their place in farmers' fields. These include contour alley cropping and hedgerows of perennial crops (*bann manje*). Despite the fact that most Haitian farmers are aware of most of these conservation practices and their use is in evidence around the country, the majority of farmland is not protected by any of these practices.

Inadequate adoption of soil conservation practices by farmers has engendered considerable speculation over the years by both professionals and the public at large, and is the subject of on-going research. There are many reasons given, some technical, some economic or sociological. These will not be discussed in detail here, except as necessary to provide the context for specific practices being described.

Ridging. The use of ridging varies, depending upon location within the country and crop grown. Ridges are used for crop associations of various combinations including maize, common bean, sorghum, cassava, pigeon pea, and cowpea, but less often for peanut or sole crops of common bean or cowpea. Sweet potatoes may also be planted on ridges, but these ridges tend to be small in many areas. At high elevations, ridging is consistently used for Irish potato. Soil parent material may also influence the decision to build ridges. Perhaps the most striking examples of ridging use on steep slopes are to be found around Palmiste à Vin, where whole mountainsides are meticulously ridged and almost continually cropped (Photo 1). The soils in this area are derived from basalt and are highly susceptible to erosion. Stone is not readily available in this area and frequent cultivation of these steep slopes would not be possible without ridging or other soil conservation measures.

Rock walls. The construction of rock walls is practiced in many parts of Haiti (photos 2 and 3). It is also referred to as dry wall terracing, because no mortar is used and because it leads, over time, to the formation of terraces. Rock walls are constructed by first digging a shallow trench, ideally on the contour, and carefully stacking rocks in such a manner that the wall is stable unless disturbed. The base is usually 40 to 80 centimeters (cm) across, while the top may be 20 to 40 cm across. The downhill face of properly constructed walls slants slightly into the hill, so as to increase stability. Tillage and water erosion lead to the accumulation of soil behind the structures, and thus the creation of terraces without additional effort (Photo 4). The walls must be built higher over time as more soil is deposited behind them. Rock walls are advantageous in many areas of the country where the bedrock is limestone, since rock is readily available in the field, and rearrangement of this rock into walls leaves more room for crops to grow. However, due to the high labor requirement to construct the walls, farmers in many areas appear reluctant to invest in rock walls without subsidies. Rock walls also require some maintenance. In other areas, particularly on basalt-derived soils, rock is not as readily available and thus the solution is less practical.

A variation of rock walls are rock lines (*cordons de pierres*), which are simply piles of rock arranged on contour. Unlike rock walls, rock lines do not have a foundation and are not carefully stacked.

Residue barriers. *Rampes pailles*, as they are called in Creole, are created during field preparation by placing crop residues and other plant material in contour rows across the field as a barrier to erosion (Photo 5). "Improved" residue barriers (*rampe de paille améliorées*), obtained by partially burying the residues, have been promoted by development agencies. Although residue barriers are somewhat effective at retaining soil, as evidenced by some soil buildup behind them, they are only a temporary measure since they decompose over the course of the season and have to be reconstructed in the next season. Swanson *et al.* (1994b) observed that "improved" barriers may even contribute to erosion since the loose soil used to cover the dried strips of vegetation may be easily washed off with the first rains. They are nevertheless popular in some areas because of the low labor requirement.

Grass barriers. Grass rows are occasionally planted along a contour for the combined purposes of soil conservation and livestock feed. Napier (*Pennisetum purpureum*) and Guatemala grass (*Tripsacum laxum*) are the most popular species, because of their strong stems. Sugar cane may also be used in this manner. Vetiver (*Vetiveria zizanioides*) has also been used for soil conservation, but because the roots are harvested in southern Haiti for essential oils, development workers have been reluctant to promote it for soil conservation. However, systematic planting of grass rows across an entire field for conservation purposes is extremely rare. More commonly, grasses may be found as border plantings or along footpaths.

Contour hedgerows. Hedgerows of fast-growing trees, especially *Leucaena leucocephala*, are increasingly planted for soil conservation in cropped fields (photos 6 and 7). The tree seed are dribbled into small furrows, resulting in average densities of up to 20 to 30 plants per meter (m). In some areas, hedgerows are established in conjunction with a contour ridge and ditch system or the trees are seeded adjacent to residue barriers. Rows are frequently spaced 10 to 12 m apart, leaving wide spaces for planting of row crops. Branches are laid at the base of the hedgerows to reinforce the barrier effect (Photo 8). Livestock are often allowed to graze the hedgerows during the dry season, or the leaves are cut and carried to feed the animals. Soil accumulates behind the hedgerows, providing an area of improved soil conditions immediately uphill from the hedgerows (Bannister and Nair, 1990), but the upper parts of the alleys continue to erode and degrade. Although farmers were advised to apply the leaves as green manure when hedgerows were introduced by PADF in the early 1980s, this practice was seldom followed by farmers (M. Bannister, personal communication, 2003).

Contour alley cropping. Alley cropping was proposed in 1990 as a modification of the contour hedgerow system because of the need to halt the loss in soil fertility and improve crop yields. Leucaena hedgerows are planted 4 to 6 m apart on the contour, much as they would in the contour hedgerow system, but instead of feeding the leaves to livestock, the leaves are applied to the soil as green manure or mulch (Kang *et al.*, 1984). Although not widely practiced, it has since been promoted by PADF. Its use by farmers was documented in surveys conducted as early as 1995 (Pierre *et al.*, 1996). Farmers who practiced alley cropping in southern Haiti report improved yields and less runoff from hillsides (Photo 9). The adoption and maintenance of alley cropping hedgerows by farmers in southern Haiti was studied by Bayard (2000) and is the subject of a future Soil Management CRSP report.

Perennial crop barriers. The concept of perennial crops as conservation barriers, dubbed *bann manje* by farmers, was proposed following on-farm surveys by a multi-disciplinary team, because of reservations they had with respect to the potential adoption of alley cropping and resistance by some farmers to leucaena (Swanson *et al.*, 1994a,b). Crops vary depending upon the region, but may include true perennials and long-term annuals, such as plantain, banana, malanga (*Xanthosoma*), sugar cane, pineapple, cassava, etc. The crops forming the barrier cover an area at least 1 m across (Bannister, 2001). In areas where it has been tested, it is reported to be more readily accepted than alley cropping, but the provision of seeding material of some of the high-value species may have played a role in this preference. These systems have not been adequately tested and appropriate management practices have not been worked out.

Support to Soil Conservation by International Assistance Programs

In Haiti, non-governmental agencies, many funded by USAID, have played a dominant role in agricultural extension. It is useful to note the changing trends with respect to support for soil and water conservation.

Phase 1 - Rock Walls

Rock walls were a popular method of soil conservation from at least the 1950s through the 1970s (Smucker, 2002). Major extension efforts were supported with Food for Work programs funded by USAID. An example of successful programs in which use of rock walls for soil and water conservation has become a sustained component of the farming practices may be seen in the area of Fort Jacques in the mountains south of Port-au-Prince. There, Food for Work was utilized by rural development programs operated by Church World Service/Service Chrétien d'Haiti and other groups to subsidize rock wall construction in the 1960s and early 1970s. Thirty years after the program was suspended, rock wall terraces are an integral part of the rural landscape. Although not fully implemented in all cropped fields, rock walls cover a majority of cropped fields and are maintained as needed.

Another location where rock walls were successfully introduced was at Haut Cap Rouge, near Jacmel, where "a major portion of several watersheds were covered with a combination of rock walls, vegetative strips and fruit trees" (Villanueva, 1993, p. 16). This was achieved with support from the Agricultural Development Support II Project of USAID. It is not clear whether payment was made to farmers to construct the walls. A visit by Dr. Villanueva to Haut Cap Rouge in 1993 confirmed that farmers continued to maintain these rock walls.

Despite these successes in the promotion of rock walls for soil and water conservation, the widely-held view by Haitian agronomists and many expatriate development workers is that farmers will construct rock walls when encouraged or paid by projects to do so, but once the project has left the area, the practice is abandoned (Pierre-Marie Basquiat, personal communication, 1998). A study on the adoption and maintenance of rock walls by farmers in the Fort Jacques area was conducted by Bayard (2000) and is the subject of a future Soil Management CRSP report.

Phase 2 - Tree Planting

An assumption commonly held by the Haitian public and by expatriate development workers alike is that excessive soil erosion in Haiti was caused by cutting down the trees. Therefore, the solution to combating soil erosion is to plant trees. This simplistic relationship seems to have driven the creation of community-based tree planting projects in the 1980s. The Agroforestry Outreach and Agroforestry II Projects, funded by USAID, distributed more than 63 million trees between 1981 and 1991 for planting by individual farmers on their land (Smucker and Timyan, 1995). Part of the success of these projects lies in the fact that trees were promoted as a cash crop, rather than strictly for their environmental benefits (M. Bannister, personal communication 2003). In these social forestry projects, trees were not planted in forest plots, but in fence rows and scattered across fields planted to annual crops. Recent experience in Honduras suggests that this is a good means to protect the soil against landslides. However, it does little to protect the soil against surface runoff, since the soil surface is cleared and tilled for crop production and individually spaced trees provide little barrier to slow runoff and halt soil erosion.

The fallacy in the commonly held views on soil erosion and environmental degradation is that the tree cutting itself is **not** the major cause of environmental degradation in Haiti. Under normal logging conditions, when trees are cut, undergrowth vegetation and new tree seedlings quickly reestablish ground cover and natural succession leads to reestablishment of a forest canopy. Although there would be a relatively short period during which some surface erosion may occur locally before vegetative cover is reestablished, tree cutting cannot explain the barrenness of many hillsides, expanding gullies, and increasing flooding danger now experienced in many parts of Haiti. The problem is that natural succession does not occur because cropping, and heavy grazing during fallow, prevent reestablishment of vegetative cover. As suggested by Birgegård (1991), deforestation cannot be solved by forestry activities, but by stabilizing and improving agricultural production. We could not agree more. This paper addresses solutions to reduce soil erosion during the cropping phase. By stabilizing crop yields and at the same time conserving soil, crop land will be less quickly abandoned to clear additional land.

Phase 3 - Contour Hedgerows

Concern that tree planting alone was not providing adequate protection against erosion led to the introduction of contour hedgerows on a small scale during the mid-1980s in Agroforestry Outreach Project (AOP). Disillusionment with rock walls led to greater interest in contour hedgerows of trees as a solution to the soil erosion problem. Hedgerows have the advantage of requiring less labor to establish. The most widely used tree species is *Leucaena leucocephala*, which has the additional benefit of fixing substantial amounts of nitrogen (N). However, the benefit to crops from this nitrogen source is seldom realized because most of the leaves are fed to livestock. Branches and stems are placed at the base of the hedgerow on the uphill side in order to reinforce the barrier effect. Under AFII (1989-1992) and during the early years of the PLUS project, efforts to promote hedgerow planting increased. Contour hedgerows were also planted by the ADS II and Targeted Watershed Management projects of USAID. Other efforts included the German agency, GTZ, an FAO project at Limbé, and many private, non-governmental agencies.

Phase 4 - Marketing Based Approach

The marketing approach to soil and water conservation is based upon the premise that market forces, rather than pure altruism, guide farmer behavior with respect to land use management. By providing markets for so-called "environmentally friendly" crops, it is proposed that farmers will be induced to increase their production of perennial, high-value crops instead of low-value row crops, which expose the soil to erosion. This approach, promoted by Agricultural Economist J.D. (Zach) Lea, gained favor in the late 1990s, and appears to be a guiding principle in the new Hillside Agriculture Program of USAID. Although this approach shows promise in terms of increased revenues to farmers, any potential benefits of this approach from a soil conservation standpoint are yet to be documented. Secondly, because this approach does not address the need for soil and water conservation practices in the remaining hillside areas cultivated to low-value, staple row crops, it should be part of a more comprehensive soil and water conservation program. Nevertheless, the need, by farmers, for economic incentives to adopt improved soil and water conservation practices is a concept that merits special consideration, especially in light of the experimental results presented in this report.

Yield Effects of Soil Conservation Practices

Although a vast literature exists on the effects of soil conservation structures on reducing soil loss and runoff, documented evidence of the effects of soil conservation practices are harder to obtain. Bojö (1992), reviewing 20 cost-benefit studies on effects of soil and water conservation projects, lamented the lack of quantitative yield data on which to base the analyses. Siebert and Belsky (1990) reported a lack of data on the effect of bench terraces on crop production. The assumption seems to be that if soil is "saved" from loss by erosion, it must increase crop yields. That is not necessarily so.

In on-farm trials in Ethiopia and Eritrea comparing ridge canal systems (*fanya juu* and bund systems) and grass barriers to traditional practices without conservation barriers, the conservation practices almost invariably resulted in lower soil loss and runoff compared to the local practice, but significant increases in crop yield were not observed (Herwig and Ludi,1999). Only in areas classed as sub-humid with "secure" rainfall were the relative effects of soil conservation practices on yield shown as positive trends, whereas at the semi-arid location and the sub-humid locations with "insecure" rainfall, the trends were more often negative. The lack of increased yields with soil conservation practices was attributed in large measure to loss of productive area due to the area occupied by conservation structure and topsoil erosion below the conservation structures. In the case of *fanya juu*, where the soil from the canals is thrown onto ridges up-slope from the canals, reduced productivity was also attributed to the deposition of less fertile subsoil over topsoil. Under some conditions, additional area was lost above conservation structures due to water logging.

By contrast, Yohannes (1992) reported 15-47% higher barley yields in fields where *Fanya juu* was practiced than in fields with the traditional practice, consisting of ditches to evacuate excess water. Barley yields were also 31% higher in *fanyu juu* fields compared to fields with level bunds. Within *fanya juu* fields, yields were highest above the bunds and lowest immediately below bunds. Nevertheless farmers were resistant to adopting *fanyu juu* technology as promoted, because of the loss of cropping area, insufficient turning area when plowing with oxen, and concern over erosion-risk of the drainage waterways.

Losses in up to 32% of cropping area were reported on slopes of 20-50% in Indonesia due to bench terraces on steep slopes, without compensating yield increases due to the conservation practice (Siebert and Belsky, 1990). In temperate central United States, maize yields on level terraces were lower in each of seven years, compared to yields on unterraced watersheds (Spomer *et al.*, 1973). This lower yield was attributed to a reduction in cropping area. The authors concluded that there was no economic benefit in the short term, when considering only on-site costs and benefits. However, they did report that the terraced fields became smoother and easier to farm over time, whereas the unterraced fields became more difficult to farm over time because of gullying in the field. This suggests that over the long-term, the conservation practices would be economically beneficial.

In an alley cropping system in which leucaena hedgerows occupied 25% of the land area, O'Sullivan (1995) reported higher maize yields with alley cropping than without when no fertilizer was applied, but no substantial yield benefit when fertilizer was applied. By contrast, Shannon *et al.* (1994) obtained similar yield increases from alley cropping with leucaena regardless of presence or absence of fertilizer. Kang and Akinnifesi (2000) showed higher maize yields, averaged over 12 years, when alley cropped than when sole cropped, regardless of whether fertilizer was applied. By contrast, Mendoza Corrales and Cassel (2002) did not record a benefit in yield of maize or bean due to alley cropping with gliricidia hedgerows over six years.

Comparisons of Various Soil Conservation Practices

Comparisons between mechanical barriers and biological barriers for their effectiveness against erosion are not bountiful in the literature (Siebert and Belsky, 1990). In a comparison of several conservation practices in East Africa, grass rows had a low labor requirement, while *fanya juu* required the most labor (Herwig and Ludi, 1999). The grass also drained better than the contour canal systems tested**.** The grass barriers appeared to retain similar amounts of soils as the other contour canal systems, although runoff tended in most locations to be slightly higher than with the mechanical barriers. However, grass barriers reduced crop yields relative to the traditional practice in four locations and only increased yields in two locations. Nevertheless, there seemed to be no strong trend with respect to its impact on crop yields relative to the contour canal systems.

On a 35%-slope in Indonesia, the area available for production of peanuts was reduced by 32% by bench terraces, by 17% by grass bunds, and by 10% by grass plus G*liricidia* bunds (Siebert and Belsky, 1990). Grass barriers were at least as effective as bench terraces at reducing soil loss.

Garrity and Mercado (1994) reported that grass barriers of *Pennisetum purpureum* reduced maize yield by 86% in the second year of a trial on a 15% slope. This was attributed to removal of nutrients in the harvested prunings and competition for water. Higher maize yields were attained by alley cropping hedgerows of

Senna spectabilis or *Gliricidia sepium*. Agus *et al.* (1999b) reported that maize yields with *Pennisetum purpureum* were 26% of the control yields and rice yields were 79% of the control, compared to 172% and 237%, respectively, for gliricidia hedgerows, four years after tree and grass rows were established. Addition of 60 kilograms (kg) N ha^{-1} had no effect on rice grown with *Pennisetum* and only a small effect on maize grown with the grass. The authors did not apply the grass clippings to the alleys.

Alley cropping on land graded to 0.4-0.5% had 90% less soil loss than that observed with plough farming (Dharmasena, 1994). Graded bund farming and strip-mulch farming with *Mucuna utilis* reduced soil loss by 33% and 84%, respectively.

Alley Cropping and Soil Erosion

Alley cropping with triple rows of *Desmodium virgatum* resulted in a 98% reduction in soil loss and a 75% reduction in runoff over three years on a clay soil on a slope of 17% (Comia *et al.*, 1994). Soil loss was insignificant under alley cropping but 140 megagrams (tonnes) per hectare (Mg ha^{-1}) under traditional practice. Hedgerow plants were spaced 10 cm in rows and 40 cm between paired rows with 5-m-wide alleys. Paningbatan *et al.* (1995) attributed this to the combined effects of contour ridging, the terracing effect and higher contact cover in the alley cropping treatments. Eighty-five percent of the reduction in soil erosion was due to the hedgerows, while 15% was due to soil application of the prunings. In a trial on a 20-45% slope, double rows of *Gliricidia sepium*, spaced 0.25 m within and between paired rows with 5-m alleys, reduced runoff by 40-60% and soil erosion by 85% early in season and 77% at mid-season (Augustin and Nortcliff, 1994). Using prunings for mulch or to reinforce the hedgerow barriers further reduced runoff by half and erosion by up to an additional 85%. In a pasture-fallow system, runoff as a percent of total rainfall was estimated at 31% with contour hedgerows of *Leucaena diversifolia* and mixed grasses spaced at 4- to 7-m intervals, compared to 76% without hedgerows (Chandler and Walker, 1998). This difference is even more striking since the alley cropped field was on a slope of 53%, while the field without hedgerows was on a slope of 30%. Barriers consisting of paired rows of *Gliricidia sepium* and *Penisetum purpureum* reduced soil erosion loss by 67 and 77% on Oxisols with slopes of 22-30% (Agus *et al.*, 1999b). Kiepe (1996) reported a 98% reduction in soil erosion with alley cropping on a 14% slope. When the prunings were not applied to the soil, soil loss was reduced by 93%, but mulching without a tree barrier only reduced soil erosion by 83%. In another study on a 26% slope, O'Sullivan (1985) applied the Universal Soil Loss Equation (USLE) to estimate that alley cropping with leucaena reduced soil erosion by 60%. Similar reductions were estimated for zero tillage. Alley cropping in the Amazon basin of Peru reduced soil loss from 53 megagram per hectare per year (Mg ha^{-1} y^{-1}) with two annual crops to 0.9 Mg ha^{-1} y^{-1}, a 98% reduction, on a 15-20% slope (Alegre and Cassel, 1996). Alley cropping with gliricidia in Nicaragua reduced runoff and sediment loss by 13% and 14%, respectively, on a 45% slope and by 33% and 34% on a 16% slope (Mendoza Corrales and Cassel, 2002).

Alley Cropping and Sustaining Crop Yield

Alley cropping has been shown to stabilize crop yields over time (Kang, 1993; Aihou *et al.*, 1999) and to increase yields on degraded soils (Aihou *et al.*, 1999; Shannon *et al.*, 1994). Rice yields declined over four years in control plots without fertilizer application, but increased over the same period in contour alley cropping plots with gliricidia hedgerows (Agus *et al.*, 1999b). With fertilizer application, there were no differences in rice yields between the no-barrier control and alley cropping plots with gliricidia hedgerows or mixed barriers of gliricidia with either of the grasses, *Pennisetum purpureum* or *Paspalum conjugatum*. With maize, the yield trend was consistently in favor of higher yields for contour alley cropping with gliricidia hedgerows, but the difference with the control was significant in one season with fertilizer and in two seasons without fertilizer. Yields between hedgerows containing *Pennisetum* were generally lower than between gliricidia hedgerows.

Grass Barriers

Grass barriers, nearly abandoned as a conservation practice in the United States with the availability of bulldozers to quickly establish terraces, are the subject of renewed interest, due to their lower cost, and their ability to promote infiltration of surface water, rather than evacuating it. Grass barriers concentrated flows, thereby trapping sediment and reducing the chance of failure during large rains, compared to earthen structures (Kemper *et al.*, 1992). Coarse-stemmed vetiver (*Vetivera zizanioides*) and switchgrass (*Panicum virgatum*) were effective at trapping sediment behind them, whereas finer stemmed grasses (*Miscanthus sinensis* and *Festuca arundinacae*) were less effective (Meyer *et al.*, 1995). This occurred primarily due to ponding. The finer grasses either were over-topped by the water or parted, allowing the water to pass through.

Barriers containing *Pennisetum* did not generally have a beneficial effect on yield, and barriers consisting uniquely of *Pennisetum* depressed yields of maize and rice (Agus *et al.*, 1999b). Agus *et al.*, (1999a) attributed this to depletion of soil magnesium (Mg), potassium (K), calcium (Ca), and phosphorus (P) by removal of grass prunings from the plot. Soil nutrient status remained unchanged in alley cropping plots with gliricidia. Samsuzzaman *et al.* (1999) reported a depression in crop yield in association with *Pennisetum* and a more rapid depletion of organic C, N, and P when compared to alley cropping with *Senna siamea* or *Gliricidia sepium*. On a 40% slope, barriers of elephant grass (*Pennisetum purpureum*) and imperial grass (*Axonopus escarparias*) reduced cassava yields by 77% and 26%, respectively (Howeler, 1991). Elephant grass and vetiver (*Vetivera zizanioides*) barriers reduced cassava yields at four sites in Colombia (Leihner *et al.*, 1996), with greatest yield reductions usually observed with elephant grass.

Rock Walls

In a study of existing 10-year old rock walls in farmers' fields compared with adjacent cropping areas without rock walls, Toness *et al.* (1998) reported a reduction in runoff from 5.4% of total rainfall to 2.1%. Because sediment had collected to the top of the rock walls, there was not a significant difference in soil loss, which averaged 1.66 Mg ha^{-1}.

Objectives

As our literature review has shown, the effects on crop yields of soil conservation barriers on steep slopes has not been adequately studied, and the results available do not consistently show higher crop yields with the adoption of these conservation practices. This is an important issue because farmers are often assumed to be lazy or irresponsible for not adopting conservation practices that would "obviously" be beneficial to them, and development agencies are often assigned blame for achieving poor adoption of conservation practices by farmers. If, however, adoption of conservation practices does not substantially increase crop yields in the short or medium term, then farmers' failure to adopt might be more understandable, even if undesirable in the long run. Secondly, if the economic returns from installation of conservation barriers do not compensate farmers for the installation and maintenance costs, this needs to be taken into consideration in the extension strategy adopted by development agencies. In designing this research, we wanted to know how alley cropping between tree barriers compared to the more traditional conservation barriers used in Haiti in terms of long-term crop yields. Our hypothesis was that alley cropping (between leucaena barriers), which is a system designed to sustain crop yields through recycling of plant nutrients and additions of organic matter and N, would sustain crop yields at a higher level than rock walls, contour canals, or grass rows. Secondly, we hypothesized that addition of a modest fertilizer would result in additional benefits.

DESCRIPTION OF EXPERIMENT

The trial was conducted at Bois Greffin, Pernier, approximately 5 kilometers (km) east of Pétion Ville. Annual rainfall recorded over an eight-year-period averaged 1,318 millimeters (mm), with a range of 900-1,811 mm. The rainfall pattern is bimodal, with rains occurring from late February until early June and from August through November. The two seasons are separated by a short dry spell from mid June to mid August and a longer dry season lasting from late November to mid February. This rainfall distribution pattern permits two maize crops a year. Based upon average rainfall, the site may be considered intermediate in terms of the range in rainfall conditions within which alley cropping is expected to be practiced in Haiti. However, due to the erratic nature of rainfall, the shallow soil with low water storage capacity, a steep slope, and hot, drying winds, the site was much more drought-prone than would be suggested by annual rainfall totals. Farmers in the area had abandoned maize production for sorghum or irrigated vegetable crops.

The elevation is about 240 m above sea level and the mean annual temperature is 27.5^0 Centigrade (C). The soil is a fine, mixed isohyperthermic Lithic Eutropept (Guthrie *et al.*, 1995) over limestone bedrock. It has a dark brown gravelly clay loam surface horizon with a pH of 8.0 over a dusky red clay B horizon. Depth to bedrock varies but is generally shallow. The site has a north-facing slope of 23-30%. Pre-existing stone walls resulted in terraces with slopes 17-21% at the start of the experiment. These slopes generally moderated over time, because of soil relocation within plots.

During the last three years prior to establishing the trial, carrot (*Daucus carota*) and lima bean (*Phaseolus lunatus*) were planted in the second season following a pasture fallow in first season. In prior years, maize (*Zea mays*), cassava (*Manihot esculenta*), and pigeon pea (*Cajanus cajan*) were planted in the first rainy season, followed by carrots and sweet potato (*Ipomea batatas*) in the second season.

Site Preparation

Trial layout was a major undertaking owing to the rough terrain, comprised of many outcroppings in a shallow soil on steep slope and existing rock walls in parts of the field. Plots of 8 m up and down hill and 7.5 m along contour were laid out in the field in late April 1991. Care was taken to avoid outcroppings or very shallow soil within the main plot area, particularly the harvest area. The upper limit of the plots was determined by the presence of a terrace wall or outcropping. The lower limit was placed at least 1.5 m from the edge of the lower stone wall, if one was present, except for two plots where 1 m was allowed. Where not enough space was available, the lower terrace wall was displaced and soil was filled in behind the new wall. Where no wall previously existed, a wall was built but no fill was added. Where large boulders were present within the plot, these were removed. In some plots where bedrock within 10 cm of the surface could not be avoided, the bedrock was chipped away to allow at least 20 cm of soil at the edges of the plots and considerably deeper in the harvest areas.

The locations of conservation structures were marked out in each plot separately, using a line level to locate the structures along the contour. Two rows of 7.5-m long were spaced 8 m apart, determining at the same time the upper and lower borders of the plot. A third row was located between the other two, leaving alleys of 4 m in the upper and lower parts of the plot. Where the outside contour lines converged or diverged because of variations in slope, the upper and lower rows were adjusted to 4 m above and below the central row. Contour was determined for each plot separately, resulting in irregular field layout. Plots were grouped into three blocks based on position on the slope and other visible soil characteristics, such as color and extent of stone fragments in the soil (see Appendix Figure A.1.). Details of the site preparation and the establishment of different structures of soil conservation are presented in SECID/Auburn PLUS Report No. 30 (Isaac *et al.*, 1995).

Experimental Design

The experimental design was a randomized complete block with three replications. The conservation barrier treatments were: 1.) control without structure; 2.) contour canal; 3.) alley cropping with hedgerows of leucaena (*Leucaena leucocephala*), hereafter called "tree alone"; 4.) alley cropping with rows of *Panicum maximum*, hereafter called "grass rows"; 5.) hedgerows of leucaena and *P. maximum*, hereafter called "tree and grass"; 6.) rock or stone wall; and 7.) alley cropping with leucaena and fertilizer, hereafter called "tree and fertilizer."

Establishment of Conservation Structures

Land preparation in plots with leucaena hedgerows was carried out in the first two weeks of May 1991. A width of about 30 cm was deep-hoed with a pick and leveled with a rake. *L. leucocephala* variety K8 was planted for tree hedgerows on May 16, 1991. Seeds were scarified by cutting the rounded end with a razor blade. Four seeds were planted per hill at a spacing of 0.1 m within rows. Seedlings were thinned to one per hill at approximately six weeks after planting. Because of drought following planting, hand irrigation was applied on June 17 and 25, 1991, 2.5 liters per meter row to ensure survival of the seedlings until the next rainy season.

Panicum maximum grass was planted 4 m apart on contour in September 1991 following deep tillage as described above. Stem cuttings of approximately 15 cm long with two or three nodes were planted at a 20-cm spacing within row. Where leucaena was planted together with grass, the grass rows were located 25 cm downhill from the leucaena hedgerows.

The stone walls were laid out on contour in September 1991. Furrows were dug approximately 15 cm deep to form a foundation, and the walls were constructed to a height of approximately 25 cm above the soil level at a width of approximately 30 cm. No mortar was used, and the structure's strength was achieved by careful positioning of the rocks and giving a back-tilt of the structure to counter the effects of gravity. The walls were built up over time to keep up with soil accumulation behind the walls.

The contour canals were established in mid-March 1993 after the first soil preparation prior to planting maize. Furrows of 30 cm in width (15 cm up and down of the corresponding line of hedgerow) were dug to a depth of approximately 25 cm. The soil from each canal was spread on both sides of the canal at the start of the first cropping season. In subsequent cropping seasons, the soil from the central and lower canals was redistributed respectively in the upper and lower parts of the plot. Maize residues were placed into the canals. The canals were maintained in the same positions until Season 14, after which the positions of the canals were rotated in the plots seasonally in order to spread the benefits of crop residues throughout the plots.

Hedgerow and Grass Management

The leucaena hedgerows were approximately 22 months old at the start of the experiment. Hedgerows were pruned to a 50-cm height, beginning approximately ten days before the first maize seeding. The prunings were applied as mulch in the inter-hedgerow spacings, or alleys. The first pruning took place between March 11 and March 17, 1993, on leucaena hedgerows of approximately 4 m in height. In subsequent cropping seasons, the first pruning was made a few days prior to planting maize. During the first two seasons, one more pruning was carried out 35 days later. Three prunings per season were carried out during later seasons, with target intervals of 0, 30, and 60 days after planting of maize. The unpredictability of rainfall and the demands of other trials made it difficult to adhere strictly to that schedule, especially at planting time (see appendix tables A1 and A2)). Timing of the third pruning often coincided with or slightly preceded silking by the maize.

The grass was pruned at ground level at each cut and the prunings were applied as mulch to the soil surface. During each cropping season, the first pruning took place approximately one day prior to planting maize. The pruning frequency used for grass species was the same as that used for leucaena hedgerows.

At harvest of hedgerows, prunings were divided into leaves, green stems less than 1 cm in diameter, stems 1-5 cm in diameter, stems greater than 5 cm in diameter, and pods. Fresh weight of each component was determined separately in the field. Samples of fresh biomass of each component and leaves of *P. maximum* grass were oven-dried at 71.0^0 C for dry matter determination. Analysis of variance was calculated for the total of cuts made during each cropping season using the Statistical Analysis System (SAS).

Maize Crop

Two maize crops per year were grown. March plantings were harvested in June or July (first rainy season, or Season A) and August plantings were harvested in December (second rainy season; Season B). Initial start of cropping was to have begun in March 1992, but was delayed for one year because of project suspension due to political events. Approximately one month prior to the initial planting, the first soil preparation was made with hoe and pick and the plant residues left on the soil surface. In subsequent seasons, the first soil preparation took place approximately fifteen days before seeding of maize. A second soil preparation with a hoe was done on all plots approximately three days before maize planting. In alley plots, harvested leaves and green stem biomass (referred to as prunings) were returned to the soil surface as mulch. In subsequent seasons, residue from the previous maize crop was incorporated into the soil with the first soil preparation. Timing and dates of field operations are listed in Appendix Tables A1 and A2.

A local population of maize was seeded in rows spaced 80 cm apart and 40 cm within row. Eight rows of maize were planted in the alley plots with leucaena or grass (four in each alley) and ten rows in the stone wall, contour canal, and control plots, respectively (Figure 1). The harvest area was 5.5 m by 8 m. Three seeds were planted per hill. Fifteen days after planting, the maize was thinned to one plant per hill, giving a population density of 25,000 plants ha^{-1} in the alley-cropped and grass plots and 31,250 plants ha^{-1} in the other plots during the first six cropping seasons. In the seventh season, the maize was thinned to two plants per hill, giving a density of 50,000 plants ha^{-1} in the alley-cropped plots and 62,500 plants ha^{-1} in the other plots. In the tree plus fertilizer treatment, 250 kg of a 15-15-15 compound fertilizer was applied to the maize in hill at planting, giving approximately 37.5 kg N, 37.5 kg P_2O_5, and 37.5 kg K_2O ha^{-1} during the first five cropping seasons. From the sixth season, 200 kg of a 20-20-10 compound fertilizer was applied to the maize, giving approximately 40 kg N, 40 kg P_2O_5, and 20 kg K_2O ha^{-1}. In seasons 15, 16, and 17, a basal dose of 18.4 kg P_2O_5 was applied to all plots. Nitrogen was not applied in these seasons. Also, beginning in Season 15, the number of rows of maize planted in the alleys of rock wall and canal treatments were reduced from five to four. The position of the canal was also rotated seasonally in order to spread the benefits from the residues in the canals around the plots.

Weeds were controlled by means of machetes. Up to two weedings were carried out per season depending upon the weed pressure. In seasons of extreme drought, only one weeding was carried out. Maize was grown during season A and season B.

Observations

Maize plants were counted after thinning and at harvest. Data recorded at harvest included grain yield, adjusted 13% moisture, percent lodging, number of ears harvested, number of fertile plants per harvest area, maize height, and fresh weight of ears. Percent moisture of harvested grain was determined by means of a grain moisture tester.

Soil samples were collected from the 0- to 5-cm, 5- to 10-cm, and 10- to 20-cm depths during January 2000, following 14 seasons of continuous maize cropping. The samples were analyzed for organic C and total N via combustion with a Leco CHN-600 autoanalyzer.

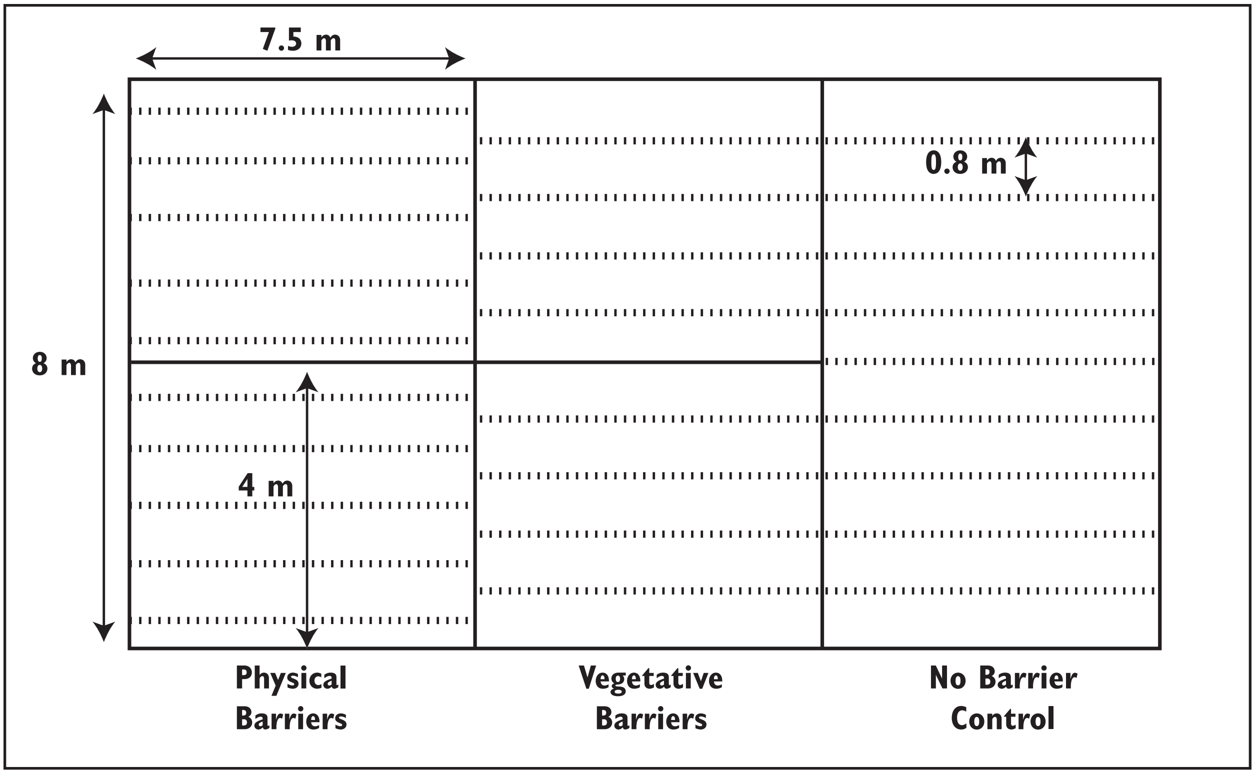

Figure 1. Schematic diagram showing plot layout and relative positions of conservation barriers (solid lines) and maize rows (dotted lines).

RESULTS AND DISCUSSION

Rainfall Conditions and Crop Yield

Yields fluctuated greatly between seasons, largely owing to seasonal differences in total rainfall and rainfall distribution (Figure 2). Seasons 15-17 are omitted from this and subsequent figures because of changes in fertility management, but yield data are presented in Appendix Table A3. Complete crop loss due to drought occurred in seasons 8, 9, and 15. Although total rainfall for the site averaged 1,318 mm, the shallow soil depth, steep slope, high evapo-transpiration, and erratic rainfall distribution combine to make this a highly drought-prone site.

An assessment of daily rainfall records reveal that drought stress was experienced in all seasons. Seasons 2, 4, 10, 12, and probably 14 were characterized by insufficient rainfall during the critically important tasseling period (Figure A.2). With the exception of Season 2, which benefited from residual soil fertility, these seasons were characterized by yields under 1 metric tonne per hectare (Figure 2). Drought during silking may explain the low average yields in Season 6, although rainfall also appeared to be inadequate during silking in seasons 7 and 13, seasons which had relatively higher average yields. Highest yields were recorded in seasons 1, 7, 11, and 13. Rainfall appeared to be inadequate during grain filling in seasons 1, 7, and 11, but appeared to be adequate during the critically important period of tasseling.

Yield Responses to Conservation Practices

Yields tested significant in all but Season 5, which had drought episodes in the vegetative stage, at tasseling, and again during late grain fill, and Season 6, which had drought during the late vegetative stage and during grain fill (Table A.3). In seasons 8, 9, and 15 no test was possible due to total crop failure. Highest yields in the first season were recorded for the stone wall, control treatment without conservation practices,

Photo 1. Ridging on steep slope at Palmiste-à-Vin, Southeast Haiti. Crops included intercropped maize, sorghum, bean, cowpea, occasionally cassava and pigeon pea. Residues from previous season are incorporated into ridges.

Photo 2. Rock walls are used for soil conservation in areas with limestone bedrock, where rocks are plentiful. This community in Bannate, Southern Haiti, received assistance from USAID.

Photo 3. Rock walls are found more frequently where high-value crops are grown. This photo was taken near Fort Jacques, south of the capital, Port-au-Prince. Vegetables are grown here to serve the urban market.

Photo 4. Soil displaced by tillage and water erosion rapidly accumulate behind rock walls to form terraces. These rock walls are less than two years old. Pernier, Haiti.

Photo 5. Residue barriers (*rampes pailles*). Note stakes in ground to hold barrier. Most residue barriers are not this tall or elaborate. Nan Paul, Northwest Haiti.

Photo 6. This farmer in Bannate, Southern Haiti, practices contour alley cropping with hedgerows of *Leucaena leucocephala*. Prunings are applied to the soil and fed to livestock.

Photo 7. Hedgerows of *Leucaena leucocephala* at Bannate, Southern Haiti.

Photo 8. Branches are placed at the base of the hedgerows on the uphill side in order to reinforce the barrier. Pernier, Haiti.

Photo 9. Contour alley cropping with tree hedgerow barriers of *Leucaena leucocephala.* Maize was fertilized in this plot. Season 14.

Photo 10. In tree/grass barriers, growth of *Panicum maximum* grass was suppressed by vigorous growth of leucaena. Season 14.

Photo 11. Maize row uphill from contour canal may suffer from drier soil conditions and root exposure as soil falls into canal.

Photo 12. Rock wall barrier in 14th season. Note stunted and missing plants below rock wall due to shallow soil over bedrock.

The effects of conservation barriers on maize after 17 seasons continuous cropping. All plots shown received no fertilizer during the first 14 seasons and a low rate of phosphorus during seasons 15-17. Treatments are:
Photo 13. Leucaena tree barriers (alley cropping).
Photo 14. No barrier control.
Photo 15. Grass barrier,
Photo 16. Rock wall barrier.

and contour canal treatments (Figure 2). This was due in large part to the 20% loss in cropping area in plots with vegetative barriers. However, yields in the control and the physical barrier treatments rapidly declined, such that by the fourth season, these treatments ranked among the lowest yielding in the trial. The grass barrier treatment also gave declining maize yields over the first four seasons, whereas maize yields in the three alley cropping treatments containing leucaena trees remained stable or increased slightly over the same period. The tree barrier alley cropping treatment receiving a moderate rate of fertilizer yielded highest from the third season onward. By the 13'th and 14'th seasons, the two unfertilized alley cropping treatments gave maize yields that consistently ranked higher than those associated with the remaining conservation barriers and the control treatment. This ranking was maintained in the seasons 16 and 17, when all plots received an equal amount of phosphate fertilizer (Table A.3). Although the rock wall treatment did not differ significantly from the unfertilized alley cropping treatments in any given season, it consistently yielded less from Season 6 through Season 17. With greater precision, as might have been achieved from a fourth replicate in the trial, there can be little doubt that these differences would have tested significant.

In Figure 3, seasonal variability is eliminated by standardizing yields to the control (no barrier) treatment. Maize yields in the unfertilized alley cropping treatments ranked higher than the control in Season 4 and from Season 6 onward, despite the lower maize density. An exception occurred in Season 12, where the control treatments gave maize yields higher than the unfertilized tree hedgerow treatments. In this season, there was a 16-day gap between first pruning and planting, and the second pruning was carried out late, such that the interval between first and second pruning was 57 days (Table A.2). It is likely that the combined effects of drought and inadequate pruning regime contributed to competition between the hedgerows and maize for water, as well as light and nutrients, resulting in lower yields in the alley-cropped plots than in the control. Similar problems in Season 10, and to a lesser extent in Season 11, may explain the similarity in yields unfertilized alley cropping and control (Figure 3 and Figure A.2).

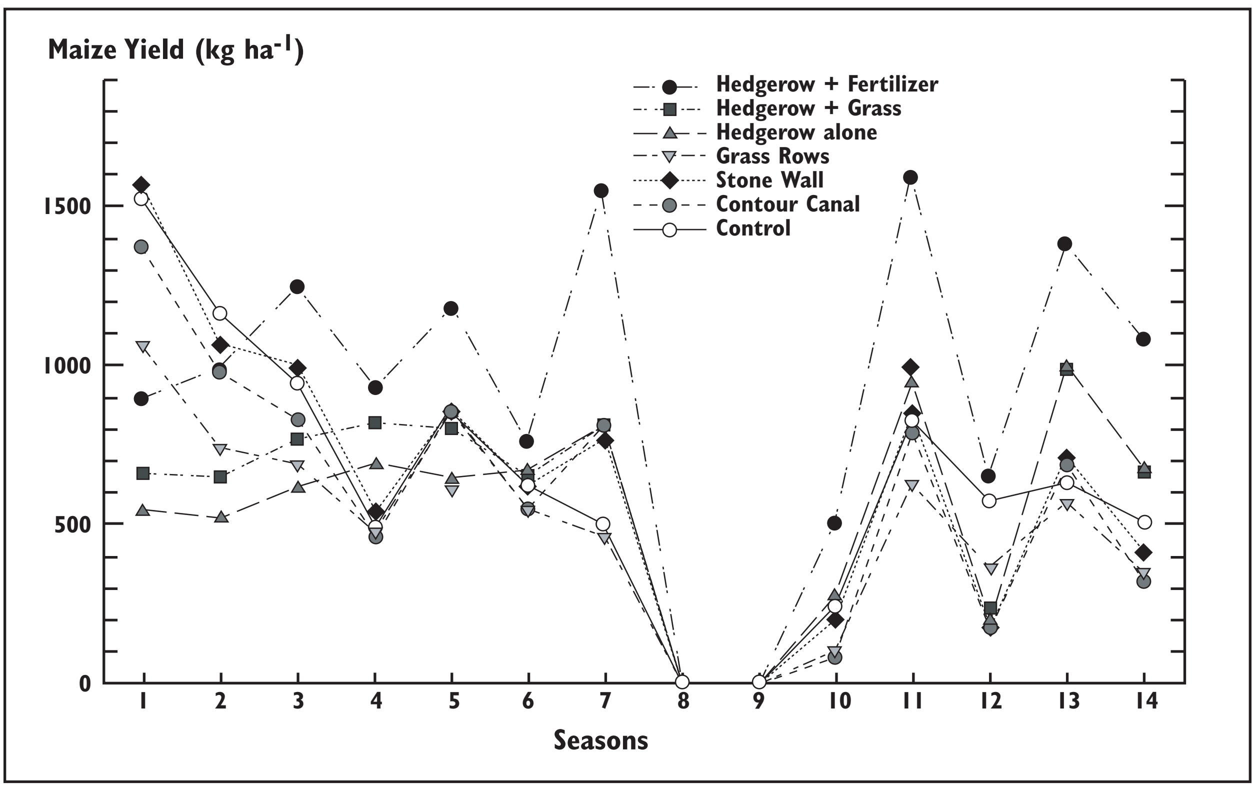

Figure 2. Maize yields under various soil conservation practices over 14 seasons. Pernier, Haiti. 1993-1999.

Comparing the four types of conservation barriers without fertilizer, tree hedgerows managed for alley cropping provided a substantial yield benefit in three seasons, rock walls and contour canals in one season, whereas grass, also managed for alley cropping, never out-yielded the no-barrier control. In Season 12, the control treatment gave higher maize yields than any of the barrier treatments. The control also out-yielded alley cropping with tree barriers during the first three seasons. The fertilized alley cropping treatment, not shown, out-yielded the control in all but the first two seasons.

Alley cropping with tree and grass, also not shown in Figure 2, gave similar results to that shown for tree alone (Figure 2). In the initial seasons, there was a slight advantage over tree alone due to additional biomass provided by the grass, but this advantage diminished as vigorous growth by the leucaen-hedgerows suppressed growth of the *Panicum maximum* rows.

Average Yield Over 14 Seasons

In order to further simplify the data presented in figures 2 and 3, mean maize yields across all seasons were computed for each treatment (rear bars in Figure 4). When averaged over all 14 seasons, including the two seasons in which no grain was harvested, only the treatment receiving fertilizer gave higher maize yields than the control. No yield advantage was shown for rock walls or contour canals, while tree or grass barriers managed for alley cropping gave, on average, lower yields than the control. It thus appears from this analysis that farmers will have no economic incentive to apply any of the soil conservation practices on similar sites. However several factors must be considered. Firstly, the first maize crop followed a fallow peri-

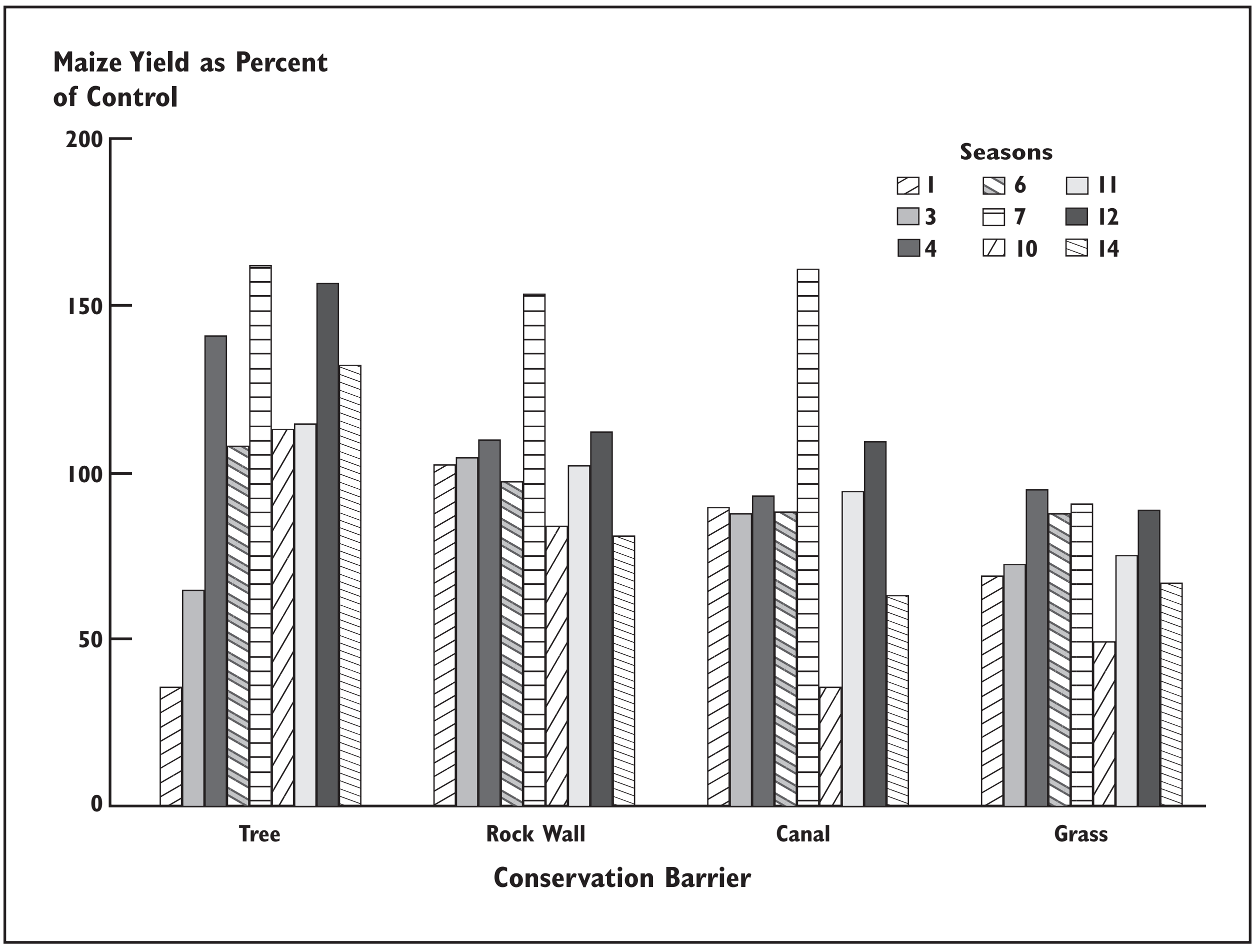

Figure 3. Yield of maize with different soil conservation barriers, expressed as percentage of no-barrier control treatment. Tree hedgerows and grass barriers were managed for alley cropping. Pernier, Haiti. 1992-1999.

od of nearly two years, during which the primarily grass vegetation was allowed to grow with very little disturbance by livestock. This is atypical of Haitian agricultural practices, where "fallows" are very heavily grazed, often to within centimeters of the soil surface, thus providing little opportunity for buildup of organic matter and nutrients in the soil surface. This is also typical of conditions in many other densely populated tropical steeplands. Thus the high yields recorded for control, rock wall, and contour canal treatments during the first two seasons reflect, in part, soil fertility conditions that would not be representative of the normal farm conditions under which soil conservation structures would be established. Also, because the tree hedgerows were nearly two years old at the start of maize cropping, they provided more competition than would be normal, without the benefits of a buildup in fertility associated with the tree-based conservation barriers. By eliminating from consideration the first two seasons, which bias the results against the tree barriers, the tree barriers without fertilizer gave slightly higher mean yields than the other conservation barriers and no-barrier control (front row of bars in Figure 4). The rock wall treatment gave a mean yield similar to the control treatment and higher than the grass and contour canal barriers.

How drought influenced barrier effects on yields

One of the defining characteristics of the Pernier site in terms of plant growth is the high probability of drought stress within the growing season. This is reflected in the low maize yields. In only four seasons did treatment mean yields surpass 1,500 kg ha^{-1}, while during six seasons, no treatment attained 1,000 kg ha^{-1} (Figure 2). Two of these seasons represented total crop failures. An examination of treatment yields

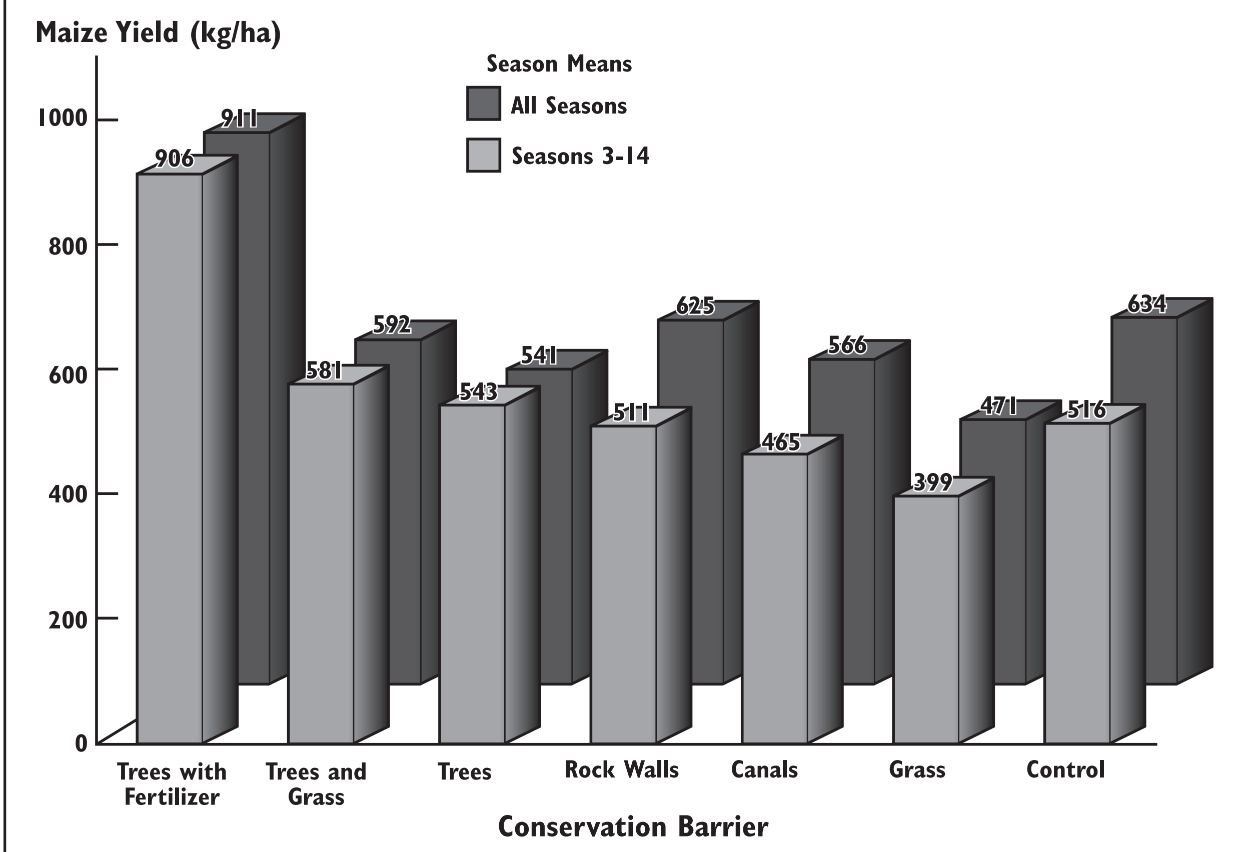

Figure 4. Maize yields averages over 14 and 12 seasons for conservation barriers consisting of trees with fertilizer applied to the crop (T/F), trees and grass (T/G), trees, rockwalls, canals, grass, and no-barrier control. Biomass from trees and grass were applied to alleys. Pernier, Haiti. 1993-1999.

averaged over the best and worst seasons presents a different picture with respect to treatment effects (Figure 5). Seasons 1 and 2 were eliminated from the assessment for the reasons described previously. Seasons 3, 5, and 14 were considered intermediate and omitted. During the six seasons for which drought stress was the most limiting, especially during tasseling, alley cropping between tree barriers gave yields equivalent to that of the control and rock wall treatments, and apparently superior to the grass and canal barriers. If Season 14, which had drought towards the end of tasseling and generally poor rainfall (Figure A2), is included among the worst seasons, then alley cropping averages 5% higher than the control and 32% higher than the rock-wall treatment. In the seasons in which rainfall was least limiting, the tree barriers were clearly superior to rock, canal, or grass barriers, as well as to no barriers. Hence, at sites less drought prone than Pernier, an outcome favorable to tree barriers may be expected on a more frequent basis. Addition of a moderate dose of fertilizer to the maize increased maize yields by 63% in the best seasons and by 49% during droughty seasons, although the latter increase was insignificant in absolute terms.

Effect of Conservation Practices on Soil Quality

Soil organic carbon (C) is an important measure of soil quality or soil health, while N is important to plant nutrition. Soil samples collected from the 0- to 5-cm, 5- to 10-cm, and 10- to 20-cm depths from each plot following 14 seasons of continuous cropping provide an indication of the effect of conservation practices on soil quality. Although mean differences for organic C at all depths and for N at the 10- to 20-

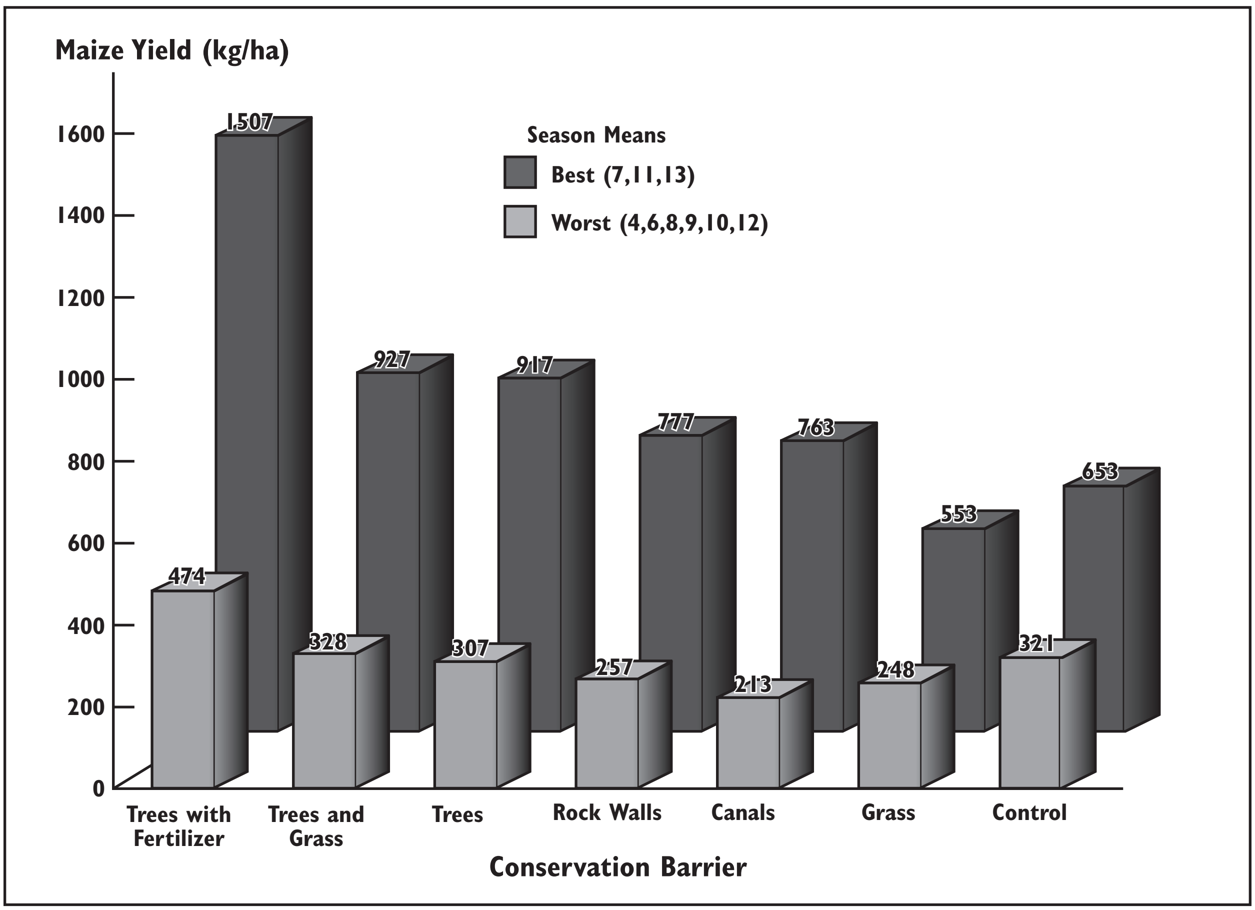

Figure 5. Maize yields averaged over best and worst seasons, when grown with conservation barriers of trees with fertilizer applied to the crop (T/F), trees and grass (T/G), trees, rock walls, canals, grass, and control without conservation barrier. Biomass from trees and grass were applied to the alleys. Pernier, Haiti. 1993-1999.

cm depth did not test significant by the F-test, important trends did test significant in one degree of freedom (df) comparisons (see table). The lack of a significant F test is in part related to the low number of repetitions in the trial.

Alley cropping with leucaena trees sustained organic C at higher levels at the 0- to 5- and 5- to 10-cm depths and N at all depths measured (see table). Application of fertilizer to the tree alley cropping treatment did not significantly affect organic C and N except for a slight decrease in N at the 5- to 10-cm level. Alley cropping without fertilizer resulted in higher organic C and N than did other conservation practices. Alley cropping without fertilizer gave higher soil organic C levels than did grass barriers, but there were no differences between alley cropping and rock walls or contour canals for organic C. This implies that grass barriers were less effective at sustaining soil organic C than were rock walls or contour canals. This was not anticipated, since grass leaves were returned to the soil surface when pruned, whereas the only biomass returned to the soil in the rock wall and canal treatments were from maize stover and weeds. Perhaps the lower amount of maize stover obtained with the grass rows compared to other treatments may explain the lower organic C levels in this treatment. Alley cropping without fertilizer gave higher soil N levels than either grass or rock walls and contour canals. The rock walls and contour canals gave slightly higher soil N concentrations than the control at the 5- to 10-cm depth.

In summary, alley cropping using tree barriers was the conservation practice most effective at maintaining soil organic matter content and N content in the soil. Grass rows appeared to be less effective than even rock walls and contour canals at maintaining these soil quality parameters.

Summary of Conservation Barrier Effects

The yield data presented in figures 2-5 represent complex, dynamic processes involving seasonal differences in weather patterns, changes over seven years in soil nutrient status, changes in plant maturity, and spatial changes in soil distribution. The various barrier treatments interacted differently with these various factors The treatments are illustrated in photos 9 - 16.

The Effect of Soil Conservation Practices on Soil Organic C and Total N by Depth (cm)

Conservation practice	Organic C			Nitrogen		
	0-5	5-10	10-20	0-5 cm	5-10	10-20
		%			%	
Tree plus fertilizer (alley cropping)	3.16	3.10	2.77	0.123	0.113	0.110
Tree and grass (alley cropping)	3.34	3.08	3.03	0.130	0.123	0.117
Tree (alley cropping)	3.07	3.10	2.95	0.133	0.123	0.120
Rock walls	2.96	3.92	2.79	0.107	0.117	0.103
Contour canals	2.94	2.99	2.63	0.110	0.117	0.100
Grass row	2.81	2.63	2.63	0.107	0.103	0.103
No barrier control	2.72	2.62	2.77	0.107	0.107	0.103
Significance (F test)	ns	ns	ns	***	*	ns
$LSD_{0.05}$	ns	ns	ns	0.015	0.014	ns
CV %	8.4	9.8	11.3	7.2	6.7	12.3
1 df Contrasts						
Tree vs no tree	**	*	ns	***	*	*
Tree plus fert. vs tree (no fert.)	ns	ns	ns	ns	0.1	ns
Tree (no fert.) vs no tree[a]	*	0.1	0.1	***	**	*
Tree (no fert.) vs other Conservation practice[b]	*	ns	0.1	***	*	*
Tree (no fert.) vs (rock, canal)	ns	ns	ns	***	ns	*
Tree (no fert.) vs grass	*	*	ns	***	***	ns
Grass vs (rock, canal, cont.)	ns	ns	ns	ns	0.1	ns
Control vs (rock, canal)	ns	ns	ns	ns	0.1	ns

ns, *, **, *** Not statistically significant, significant at the 0.05, 0.01, and 0.005 levels of probability, respectively.

[a]Control included.

[b]Control excluded.

No Barrier

The yield of maize in the no-barrier control treatment declined by 68% during the first four seasons (Figure 2), fluctuating around a mean yield of 500 kg ha^{-1} for the remainder of the period (ignoring seasons with total crop failures). The initial decline was undoubtedly related to the decomposition of organic matter and residues associated with the previous cover crop. The soil at the Pernier site has a CEC of 58 cmolc kg^{-1} and an organic matter content of 10% (Guthrie et al., 1995), indicating a large reservoir of nutrients. The uniform distribution of soil over the field provided the control treatment with some advantages over the conservation barriers, as discussed below.

Grass Barriers

As with the tree barriers, the grass was regularly pruned, and the clippings applied to the soil, so as to recycle plant nutrients and to contribute organic matter to the soil. Maize yields with grass barriers were consistently lower than with the no-barrier control (Figure 3), and were lower, on average, than with the other barrier treatments. The 20% loss in area available to the maize crop explains much of this difference. Since the grass residues were not removed from the plots, nutrients taken up by the grass were recycled. Despite this, organic matter and N was not maintained in the soil (see table). Had the grass leaves been removed as forage, the nutrient status of the plots would have declined to a greater extent.

Competition from the grass appeared to be low, even during droughty seasons (Figure 5). The low competition from grass may be attributed to the lack of vigorous growth on the part of the grass species used in this trial. Panicum maximum is a popular forage bunch grass that grows to approximately 1 m in height. It does not form the most effective barriers, because of its small stems, but was chosen instead of Pennisetum purpureum, more commonly used as a soil conservation barrier, because it was assumed that vigorous growth and tall habit of the latter species would provide greater competition to the maize crop. Had Pennisetum or another of the larger grasses been used as the conservation barrier, maize yields would most likely have been lower than that obtained with P. maximum. Agus et al. (1999b) reported that maize yields planted with four-year-old barriers of Pennisetum purpureum were 26% of control yields. Addition of 60 kg N ha^{1} had only a small effect on maize grown with the grass. Howeler (1991) and Leihner et al. (1996) also reported significant competition from Pennisetum. Although grass barriers may be effective for soil conservation, farmers should not expect a benefit in terms of yield of associated crop. For grass barriers to be economically viable, the benefit from use of the grass erosion control barriers would have to be greater than the loss in production by the associated crop.

Contour Canals

Unlike the grass treatment, the same population of maize was planted with contour canals as in the no-barrier control. Despite that fact, only in Season 7 were maize yields in the canal treatment substantially higher than that in the control (Figure 3), and this difference was not statistically significant. Averaged over the best seasons, maize yields in contour canal plots were comparable to those with rock walls and slightly higher than with no barrier, but during very droughty seasons, maize yields averaged lowest for the trial. This was surprising, because one would have expected the canals to improve soil moisture status by trapping what rain there was, and therefore should have given higher yields than the control and grass treatments.

One of the reasons for lower yields in contour canal plots than in the control plots was the fact that the maize rows directly above the canals were apparently affected by soil movement into the canals, leaving the maize roots next to the canal exposed (Photo 11). Although during the course of the season, soil was gathered from the canals and thrown back onto the adjacent maize row, development of the maize plants was affected and yields were lower in these rows. The control plots had uniform seedbeds and therefore were not subject to this problem. Another reason may have been the shallow soil depth. Contour canals may be effective at trapping surface water and increasing infiltration, but on a shallow soil the water holding capacity is limited and any benefit in terms of infiltration may be counteracted by increased evaporation from the extra surface area to which the soil is exposed.

Rock Walls

Only in Season 7 did maize yields with rock walls substantially surpass those of the no-barrier control (Figure 3). That difference was not significant by the LSD test. As with the canal treatment, maize seeding densities were identical to that of the control. In Season 12, which was characterized by drought at tasseling and early silking, yield in the rock wall treatment tested significantly less than in the control. This is contrary to what might be expected, since the terracing effect and rock wall barriers should enhance retention of runoff. This can be explained by the shallow depth to bedrock, which, with water and tillage erosion, resulted in exposure of bedrock at the extreme top of the alleys. The maize in the upper two rows in the alleys had very little soil volume and hence was very vulnerable to drought (Photo 10). Under adequate rainfall, these rows were able to produce, but under conditions of drought, most of the grain was produced in the lower three rows of the plots. Thus, although rock walls were very effective at stabilizing soil, overall, they did not increase maize yield at Pernier, due to loss of cultivable area.

Tree Barriers (Alley Cropping)

The trees were nearly two years old, and had grown to a height of approximately 4-6 m prior to first pruning. Hence, when the trial was initiated, the vigorously-growing trees provided substantial competition for water and nutrients, while the benefits from soil application of the prunings had not yet accrued. During the first two seasons, maize yields with the tree barriers were the lowest in the trial (Figure 2). The 65% loss in yield cannot be explained by the 20% reduction in plant numbers and must be attributed primarily to competition from the trees. However, while yields during the first four seasons declined in the control, rock wall, canal and grass plots, yields in the tree plots appeared to increase. In the third season, tree hedgerow pruning was increased from two to three prunings per season, which, together with the cumulative benefits of biomass applications to the soil, may explain the apparent increase in maize yields in seasons three and four. During seasons most characterized by drought, the average yields with alley cropping of tree barriers were similar to those of the no-barrier and rock wall (Figure 5), whereas in the best seasons the average yields with alley cropping were superior to that of rock walls, canals and the no-barrier control. This implies that in areas where drought is common, alley cropping in tree hedgerows can be expected to give comparable yields to those obtained with rock walls or no barriers, but in areas where rains are reliable, higher yields may be anticipated with alley cropping. Photos 13-16 illustrate the long-term superiority of alley cropping with leucaena over other conservation barriers.

Tree/grass Barriers (Alley Cropping)

The trend in maize yields with tree/grass barriers was similar to that obtained with trees alone (figures 2 and 5). In the early seasons, a slight yield advantage was recorded for tree/grass barriers over trees alone. This difference is associated with a higher biomass yield obtained from trees and grass, but the difference narrowed over time (Figure 2) as the productivity of the grass declined over time, presumably due to the shade from the associated trees (Photo 12).

Tree Barriers with Fertilized Crop (Alley Cropping)

Application of N-P-K fertilizer had the greatest effect on maize yield (figures 2, 4, and 5). Only in the first season did the control yield significantly higher than fertilized alley cropping treatment. In the three best seasons, fertilization in the tree barrier treatment increased grain yield by an average of 580 kg ha^{-1}.

This soil is extremely low in P (Guthrie et al., 1995) and the high pH limits its availability. Biomass applications do not provide sufficient P to sustain maize production at a high level (Haggar et al., 1991; Lupwayi and Haque, 1999). Studies currently underway should provide information on whether there is a synergistic effect of biomass application on P uptake in maize. In a study on an Alfisol in Congo, alley cropping and fertilizer effects on yield were additive (Shannon et al., 1994). However, this soil did not have the chemical properties associated with high P fixation.

Fertilizer application by low resource Haitian farmers is not common on maize, although fertilizers are used on high value vegetable crops. These results suggest that its application on maize may be economic in areas of Haiti where rainfall is adequate, particularly in conjunction with contour alley cropping.

SUMMARY AND CONCLUSIONS

In seasons when drought stress conditions were severe, none of the soil conservation practices without fertilizer substantially increased maize yield on a total area basis compared to the no-barrier control. In seasons where drought stress was less limiting (and excluding the initial two seasons in the trial), tree barriers (alley cropping) without fertilizer provided 40% higher yield than no barrier, whereas rock walls and contour canals provided 20% and 17% higher yield, respectively. In addition to higher yields, alley cropping was the only practice that sustained crop yields over time. It also sustained soil N and organic C at higher levels than did other conservation practices. Use of contour canals depressed yield in droughty seasons. Grass barriers resulted in decreased yields under all conditions and had the lowest soil N and organic C concentrations. Fertilizer application in contour alley cropping substantially increased yield over alley cropping alone.

These comparisons are based on total field area. In all barrier systems tested, cropping area was eventually reduced. If yield estimates are based upon productive cropping area, the conservation practices compare more favorably with the control. It is also important to point out that these results were obtained on a shallow soil under drought-prone conditions. On deep soils and also under more reliable rainfall conditions, productivity in the upper areas of alleys or terraces would not have been reduced as dramatically as they were on the shallow soil. Shallow soils are nevertheless common on mountain slopes in Haiti.

It is easy to see from this data why low resource farmers are reluctant to invest in soil conservation structures on their own, regardless of the type. Under drought-prone conditions, the economic benefit from a sizeable labor investment is likely to be negligible, at least in the short to medium term. Even in the best seasons, soil conservation alone was not nearly as effective at increasing crop yield as was fertilizer application. Pandey and Lapar (1998), evaluating adoption of various conservation hedgerows in the Philippines, concluded that without access to improved technology and better marketing infrastructure, farmers are not likely to view soil conservation practices as economically beneficial. They recommend that farmers shift from subsistence to high value crops in order to improve the returns to investment in soil conservation. An integrated approach that seeks to increase economic output per unit land is more likely to result in successful adoption of soil and water conservation practices than by focusing solely on reducing soil erosion.

Reducing soil erosion is not sufficient to sustain crop yields on steep slopes. Soil erosion control should be accompanied by efforts to improve soil fertility. For low resource farmers, contour alley cropping is the best alternative among those tested for soil conservation on tropical steeplands, because it sustains soil organic matter and N at a higher level and thus sustains crop yields over time, while also reducing runoff and soil erosion. To sustain yields at higher than subsistence levels will require application of fertilizers to correct nutrient deficiencies.

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Appendix
Figures and Data Tables

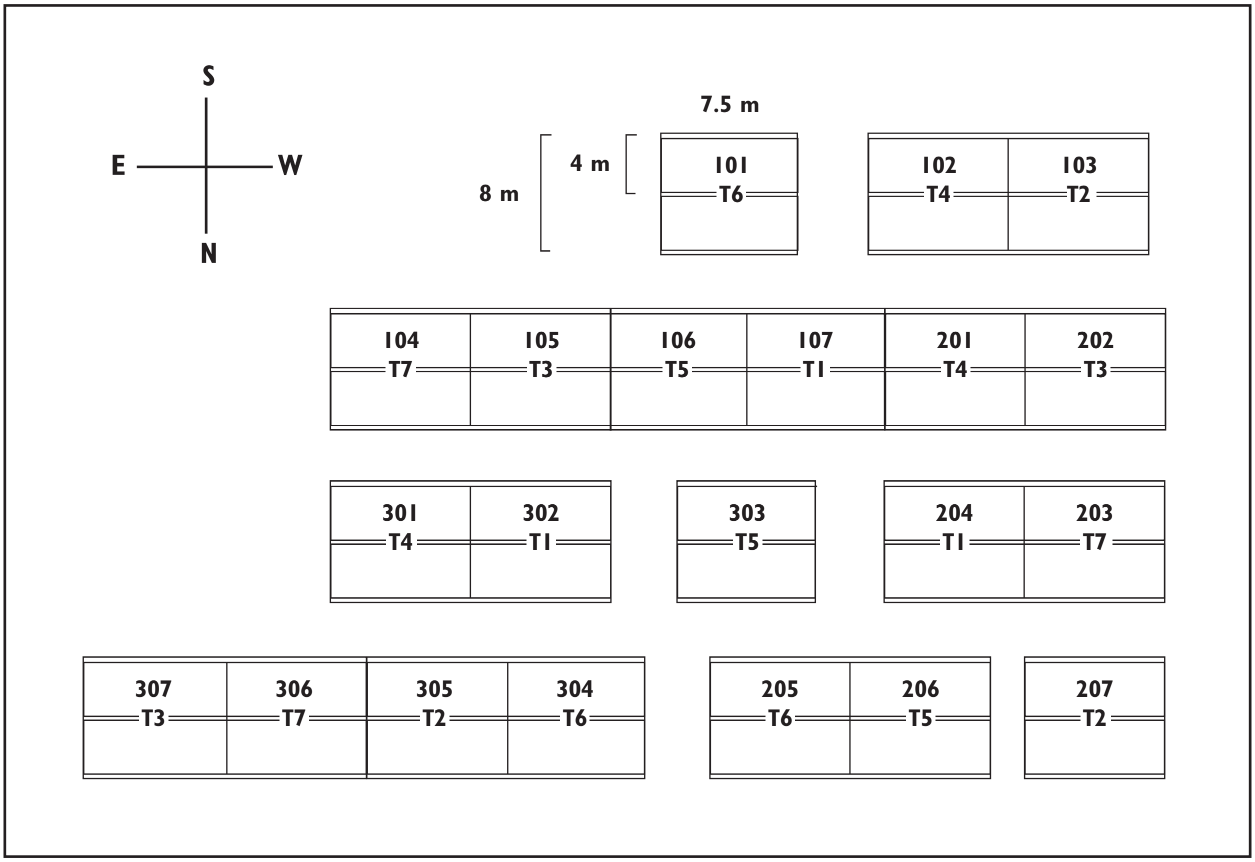

Figure A1. Plot plan showing approximate layout of plots and treatments in field in Pernier, Haiti. The block is indicated by the first digit in the plot number. T1 = no barrier control; T2 = contour canal; T3 = tree alone; T4 = grass; T5 = tree and grass; T6 = rock wall; T7 = tree + fertilizer.

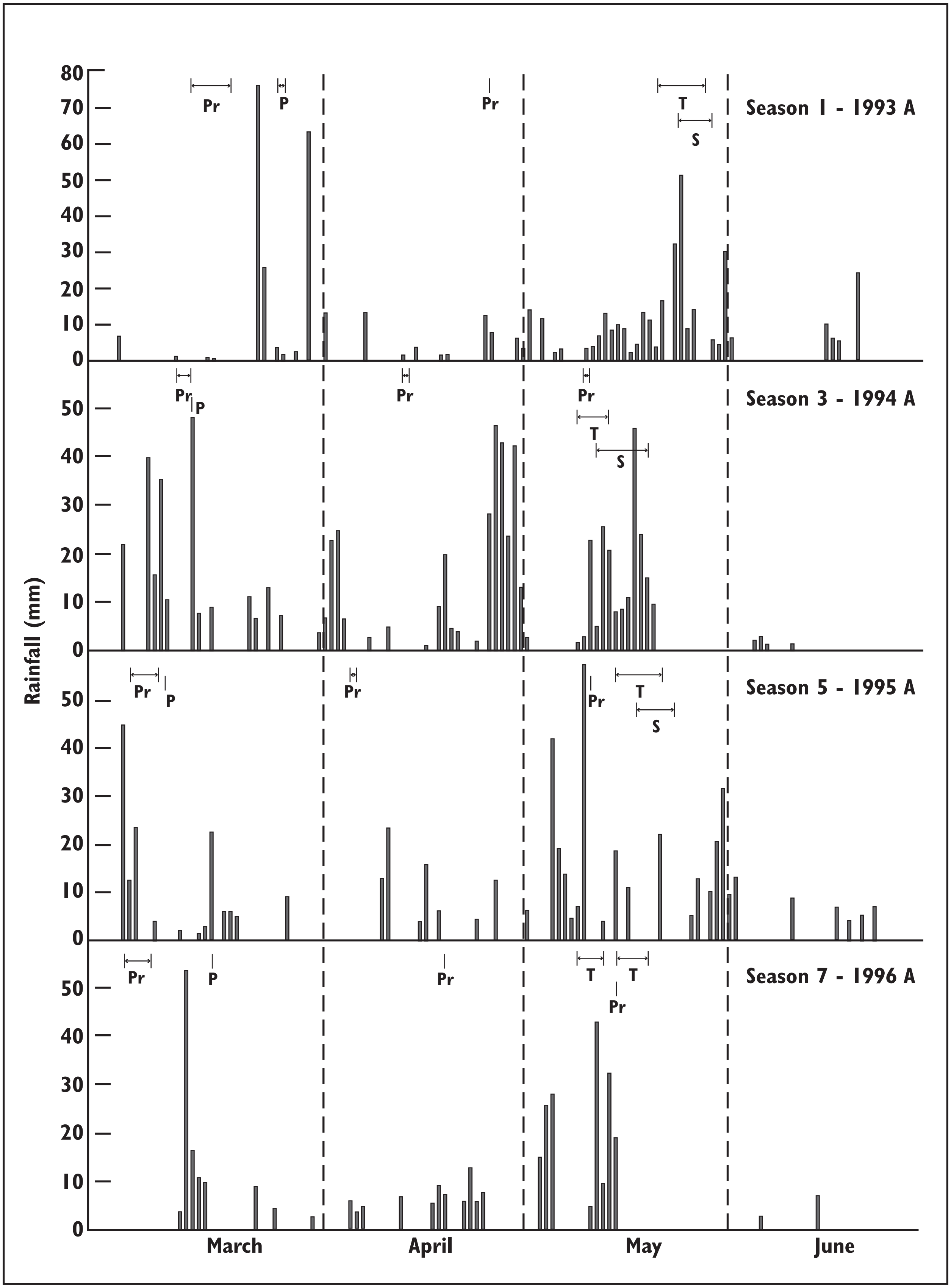

Figure A2. Rainfall distribution pattern at Pernier, Haiti, and timing of planting (P) and pruning (Pr) operations with respect to rainfall and tasseling (T) and silking (S) dates in the experiment.

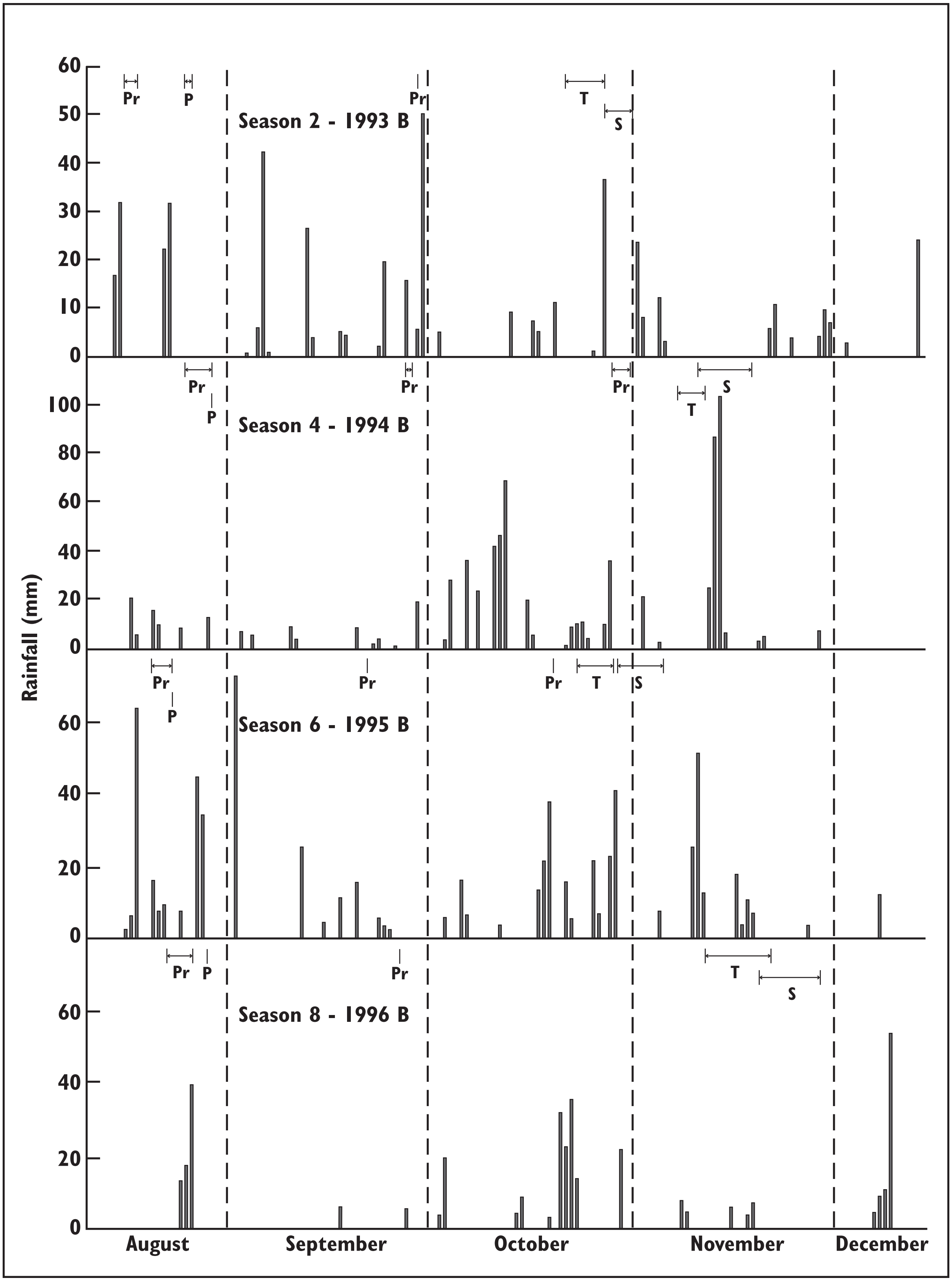

Figure A2, continued. Rainfall distribution pattern at Pernier, Haiti, and timing of planting (P) and pruning (Pr) operations with respect to rainfall and tasseling (T) and silking (S) dates in the experiment.

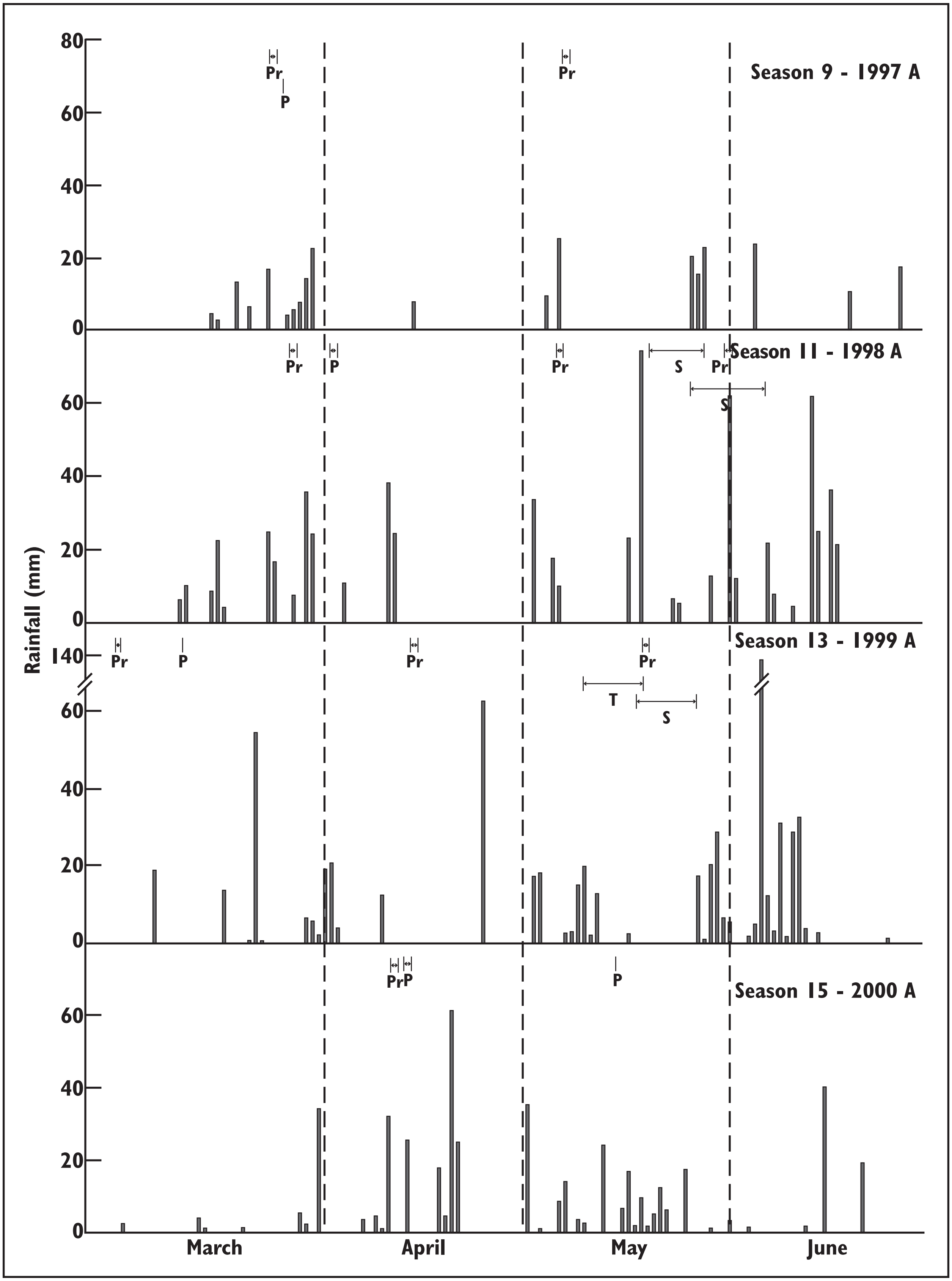

Figure A2, continued. Rainfall distribution pattern at Pernier, Haiti, and timing of planting (P) and pruning (Pr) operations with respect to rainfall and tasseling (T) and silking (S) dates in the experiment.

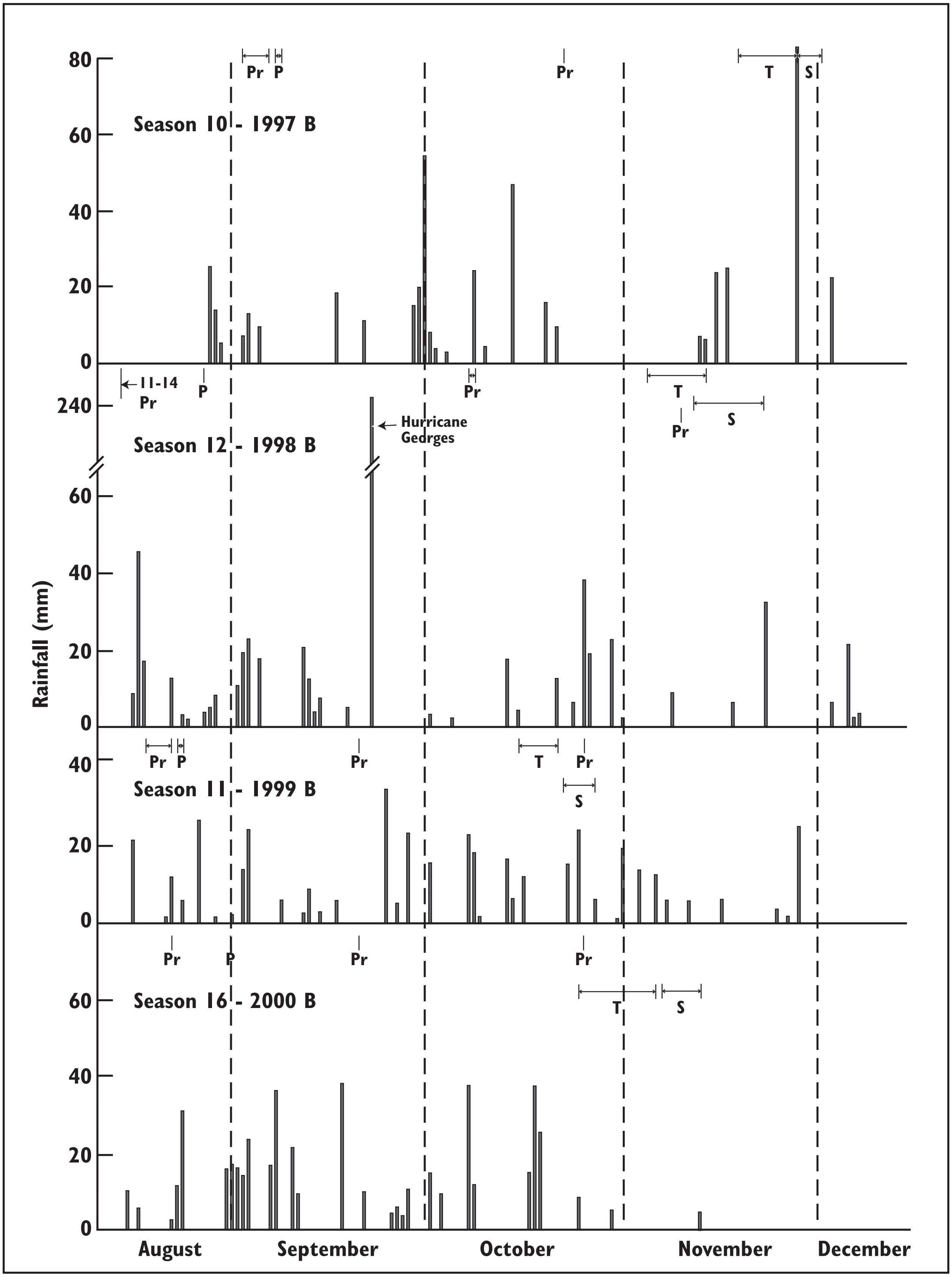

Figure A2, continued. Rainfall distribution pattern at Pernier, Haiti, and timing of planting (P) and pruning (Pr) operations with respect to rainfall and tasseling (T) and silking (S) dates in the experiment.

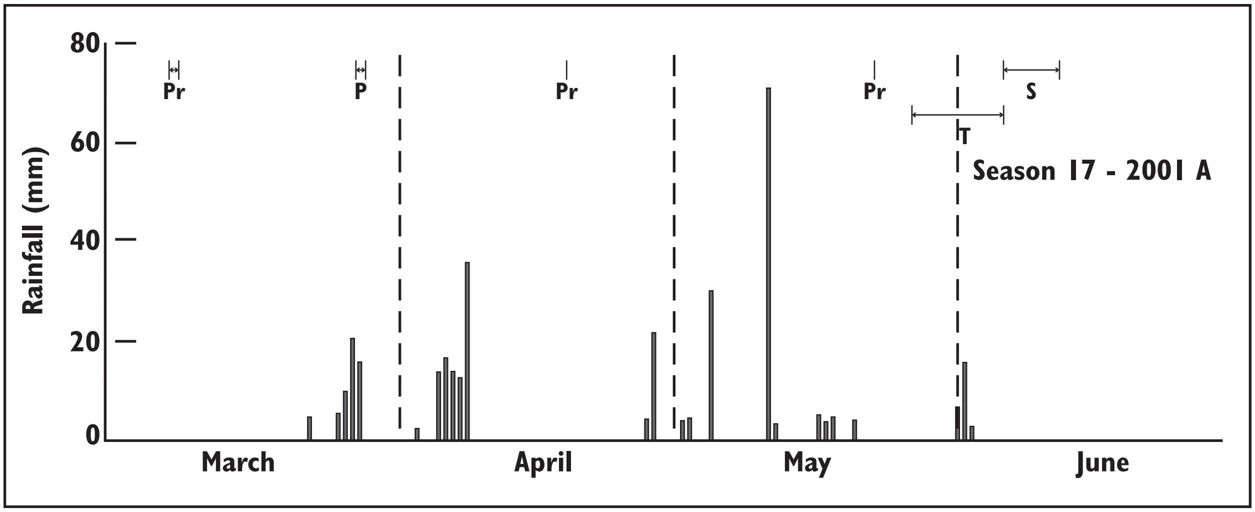

Figure A2, continued. Rainfall distribution pattern at Pernier, Haiti, and timing of planting (P) and pruning (Pr) operations with respect to rainfall and tasseling (T) and silking (S) dates in the experiment.

Table A1. Timetable of Field Operations on Hedgerows and Growth Stage of Maize

		Field operations					Maize stages		
		Final	1st	2nd	3rd		50%	50%	
Seasons		Tillage	Pruning	Pruning	Pruning	Plant	Tassel	Silk	Harvest
1	1993	15-19/2	11-17/3	26/4		24-25/3	21-28/5	25-30/5	15-20/7
2	1993	2-9/8	16-18/8	29/9		25-26/8	22-28/10	28/10-1/11	15-20/12
3	1994	28/2-2/3	9-11/3	13/14/4	10-11/5	11/3	9-14/5	12-20/5	7-8/7
4	1994	10-16/8	25-29/8	28-29/9	28-31/10	29/8	7-11/11	10-18/11	4-5/1
5	1995	6-10/2	2-6/3	5-6/4	11/5	7/3	15-22/5	18-24/5	6/7
6	1995	27-31/7	21-24/8	22/9	20/10	24/8	24-29/10	30/10-6/11	19-21/12
7	1996	9-13/2	1-5/3	19/4	15/5	14/3	9-13/5	15-20/5	16-18/7
8	1996	5-13/8	23-27/8	27/9		29/8	12-22/11	20-29/11	
9	1997	10-14/3	24-25/3	6-7/5		26/3			
10	1997	1-6/9	3-7/9	23/10		8-9/9	19-28/11	28/11-2/12	14/1
11	1998	16-20/3	26-27/3	6-7/5	4-5/6	2-3/4	20-28/5	26/5-6/6	22-24/7
12	1998	11-14/8	11-14/8	8-9/10	10/11	28/8	5-14/11	12-23/11	22-23/12
13	1999	15-19/2	26/2-2/3	14-15/4	19-20/5	11/3	10-19/5	18-27/5	14/7
14	1999	16-23/8	19-23/8	21/9	26/10	24-25/8	16-22/10	23-28/10	4/1
15	2000	24-28/2	11-12/4	15/5		13-14/4	6-22/6	20-28	N/A
16	2000	17-22/8	23/8	21/9	26/10	1/9	25/10-6/11	7-13/11	9/1
17	2001	12-17/1	7-8/3	19/4	23/5	27-28/3	27/5-7/6	6-12/6	13/7

Note: Dates given as day/month. January harvests are in year subsequent to that shown.

Table A2. Timing Hedgerow Management Operations and Growth Stage of Maize with Respect to Planting Date

		Field operations				Maize stages		
		Planting	1st	2nd	3rd	50%	50%	
Seasons		Date	Pruning	Pruning	Pruning	Tassel	Silk	Harvest
1	1993	24-25/3	-11	33		61	64	115
2	1993	25-26/8	-9	35		61	66	114
3	1994	11/3	-1	34	61	62	66	119
4	1994	27-29/8	-2	31	62	72	77	129
5	1995	7/3	-3	30	65	73	75	121
6	1995	23,24/8	-2	29	57	64	71	118
7	1996	14/3	-11	36	62	58	65	125
8	1996	29/8	-4	29		80	88	
9	1997	26/3	-2	42		NA	NA	
10	1997	8-9/9	-5	45	76	83	128	
11	1998	2-3/4	-7	34	63	52	59	112
12	1998	28/8	-16	42	74	74	82	87
13	1999	11/3	-11	35	70	65	73	125
14	1999	24-25/8	-5	28	63	56	62	133
15	1999	13-14/4	-2	32		62	71	
16	2000	1-2/9	-9	20	55	60	70	130
17	2001	27-28/3	-20	23	57	66	74	108

Note: When operations involve multiple dates, value is mean of differences between start and finish dates of each operation.

Table A3. The Effect of Soil Conservation Barriers on Maize Grain Yield at 13% Moisture Over 17 Consecutive Cropping Seasons, Pernier, Haiti, 1993-2001

	Cropping seasons[a]													
	1	2	3	4	5	6	7	10	11	12	13	14	16	17
Treatments	93-A	93-B	94-A	94-B	95-A	95-B	96-A	97-B	98-A	98-B	99-A	99-B	00-B	01-A
	Kg ha-1													
Tree[b] and fertilizer	890	990	1,250	930	1,180	760	1,550	503	1,590	650	1,380	1,083	640	632
Tree and grass[c]	660	650	770	820	800	650	810	255	990	240	980	662	517	607
Tree alone	540	520	610	690	640	670	810	280	950	200	990	671	408	514
Stone wall	1,560	1,060	990	540	860	610	770	210	850	180	710	415	301	239
Control (no Structure)	1,520	1,160	940	490	860	620	500	248	830	570	630	508	268	402
Grass row	1,060	740	690	470	610	550	460	108	630	360	570	343	252	408
Contour canal	1,370	980	830	460	850	550	820	90	790	180	690	327	239	309
Significance (F test)	*	*	*	***	ns	ns	*	***	0.06	*	0.06	***	*	ns
$LSD_{0.05}$	580	350	370	230	410	340	480	150	510	330	340	309	238	367
CV %	30.1	22.7	23.8	20.7	28.1	30.0	31.8	35.7	30.4	54.8	22.2	30.3	35.7	46.4

ns, *, **, *** Not significant, significant at the 0.05, 0.01, and 0.005 levels of probability, respectively.
Notes: From Season 15 onward, P applied to all plots. In seasons 8, 9, and 15, the entire crop was lost due to drought.
[a] A = 1st rainy season, Mar-Jul; B = 2nd rainy season, Aug-Dec/Jan.
[b] Hedgerows of *Leucaena leucocephala* managed for alley cropping.
[c] Rows of *P. maximum*. Prunings were applied to plots.

Table A4. Total Dry Weight Biomass Harvested from Trees and Grass in 17 Consecutive Cropping Seasons, Pernier, Haiti, 1993-2001

	Cropping seasons[a]																
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Treatments	93-A	93-B	94-A	94-B	95-A	95-B	96-A	96-B	97-A	97-B	98-A	98-B	99-A	99-B	00-A	00-B	01-A
	Mg ha-1																
(Leucaena and grass)																	
Tree[b] and grass	21.02	4.54	4.09	2.99	2.16	4.77	3.50	2.52	3.11	1.70	4.39	4.78	3.49	3.71	2.61	3.96	3.51
Tree alone	16.00	3.83	3.39	2.42	1.76	3.83	2.91	1.95	2.36	1.09	4.22	4.22	2.84	3.42	2.13	3.03	2.64
Tree and fertilizer	16.35	4.07	3.83	2.49	1.70	3.72	3.19	2.20	3.08	1.29	4.47	4.47	3.07	3.59	2.33	3.17	2.72
Grass[c] row	2.03	1.41	0.94	0.62	0.45	0.68	0.59	0.47	0.37	0.37	0.18	0.18	0.58	0.64	0.74	0.89	0.26
Significance (F test)	***	***	***	***	***	***	***	***	*	**	***	***	***	***	**	***	***
$LSD_{.05}$	5.89	0.99	0.94	0.60	0.41	1.13	0.94	0.45	1.44	0.50	1.06	0.98	0.54	0.64	0.70	0.61	0.51
CV %	21.28	14.32	15.43	14.21	13.62	17.36	18.43	12.67	32.28	22.42	15.94	13.92	10.86	11.23	18.02	11.00	11.13
(Leucaena biomass)																	
Tree and grass	20.61	4.37	3.96	2.74	1.93	4.35	3.19	2.19	2.79	1.40	4.30	4.30	3.26	3.41	2.27	3.54	3.27
Tree alone	16.00	3.83	3.39	2.42	1.76	3.83	2.91	1.95	2.36	1.90	4.22	3.88	2.84	3.42	2.13	3.03	2.64
Tree and fertilizer	16.35	4.07	3.83	2.49	1.70	3.72	3.19	2.20	3.08	1.29	4.47	4.45	3.07	3.59	2.33	3.17	2.72
Significance (F test)	ns	*	*	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
$LSD_{.05}$	6.23	0.31	0.41	0.60	0.60	1.50	1.09	0.36	1.77	0.66	1.37	1.09	0.62	0.54	0.65	0.75	0.63
CV %	15.58	3.31	4.86	10.46	14.81	16.69	15.56	7.49	28.52	23.08	13.99	11.45	8.96	6.85	12.76	10.18	9.60

ns, *, **, *** Not significant, significant at the 0.05, 0.01, and 0.005 levels of probability, respectively. a, b, c footnotes: See above.

Table A5. Leaf Dry Weight Biomass Harvested from Tree and Grass Barriers in Seven Consecutive Seasons, Pernier, Haiti, 1993-2001

	Cropping seasons[a]																
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Treatments	93-A	93-B	94-A	94-B	95-A	95-B	96-A	96-B	97-A	97-B	98-A	98-B	99-A	99-B	00-A	00-B	01-A
	Mg ha-1																
(Leucaena and grass)																	
Tree and grass	3.81	2.35	2.23	2.00	1.77	3.10	2.34	1.71	1.83	1.01	2.66	2.82	2.32	2.48	1.77	2.25	2.77
Tree alone	3.27	1.89	1.82	1.54	1.41	2.33	1.84	1.19	1.26	0.56	2.35	2.11	1.85	2.28	1.38	1.73	2.03
Tree and fertilizer	3.19	2.10	2.01	1.63	1.35	2.29	1.92	1.31	1.62	0.67	2.53	2.38	2.00	2.38	1.52	1.77	2.09
Grass row	2.03	1.41	0.94	0.62	0.45	0.68	0.59	0.47	0.37	0.37	0.18	0.94	0.58	0.64	0.74	0.89	0.26
Significance (F test)	ns	ns	*	***	***	***	***	**	**	***	***	***	***	***	ns	***	***
$LSD_{.05}$	1.69	0.80	0.74	0.49	0.28	0.61	0.69	0.43	0.61	0.16	0.50	0.60	0.38	0.63	0.57	0.42	0.40
CV %	27.54	20.56	21.21	16.95	11.09	14.52	20.69	18.27	24.12	12.49	12.89	14.60	11.23	16.25	2.12	12.80	11.18
(Leucaena biomass)																	
Tree and grass	3.40	2.18	2.10	1.75	1.54	2.68	2.03	1.39	1.51	0.70	2.57	2.35	2.09	2.18	1.43	1.83	2.52
Tree alone	3.27	1.89	1.82	1.54	1.41	2.33	1.84	1.19	1.26	0.562.35	2.11	1.85	2.28	1.38	1.73	2.03	
Tree and fertilizer	3.19	2.10	2.01	1.63	1.35	2.29	1.92	1.31	1.62	0.67	2.53	2.38	2.00	2.38	1.52	1.77	2.09
Significance (F test)	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
$LSD_{.05}$	0.83	0.36	0.35	0.51	0.41	0.77	0.71	0.21	0.67	0.21	0.44	0.37	0.40	0.50	0.42	0.48	0.49
CV %	11.15	7.78	7.88	13.71	12.55	13.93	16.24	6.96	27.38	21.39	11.88	10.82	8.95	9.75	12.7	12.00	9.70
(Grass leaves)																	
Tree and grass	0.41	0.16	0.13	0.25	0.23	0.42	0.28	0.32	0.32	0.30	0.09	0.47	0.23	0.31	0.34	0.42	0.24
Grass row	2.03	1.41	0.94	0.62	0.45	0.68	0.59	0.47	0.37	0.37	0.18	0.94	0.58	0.64	0.74	0.89	0.26
Significance (F test)	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
$LSD_{.05}$	3.26	1.34	1.11	0.68	0.23	0.96	3.93	0.85	0.31	0.07	0.39	1.63	0.32	1.26	1.30	0.88	0.06
CV %	75.95	48.68	59.08	44.39	19.51	49.84	72.79	61.47	25.18	6.06	84.24	65.96	22.27	76.03	68.36	38.00	7.07

ns, *, *** Not significant, significant at the 5% and 0.5% levels of probability, respectively. [a] A = 1st rainy season, Mar-Jul; B = 2nd rainy season, Aug-Dec/Jan.

Table A6. Branch and Stem Dry Weight Biomass Harvested From Tree Barriers, Pernier, Haiti, 1993-2001

	Cropping seasons[a]																
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Treatments	93-A	93-B	94-A	94-B	95-A	95-B	96-A	96-B	97-A	97-B	98-A	98-B	99-A	99-B	00-A	00-B	01-A
	---Mg ha-1---																
Branches[b]																	
Tree[c] and grass[d]	3.54	1.57	1.03	0.80	0.38	1.20	1.01	0.78	1.10	0.69	1.47	1.84	1.16	1.23	0.84	1.17	0.75
Tree alone	2.60	1.48	0.96	0.74	0.34	1.15	0.95	0.76	0.92	0.53	1.58	1.68	0.96	1.14	0.74	1.02	0.60
Tree and fertilizer	2.61	1.48	1.09	0.73	0.32	1.07	1.09	0.86	1.16	0.62	1.68	1.70	1.06	1.21	0.81	1.05	0.63
Significance (F test)	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
$LSD_{.05}$	1.10	0.22	0.14	0.26	0.18	0.41	0.24	0.16	0.67	0.46	0.76	0.36	0.26	0.11	0.23	0.22	0.18
CV %	16.61	6.50	5.89	15.14	22.52	15.98	10.35	8.94	27.83	33.16	21.25	9.19	10.70	4.23	12.71	8.99	11.77
Large stems[e]																	
Tree and grass	12.90	0.62	0.83	0.19	0.01	0.47	0.16	0.02	0.18	0.00	0.26	0.11	0.01	0.00	0.00	0.54	0.00
Tree alone	9.94	0.46	0.60	0.14	0.01	0.35	0.12	0.00	0.18	0.00	0.29	0.09	0.03	0.00	0.00	0.28	0.00
Tree and fertilizer	10.31	0.49	0.74	0.13	0.02	0.36	0.18	0.03	0.31	0.00	0.27	0.19	0.00	0.00	0.00	0.36	0.00
Significance (F test)	ns	*	ns	ns	ns	ns	ns	ns	ns		ns	ns	ns			ns	
$LSD_{.05}$	4.38	0.08	0.35	0.09	0.03	0.35	0.22	0.08	0.48		0.22	0.17	0.08			0.15	
CV %	17.48	6.85	21.69	25.29	103.24	39.76	63.63	238.62	96.21		34.88	56.96	66.93			16.96	

ns, *,**, *** Not significant, significant at the 0.05, 0.01, and 0.005 levels of probability, respectively.

[a] A = 1st rainy season, Mar-Jul; B = 2nd rainy season, Aug-Dec/Jan.

[b] Branches = green stems less than 1 cm (diameter).

[c] Hedgerows of *Leucaena leucocephala* managed for alley cropping.

[d] *Panicum maximum*. Prunings applied to plot.

[e] Stems 1-5 cm (diameter).

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