Long-term Research on Hedgerow Pruning Management for Alley Cropping in Haiti:

Implications for Soil Fertility Maintenance and Sustainability in Low Resource Farming in the Tropics

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Cover photo: Overview of hedgerow management trial, Pernier, Haiti, showing hedgerows at different stages of regrowth. In foreground: recently pruned hedgerows with prunings applied to soil as mulch. Rock wall from control plot is barely visible on far left. September 1998.

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FORWARD

This report summarizes results of a seven-year field study comprising 14 cropping seasons carried out in Pernier, Haiti, between 1993 and 1999 designed to determine optimum hedgerow management to sustain maize yields in an alley cropping system. Included in this report are results of dissertation research carried out by former graduate students, Dr. Lionel Isaac and Dr. Jean-René Bossa and thesis research by Ms. Hua Kang, as well as additional data not included in their theses. Agronomists Carine Bernard and Lionel Isaac played major roles in carrying out and managing the fieldwork, while Patrick Condé supervised the considerable work required to prepare the field and lay out the trials.

In 1990, I was hired by Auburn University to carry out agroforestry research in Haiti in support of extension activities of two development agencies, CARE International and the Pan American Development Foundation (PADF), as part of the Agroforestry II project, funded by USAID. The primary focus of the project was tree planting on agricultural lands, but the project also promoted planting of leguminous trees as hedgerows for soil conservation on sloping land. Food crops were planted between the hedgerows. My assignment was to design trials that would address the needs of CARE and PADF with respect to tree hedgerows. Success of the hedgerow planting effort in the project was reported in terms of “soil saved,” with the assumption that by preventing soil loss and planting leguminous trees, they were also improving soil fertility. That was a questionable assumption given the way in which the hedgerows were managed.

One of the basic concepts of alley cropping as practiced in the tropics is that the leaves and stems are used to add nitrogen and organic matter to the soil and recycle other plant nutrients. As I discussed the system with project leaders, I was made aware that the leaves and small stems of the trees were being removed to feed livestock or the hedgerows were heavily grazed by livestock. One of the purposes of designing this trial was to demonstrate the benefits to the crop of applying the hedgerow prunings to the alleys rather than removing them to feed livestock. Because of previous experience carrying out an alley cropping experiment in the Democratic Republic of Congo, I had become aware of the importance of managing the competition between the tree hedgerows and the associated crop through the timing of pruning operations. Therefore, I also felt it important to focus on identifying the proper timing and frequency of pruning operations during a growing season. Although this research was carried out in Haiti, the results relating to hedgerow management will be beneficial to those practicing alley cropping in other areas of the tropical world.

How to Read this Document

We attempted to write this document in such a manner as to be useful for administrators of agricultural development programs and extension workers, while also including sufficient data to be useful for agronomists and researchers. To that end, we included a large number of graphs and some photographs to accompany the text in order to highlight the main points stemming from the research. We placed the summary and conclusions at the start of the document, with references to relevant figures in the text for those who do not wish to read through the entire document. It was our intention that the graphs and photographs tell the main points of the story. Those who wish to delve further can read the narrative and look at the data tables in the Appendix.

The implications for alley cropping in Haiti and beyond, and its potential role among other sustainable agriculture approaches are provided at the end of the text.

Dennis Shannon

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SUMMARY AND CONCLUSIONS

An experiment was conducted in Haiti over 7 years and 14 cropping seasons to assess the long-term effect of alley cropping on continuously cropped maize, and to assess optimum pruning frequency and use of hedgerow prunings. Hedgerows consisted of leucaena (*Leucaena leucocephala* (Lam.) de Wit) in rows 4 m apart on a steep slope. We tested three pruning regimes and three methods of utilizing the prunings (Photo 1). All hedgerows were pruned to 50 cm height in each season prior to planting maize. Subsequent prunings consisted of 1) at 30 days after planting (DAP) maize, 2) at 40 DAP, and 3) at 30 and 60 DAP. Pruning utilization treatments consisted of 1) removal of leaves and small stems from the plots, 2) application of leaves and stems to the plots as mulch, 3) incorporation of the first pruning prior to planting in the soil but mulching of subsequent prunings. Because the trial was located on a steep slope (Photos 1, 2, 11) and hedgerows were used in Haiti for soil conservation, we used rock walls to minimize erosion in control plots. In order to make room for the trees and reduce competition between the trees and the maize, we replaced one in five maize rows with a row of leucaena, whereas in control plots, the rock walls were positioned between maize rows, so that they contained a uniform stand of maize throughout the plot (Figure 1). Consequently, alley cropped plots contained 20% fewer maize plants than the control plots. Fertilizer was not applied except during three seasons, in which plots were split with half receiving a low dose of P and K (60 kg P_2O_5 and 40 kg K_2O ha^{-1}) as triple superphosphate and muriate of potash) in order to test whether application of these nutrients without N would increase crop yield in addition to application of prunings alone.

The following observations were made following seven years and 14 seasons of research on hedgerow management in alley cropping on sloping land in Haiti. Reference is also made to research carried out in other trials that complement and help to interpret the results obtained.

Sustainability of Production over Time

- Alley cropping with leucaena (Leucaena leucocephala) sustained maize yields over seven years and 14 cropping seasons of continuously cropped maize without added fertilizer when hedgerow prunings were applied to the soil (Figures 5, 6). This was on a field with steep slope, shallow soil and erratic rainfall, thus prone to periods of drought stress and not optimal for maize production.

- Highest maize yields in the first seasons were observed in the rock wall control, which contained 25% more maize than did alley-cropped plots. Yield in the control plots rapidly declined over time. (Figures 5, 6)

- Maize yields in alley-cropped plots with prunings applied to the soil remained relatively stable across seasons compared to the control (Figures 5, 6).

- Highest maize yields in final seasons of the trial were observed with alley cropping when the hedgerows were pruned three times per season and hedgerow prunings applied to the soil (Figures 5, 6). In the five of the last seven seasons for which a crop was harvested, this treatment gave 42% higher yield on a whole plot basis than did the rock wall control plots. This is despite the fact that alley cropped plots contained 20% fewer maize plants than in the rock wall control plots.
- In the final seasons, the two-pruning regimes with prunings applied to the soil gave yields comparable to the rock wall control despite having 20% fewer maize plants (Figures 5, 6). When expressed on the basis of cropped area, these treatments out-yielded the control in the second half of the experiment (Figure 6).
- Removal of prunings resulted in low initial maize yields and decreased yield over time (Figure 5).

Soil Application of Prunings

- The benefit from application of hedgerow prunings to the soil compensated for the loss of cropping area to the hedgerows and competition from the hedgerows (Figure 6; see Photos 4, 7, 8, 9, 10).
- Leucaena leaves applied to the soil rapidly decompose, releasing N to the associated crop. At a tropical lowland site similar to the test site, leucaena leaves released half or their N within four weeks in a tropical lowland environment (Figure 12). Total N released from leaves and small stems approached 50 kg ha^{-1} within two weeks and 70 kg ha^{-1} within four weeks (Figure 12).
- Application of prunings to the soil increased N uptake by the maize (Figures 13 – 16), resulting in higher crop yields.
- Alley cropping with leucaena increased soil organic C (a measure of organic matter) and organic N (nitrogen contained in organic matter) when prunings were applied to the soil. Mulching with hedgerow prunings resulted in 34% more organic C and 37% more organic N in the upper 5 cm of the soil compared to removal of prunings (Figure 17).
- There was no benefit in terms of soil organic N or soil organic C from planting hedgerows when hedgerow prunings were removed from the plot (Figure 17).
- Incorporation of the first pruning prior to maize planting or surface application of the first pruning as mulch resulted in similar maize yields (Figure 3) but resulted in slightly lower soil organic N and C than when all prunings were surface applied (Figure 17). This may be due to increased tillage with incorporation of prunings into the soil.
- Removal of the prunings from alley cropped plots reduced maize yield compared to control, even when adjusted for differences in maize population (Figure 6). This may be attributed to

competition from the hedgerows for water and nutrients.

- Removal of prunings resulted in no benefit to the crop from alley cropping in terms of ear leaf N concentration and grain N uptake compared to the control (Figures 13, 14).

Pruning Regime

Timing of pruning and number of prunings is very important.

- Pruning three times gave significantly higher maize yield than did pruning twice (Figures 3, 4, 5, 6). The yield benefit from pruning at 60 days after planting (DAP) was most striking in the three seasons in which severe drought stress occurred during and following tasseling and silking (Figure 23), but the trend was present in all seasons and the difference was significant in nine seasons. This suggests that the benefit from pruning was at least partially due to reduction in competition for water.

- Pruning 3 times per season with prunings applied to the soil resulted in 60% more N uptake in grain than pruning twice and 48% more N uptake than the control plots, even though the control plots had 25% more maize plants (Figure 16).

- When prunings were removed from the plot, pruning twice per season with second pruning at 40 DAP resulted in higher average yield than pruning at 30 DAP (Figure 4). However, pruning 3 times gave higher maize yield even when prunings were removed.

- When prunings were applied to the soil, maize yield averaged higher when second pruning was carried out at 30 DAP rather than at 40 DAP (Figure 4), although the difference was not significant in most seasons.

- Higher yield when the second pruning was carried out at 30 DAP instead of 40 DAP was significant when drought occurred between 30 and 40 DAP, whereas it was not significant in seasons where there was not significant drought stress during that period (Figures 21, 22).

Competition between Maize and Hedgerows for Water

- Significantly higher maize yields when second pruning was done at 30 rather than 40 DAP in seasons where drought occurred during the same period (Figures 21, 22) suggest that scheduling the second pruning earlier served to reduce competition for water from the hedgerows.

- Pruning at 60 DAP likely reduced competition for water when drought occurred at or immediately following tasseling of the maize, the period when drought has its greatest effect on maize yields. This is suggested by the fact that the percentage increase in yield from pruning at 60 DAP was greatest when drought occurred during this period (Figure 23).

- Analysis of row-by-row yields also highlights the importance of competition for water. In seasons when severe drought stress did not occur, highest yields were recorded in the rows closest to the lowest hedgerow on the slope where soil collected on the terrace formed by the hedgerows (Figures 24, 25; Photo 11). In seasons when severe drought stress occurred, highest yields were recorded in the next higher row on the terrace, away from the hedgerow. This suggests possible competition from the hedgerows for limited soil water, which would have been most pronounced at the interface between maize and leucaena plants.

Hedgerow Biomass

- Seasonal hedgerow biomass production reflected in part rainfall conditions in the preceding season (Figure 7, Appendix Figure A1).
- Higher leucaena biomass was obtained from pruning hedgerows twice per season than from pruning three times (Figures 3, 8, 9). When pruning twice, higher average biomass yield was observed when the second pruning was done at 40 DAP than at 30 DAP.
- The hedgerows also benefited from application of prunings to the soil (Figures 3, 8, 9). When averaged over 12 seasons, application of prunings to the soil resulted in 14% higher biomass and 7% higher leaf production than did removal of prunings from the plots.
- Leucaena prunings, when applied to the soil, contributed more than 100 kg N ha^{-1} per season or 200 kg ha^{-1} per year in the leaves and small stems (Figures 10, 11).
- Leucaena prunings also contribute low amounts of P and K (Bossa et al., 2005).

Fertilization in Alley Cropping

- The combination of fertilizer and hedgerow prunings in alley cropping are complementary.
- Application of a low basal dose of compound fertilizer (37.5 kg each of N, P_2O_5 and K_2O ha^{-1}) in combination with application of hedgerow prunings to the soil increased maize yield by an additional 68% over hedgerow prunings alone in an adjacent trial over 14 seasons (Shannon et al., 2003).
- Application of a low dose of compound fertilizer had no effect on soil organic C and N, likely due to increased mineralization (Figure 17), but it increased N concentration in ear leaves and grain (Figures 13, 15), and increased grain N uptake (Figure 14). The low dose of fertilizer increased grain N uptake by 45% compared to application of prunings alone with the three-pruning regime (Figure 16).
- Prunings consisting of leucaena leaves and small stems can substitute for a significant amount of N fertilizer (Figures 10, 11, 12).

- Application of a low dose of P and K fertilizer without N significantly increased maize yield when prunings were applied to the soil, but the trend was not significant when prunings were removed from the plots (Figure 18; Photos 7, 8, 9, 10). Application of P and K increased yield by 31% when pruning was carried out three times per season and prunings applied to the soil (Figure 19).

Conclusions and Recommendations

Alley cropping can sustain crop production over an extended number of growing seasons, but only if hedgerow prunings are applied to the soil, unless other measures are taken to maintain soil fertility. For optimum maize yields, hedgerows should be pruned three times per season, beginning at planting maize and at approximately 30-day intervals after planting.

The strategy for hedgerow management in alley cropping suggested by this research is to manage the trees to benefit the crop during the periods critical for crop growth and yield, while favoring growth of the hedgerows when the crop is not actively growing in the field. During the critical periods of rapid crop growth, flowering and fruiting or grain filling, the focus should be on providing N and other nutrients to the crop while minimizing competition from the trees for nutrients, light and water. This is accomplished by removing most of the tree canopy down to about 50 cm height and applying leaves and small stems to the alleys. This not only provides nutrients for the crop but also removes the demand for water and uptake of nutrients by the hedgerows, thus leaving these resources largely to the crop. Once the crop is in the maturation phase, it no longer is actively taking up nutrients and is only translocating nutrients to the grain. Hedgerows should not be pruned during crop maturation and throughout the dry season in order to maximize biomass available to the next crop at planting time.

Prunings applied at planting provide a basal dose of N, while the second pruning at 30 days after planting (DAP) corresponds to a side dress application during the period of most active growth. The crop may also benefit from some of the N from the third pruning (Figure 16). Because leucaena leaves decompose rapidly, much of the N and other nutrients contained in the leaves are available to the crop within a short period of time (Figure 12). Where leucaena may not be desirable as a hedgerow because of presence of psyllid pests or other reason, *Gliricidia sepium* is an alternative hedgerow species for lower elevations whose prunings decompose and release N rapidly (Isaac et al., 2000). At higher elevations, *Acacia angustissima* was found to be a good substitute and was more productive than leucaena or *G. sepium* (Isaac et al., 2000; Isaac et al., 2006). Pruning at 60 days reduces competition between hedgerows and maize during the critical flowering and grain filling stages.

This pruning regime may be modified in case of occurrence of periods of drought and for other crops with different growing cycles than maize. For a crop that matures earlier than maize, pruning at 60 DAP may not be required.

Although alley cropping without use of fertilizer sustained crop yields, application of a compound fertilizer in addition to hedgerow prunings will sustain crop yield at a higher level. Application of P and K in absence of added N fertilizer increases yield when prunings are applied to the soil because of the contribution in N from the hedgerow prunings. Farmers who have limited resources to purchase fertilizer should focus on addressing soil deficiencies in P and K. A significant portion of the N requirement by maize can be met by the N contained in the leucaena prunings. Alternately, farmers can apply a basal application of a compound fertilizer containing N, P and K without need of a side dressing of urea or other N source.

Compared to other systems for low resource farmers to maintain soil fertility and productivity, alley cropping has a comparative advantage where land is limited and where there are secondary benefits, such as soil conservation on sloping land or provision of firewood in savanna. The inclusion of high value crops or practices that increase profitability will help to promote its adoption.

INTRODUCTION

Alley cropping or hedgerow intercropping, as practiced in the tropics, is an agroforestry system in which annual crops are planted between rows of leguminous trees, which are pruned during the cropping season and the prunings applied to the soil as mulch or incorporated as green manure (Kang *et al.*, 1984). Alley cropping has been shown to sustain crop yields over extended periods of several years. While most alley cropping studies tend to show stable yields over many years, in an alley cropping study with continuously cropped maize (Zea mays L.) between leucaena hedgerows on a degraded soil in Gandajika, Democratic Republic of Congo, Shannon et al., (1994) observed a yield increase over time in maize over a four year/eight season period.

Usually trees that fix nitrogen (N) are selected for the hedgerows, thereby providing the crop with a major crop nutrient, while also recycling other plant nutrients including phosphorus (P) and potassium (K) and restoration of soil organic matter. Another requirement is that the tree species selected for the hedgerows must tolerate frequent prunings and regrows quickly following prunings.

Benefits of alley cropping that favorably affect crop yield include increasing soil organic matter (Kang and Shannon, 2001), improving moisture retention (Chirwa et al., 1994), adding nitrogen, recycling other plant nutrients and reducing erosion (Kang et al., 1984; Bannister and Nair, 1990; Shannon et al., 2002). The nitrogen contribution from the hedgerow prunings to crops can be significant. Nitrogen yields above 500 Kg N ha^{-1} yr^{-1} have been reported (Sanginga et al., 1995) but yields between 200 and 300 kg N ha^{-1} yr^{-1} are more common (Kang and Shannon, 2001).

Need for Sustainable Cropping Systems in Haiti

Farming systems traditionally practiced by small farmers in Haiti are characterized by rotations with mixed cropping followed by a fallow period to restore soil productivity. These systems ensured farmers in the lowlands a diversified output for household consumption and the satisfaction of primary needs. Increasing population and shortage of suitable land have increased the pressure on sloping hillsides. These fragile lands are often farmed year after year with the same cultivation practices used in the lowlands without appropriate soil conservation practices. Fallow periods have been drastically reduced in most regions or have disappeared altogether. In low input agriculture, long fallow periods serve to restore soil productivity for future cropping. Continuous cultivation results in a decline in organic matter, loss of soil fertility and a deterioration in soil structure, rendering it more vulnerable to soil erosion. Farmers are faced with a subsequent decrease in crop yields. Methods to improve and maintain soil productivity, are needed to achieve sustainable crop production under more intensive cropping.

Experience with Contour Hedgerows in Haiti

In Haiti, the planting of contour hedgerows was introduced by internationally funded projects such as USAID's Agroforestry Outreach Project, Agroforestry II and Productive Land Use Systems

(PLUS) Projects, as well as projects by other donors. The focus of these efforts was to prevent soil erosion, often with the assumption that soil retention was synonymous with improved soil fertility. Projects reported length of hedgerows planted and justified it in terms of soil saved. Rosseau et al. (1990) estimated that 2 1/2-year-old hedgerows in farmers' fields accumulated 38 – 49 $m^3 ha^{-1} y^{-1}$ soil or 68 – 89 metric tons $ha^{-1} y^{-1}$ uphill from hedgerows. They based their estimates on measurement of slope and height of soil accumulated behind the hedgerows.

The most common species used in the hedgerows was leucaena (*Leucaena leucocephala* (Lam.) De Wit) but other species were also tried by development agencies. The trees were planted very closely within the rows, and the large stems and branches were laid next to the hedgerows on the uphill side in order to enhance the barrier effect. The combination of very closely spaced trees reinforced by large branches results in natural terrace formation, with soil accumulation and buildup up to 2-3 m uphill from the hedgerows, depending upon the slope of the field (Bannister and Nair, 1990). These hedgerows were typically spaced about five or more meters apart along slope contours. In a survey conducted in 1988, Bannister and Nair (1990) reported an average of 10 m between rows. The trees were pruned to about knee height or 50 cm once or twice a season. Management of the hedgerows was left to the farmers. Instead of applying the leaves and small stems to the soil in order to fertilize the crops, as is the recommended practice in alley cropping, most farmers removed the leaves and small stems to feed livestock or allowed their livestock to heavily graze the hedgerows.

Although these practices were not ideal from a crop production standpoint, there was anecdotal evidence of benefits to the associated crop. Crops planted immediately uphill from the hedgerows appeared to grow better, which Bannister and Nair (1990) attributed to soil enrichment and improved soil moisture status. In semi-arid Northwest Haiti, there were reports that planting contour hedgerows permitted farmers to grow maize next to hedgerows in fields where they could previously only grow sorghum (Shannon and Isaac, 1993), which is more drought tolerant than maize. Better growth of crops immediately above the hedgerows may be attributed to greater soil volume for water storage and to improved fertility from leaf drop and decomposition of small stems as well as topsoil accumulation from higher in the terraces. However, there was little evidence that soil fertility had improved in the remainder of the large alleys between the hedgerows. The removal of the N-rich leaves from the plots minimizes the potential benefit of alley cropping to crops.

Although most farmers in Haiti do not apply the hedgerow prunings to the soil, some farmers in the Southern region sowed maize between leucaena hedgerows that were pruned once during the cropping season and the prunings applied to the soil (G. Brice, personal communication; Pierre *et al.*, 1995). The first author also observed farmers in Bannate in southern Haiti applying leucaena prunings to the soil in an alley cropping system with a tomato crop (*Solanum lycopersicum* L.). Chery (1989) reported the use over two decades of hedgerow prunings as organic fertilizer at elevations between 500 and 1000 m near Jacmel, Bainet and Grand Goave.

Alley cropping has shown promise in Africa and Asia as a viable technique to sustain crop production in savanna and hillside agriculture systems. For this reason, we felt it appropriate in 1990 to test a refinement of the hedgerow system practiced in Haiti, with the assumption that properly managed alley cropping under Haitian conditions would provide low resource Haitian farmers with a means to better sustain crop productivity of their fields.

Importance of Hedgerow Management in Alley Cropping

To obtain the full benefits of the alley cropping system depends on correct choice of woody species, successful hedgerow establishment and efficient hedgerow and crop management (Kang, 1997). In a five-year assessment of tree species for alley cropping at five locations in Haiti that initially included 35 tree species including other *Leucaena* species (Isaac et al., 1993, 1994), leucaena (*L. leucocephala*) was the most productive in terms of biomass at low elevation sites, while *Acacia angustissima* (Mill.) Kuntze was the most productive at high elevation sites (Isaac et al., 2006). Leucaena and gliricidia (*Gliricidia sepium* (Jacq.) Kunth) prunings released the most N in four weeks, while *A. angustissima* released the most N at high elevation (Isaac et al., 2000). The importance of hedgerow management is highlighted by the fact that availability of nitrogen from leucaena prunings to the current season's crop has been reported to range from as low as 3.2% to as high as 65% (Guevara, 1976, Brewbaker and Evensen, 1984, cited in Chirwa *et al.*, 1994; Mulongoy and van der Meersch, 1988). In a review, Kang and Mulongoy (1992) attributed the low N use efficiency reported in several alley cropping trials to lack of synchronization between N release from the prunings and crop development.

The decision of when to prune hedgerows was often subjective in nature. In the experiment reported by Shannon et al. (1994), hedgerows were pruned at five to six-week intervals during the growing season, resulting in two to three prunings per season. Dalland *et al.*, (1993) reported significant increases in maize yields when leucaena prunings were incorporated into ridges two days before maize was sown, followed by a second pruning was made forty-five days later. There was a need to better clarify what pruning schedule would be appropriate in order to better synchronize N application with crop needs, while also minimizing competition to the crop. In order to successfully introduce alley cropping to farmers, extension workers and researchers need information on optimum management practices to recommend to farmers.

Although the alley cropping system was designed for low resource farmers, who often lack access to inputs such as chemical fertilizers, information on fertilizer use in alley cropping is needed. In a four-year study in the Democratic Republic of Congo, Shannon et al. (1994) reported similar responses to application of a low rate of nitrogen (N), phosphorus (P) and potassium (K) fertilizer in alley cropped plots and in plots without hedgerows. Since N-fixing trees such as leucaena provide significant amounts of N to associated crops, the question remained as to whether application of P and K fertilizer would be beneficial in alley cropping in absence of N fertilizer.

OBJECTIVES

The objectives of this trial were to determine the optimum pruning frequency and use of prunings in order to optimize crop yield and hedgerow biomass output in a maize-leucaena alley cropping system under lowland conditions in Haiti. Increased pruning frequency and number reduces hedgerow vigor but decreases competition with the crop. Prunings made late in the growing cycle of a crop are less likely to benefit the crop. The management strategy sought was one which 1) maximized biomass availability to the crop during the period in which it may benefit from nitrogen release through decomposition of prunings, 2) minimized competition with the crop during the vegetative and early reproductive stages of the crop, and 3) favored optimum production of hedgerow biomass given these constraints.

The study was also used to assess the effects of alley cropping and pruning management on nitrogen (N), carbon (C), dynamics, as well as response to phosphorus (P) and potassium (K) fertilization. We also looked at effects of hedgerow pruning regime on maize grain yield during periods of drought. Yields were examined on a plot basis and row-by-row. Specifically, we wanted to know if there was empirical evidence that pruning mitigated the effects of drought by reducing competition for water. Since it was not possible to take soil and plant moisture measurements during the trial, the yield data was examined together with rainfall records in order to make this assessment.

MATERIALS AND METHODS

The study site was located at Bois Greffin, Pernier, approximately six miles east of Pétion Ville. The elevation is about 250 m and the mean annual temperature, 27.5° C. Annual rainfall recorded over a seven-year-period averaged 1332 mm, distributed mainly between late February and early June and between August and November. This rainfall distribution pattern permitted two maize crops a year. The soil was a fine, mixed isohyperthermic Lithic Eutropept (Guthrie and Shannon, 2004). It was derived from limestone parent material, having a dark brown gravelly clay loam surface horizon with pH = 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 32% with stone dry walls resulting in terraces of 18-25% slopes. Based upon rainfall records, 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, because of the shallow soil and erratic rainfall occurrences, the site is highly susceptible to occasional periods of drought.

In previous years, maize, cassava (*Manihot esculenta* Crantz) and pigeon pea (*Cajanus cajan* (L.) Huth) were planted in the first rainy season of the year followed by carrots (*Daucus carota* L.) and sweet potato (*Ipomoea batatas* (L.) Lam) in the second season (Isaac et al., 1995). These were irrigated by furrow irrigation from a nearby stream. During the three years prior to establishing the trial, carrots and lima bean had been planted in the second season following a grazed fallow in first season. The farmer had used animal manure to fertilizer the crops.

Experimental Design

We tested three modes of utilization of hedgerow prunings in all combinations with three hedgerow pruning regimes (Photo 1). The pruning utilization treatments were: (1) prunings removed, (2) prunings applied as mulch, and (3) prunings incorporated before each maize planting, with subsequent prunings applied as mulch. Mulching is the broadcasting of biomass on the soil surface whereas incorporation refers to working the fresh biomass into the upper few centimeters of soil by cultivation. The three pruning regimes were: (a) pruning prior to maize planting and 30 days after planting (DAP), (b) before planting and 40 DAP and (c) before planting, 30 DAP and 60 DAP. A tenth treatment consisting of a control in which rock walls replaced hedgerows was used as a standard for assessing the effect of alley cropping. These ten treatments were replicated three times. The ten treatments were arranged in a 3 x 3 factorial design augmented with a control using a randomized complete block design.

Photo 1: *Overview of hedgerow management trial, Pernier, Haiti, showing hedgerows at different stages of regrowth following pruning. In foreground: recently pruned hedgerows with prunings applied to soil as mulch. Rock wall from control plot is barely visible on far left. September 1998.*

Rock walls were chosen as the control because of the steep slope necessitated erosion control measures in the plots and because rock walls were already used in parts of Haiti for soil conservation. The hedgerows had an erosion control function in alley cropped plots. By using rock wall barriers, the possibility of soil erosion was removed as a potential confounding factor in the comparison of alley cropping to the no alley cropping control.

The plots measured 6.5 m along contours and 8.0 m up and down the slopes with two hedgerows or rock walls 4 m apart on contours centered in the plots and 2 m from the upper and lower edges of the plots (Figure 1). In the control plots, the maize rows were planted so that the rock walls were positioned between rows of corn in order to maintain a solid stand of maize (Figure 1). There were five rows of maize 80 cm apart between pairs of rock walls. However, in alley cropped plots, we substituted a row of leucaena for a row of maize in the alley cropped plots, resulting in four rows of maize spaced 80 cm apart were planted between leucaena hedgerows. The rationale for the difference in maize rows in control and alley cropped plots was based upon the fact that trees compete with the maize for light, water and nutrients, and prior experience carrying out alley cropping research in the Democratic Republic of Congo (Shannon et al., 1994). In carrying out that experiment, we learned that competition between the hedgerows and maize negated the benefits of higher maize density when the maize rows were located 40 cm from the hedgerows. Dropping out one row of maize per alley allow a separation of 80 cm between tree hedgerows and the nearest maize row (Figure 1). The maize harvest area was 4.5 m by 4 m except in Season 11 – 13 where plots were split to allow a fertilizer treatment (discussed later in this report). In those seasons, the harvest area was

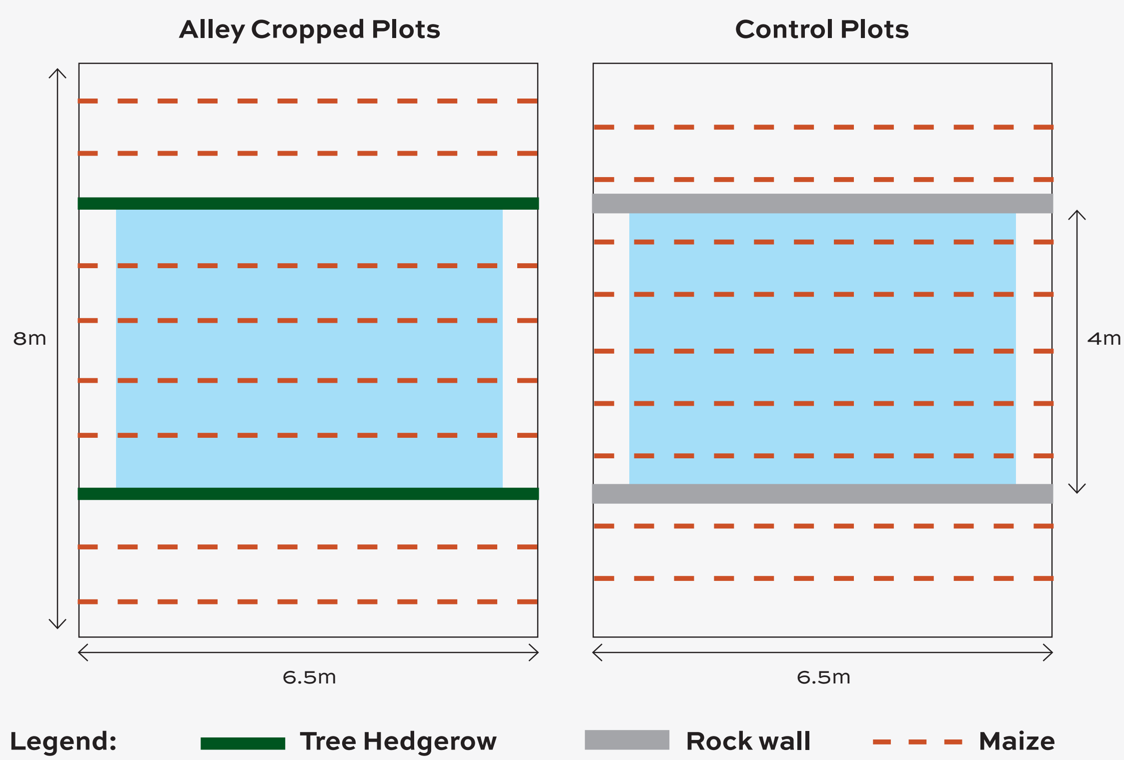

Figure 1. *Diagram showing relative placement of maize rows and hedgerows in alley cropped plots and rock walls in control plots. Maize harvest area is shown in blue. Note: plot dimensions and maize row spacing are identical, but number of maize rows was reduced in alley-cropped plots to provide greater distance from hedgerows than from rock walls.*

3.25 m by 4 m, again with the sample collected from each of the rows between a pair of rock walls or hedgerows. The samples were taken from all rows between a pair of hedgerows or rock walls.

The reader should keep this difference between the control and alley cropped plots in number of rows harvested per plot in mind when assessing the results presented. Yields in this report are presented on a total area basis. To calculate the yield on cropped areas only, multiply alley crop yields reported by 1.25.

Trial Establishment

The site was characterized by scattered outcroppings of limestone rock, boulders and sections of rock wall terraces across the field (Photo 2). The rock walls are also referred to as dry walls, as they were constructed without mortar. Plots were laid out in the field in March and April 1991 (Figure 2). Care was taken to avoid outcroppings or very shallow soil, particularly in the harvest areas. The upper limit of the plots was determined by the presence of a wall or outcropping. The lower limit was placed at least 1.5 m from the edge of the lower rock wall, if one was present. In replicates 1 and 2, stone walls were removed but the soil that had collected behind the walls was left intact. In replicate 3, it was not possible to remove the wall from all plots. Where sufficient space was not available, the wall was displaced, and soil filled in behind the new wall in order to accommodate the required dimensions of the plot. In places where the bedrock was within 10 cm of the surface, the bedrock was chipped away to allow at least 20 cm of soil. However, these areas did not fall within the harvest area. Figure 2 shows the approximate layout of the plots on the slope.

Photo 2: *Overview of research site prior to installation of trials. Bois Greffin neighborhood, Pernier, Haiti, February 1991.*

Leucaena variety K8 was used as the hedgerow species. Seed was collected from the Operation Double Harvest site at Cazeau, Haiti. Before planting, the seeds were scarified by immersion in boiling water for 30 seconds to ensure more rapid germination. Seeding was done on April 23 and 24, 1991. Four seeds were planted per hill, spaced 0.1 m apart within the row. The rows, 6.5 m long, were spaced 4 m apart on contour. Seedlings were thinned to one per hill at approximately six weeks after planting. No crop was planted during that first season since it was intended to establish the hedgerows before beginning the trials.

Photo 3 (left): *Leucaena trees prior to first pruning. Newly constructed rock wall in foreground left. Pictured (left to right) Economist Dr. John Dale (Zach) Lea, Lionel Isaac, Dr. Marianito Villanueva. February 1993.*

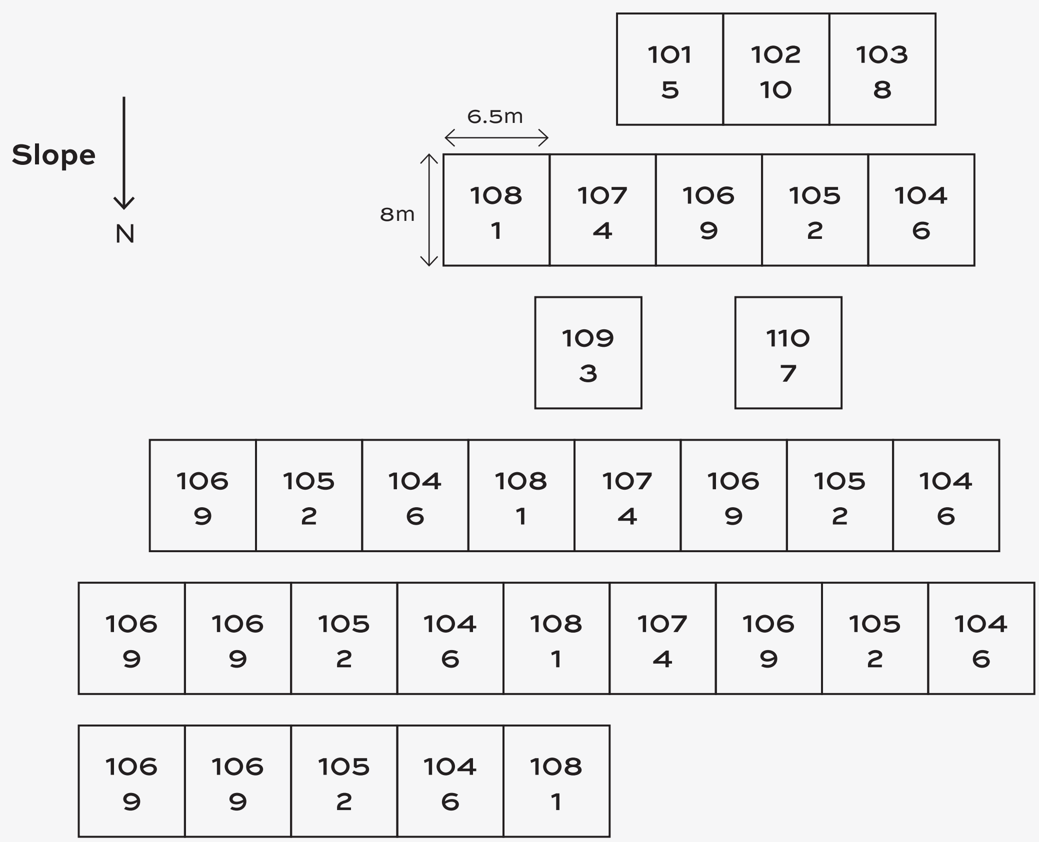

Figure 2. *Field Layout – Hedgerow Management Trial, Bois Greffin, Pernier, Haiti.*

Treatments: *Prunings Removed:* *1.) Planting, 30 days after planting (DAP); 2.) Planting, 40 DAP; 3.) Planting, 30 DAP, 60 DAP;* ***Prunings applied as mulch:*** *4.) Planting, 30 DAP; 5.) Planting, 40 DAP; 6.) Planting, 30 DAP, 60 DAP;* ***Prunings Incorporated*** *7.) Planting, 30 DAP; 8.) Planting, 40 DAP; 9.) Planting, 30 DAP, 60 DAP;* **Control:** *10.) Rock walls. The first digit in the plot numbers represent the replicate or block number.*

All plots were initially sown to leucaena, with the intention that in the control plots the seedlings would be uprooted and walls constructed in their place. Because of suspension of the project for one year, the trees had grown to 3-4 m height before the tops were removed (Photo 3). The stone dry walls were constructed in control plots in January 1993, two months before planting maize. In control plots, the leucaena hedgerows were cut at approximately 15 cm below the ground to prevent regrowth before constructing the rock walls. Foundations for the walls were constructed in 15 cm deep trenches. The walls were constructed to a height of 20 cm above the soil surface with a width of approximately 30 cm. Because of the rough shape of the limestone rock it was possible to stack the rock without use of mortar. Until the maize was planted, the alleys between hedgerows and walls were left without disturbing the soil. Residues of shrubs and weeds removed during weeding were left on the soil surface.

Hedgerow Management

The hedgerows were nearly two years old at the start of the experiment and had grown to 3-4 m in height. Hedgerows were pruned to a height of 50 cm, between twenty-two days and four days before the first maize seeding because of the considerable work involved. In subsequent seasons, the first pruning was done over several days averaging 13 days prior to planting maize. Appendix Table 1 gives dates of important operations, as well as maize tasseling and silking dates, while Table 2 gives timing of these operations relative to planting dates. Although the target date for the first pruning was at planting, operationally it varied between 2 and 18 days before planting depending upon various factors, including availability of sufficient soil moisture for planting maize. One or two subsequent prunings were made during the cropping season, depending upon the treatment.

Photo 4: *Plots with prunings applied as mulch (left) and prunings removed (right). Maize plants on left were greener and taller than those on right. Note leucaena leaves have dried and dropped off small stems and begun to decompose. June 1998.*

Following pruning, large stems were placed next to the hedgerows on the uphill side of the hedgerows to increase the barrier effect for soil conservation. This is in keeping with farmer practice in Haiti. However, in plots where prunings were removed, branches and large stems were also removed except in some cases where branches were used to fill in gaps to prevent gully formation. Leaves and small stems were either incorporated in bands next to the maize seed, spread over the surface of the alleys or removed from the plots, according to the treatment (Photo 4).

In 1996, we began carrying out root prunings around control plots to prevent leucaena roots from penetrating control plots and thus competing with maize in the control plots. This was done on each subsequent season as part of land preparation.

Photo 5. Preliminary soil preparation with hand tools.

Maize Crop

Maize was seeded in the alleys between hedgerows beginning on March 23 and August 24, 1993, and at the beginning of each subsequent rainy season. Two maize crops were planted each year. Maize was planted in March and harvested in June or July and planted again in late August and harvested in December reflecting periods of first and second rainy seasons, also referred to as Season A and Season B, respectively. The maize was grown during the first and second rainy seasons for seven years (14 cropping seasons), although data is presented for only 12 seasons because of total crop failures due to drought in seasons 96-B and 97-A.

The first soil preparation prior to planting maize was done with hoe and pick hand tools, and the plant residues were left on the soil surface (Photo 5). A few days before seeding of maize, a second soil preparation was carried out with a hoe. In alley cropping plots, harvested leaves and green stems, referred to as prunings, were returned to the soil as mulch, incorporated or removed, according to the treatment. In subsequent seasons, residue from the previous maize crop was incorporated into the soil with the first soil preparation. In plots where the first pruning was incorporated into the soil, a supplemental tillage was carried out with hoes to incorporate the prunings.

A local population of maize was planted in hills 40 cm apart in rows that were spaced at 80 cm apart. 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 plots and 31,250 plants ha^{-1} in the rock wall control plot during the first six cropping seasons. In the seventh and 10’th cropping seasons, the maize was thinned to two plants per hill, which doubled the population density, however the plants were thinned to one plant per hill in the remaining seasons. A first weeding took place about thirty days after planting and a second approximately three weeks later.

Fertility Management

The only nutrients applied to the maize crop were those contained in the leaves and stems harvested from leucaena hedgerows with the following exceptions. In Seasons, 11, 12 and 13, all of the plots were split and 60 kg P_2O_5 and 40 kg K_2O ha^{-1} as triple superphosphate and muriate of potash were applied to half of each row, selected at random. The rows were divided in half across the contour, such that half of each row had fertilizer and the other half did not. Unless indicated otherwise, data from the unfertilized portions of plots are presented. In Season 14, no fertilizer was applied and plots were harvested as in Seasons 1-10.

Observations

During the cropping season, maize plants were counted after thinning and at harvest. Data recorded at harvest were grain yield (metric tons per hectare, denoted Mg ha^{-1}) calculated at 13% moisture, plants lodged determined as% total plants lodged in each plot, number of ears harvested, number of fertile plants per harvest area, maize height, fresh weight of ears and% moisture of harvested grain determined by means of a grain moisture tester. Because of a strong location effect observed in the plots associated with position on slope and location with respect to hedgerow or rock wall, maize data was collected on a row-by-row basis within the harvest area. At harvest of hedgerows, prunings were divided into leaves, green stems < 1 cm in diameter, stems 1-5 cm in diameter, stems > 5 cm in diameter and pods. Fresh weight of each component was determined separately in the field (Photo 6). Samples of fresh biomass of each component were oven-dried at 60 - 71.0° C for dry weight determination. Subsamples from seasons 6, 7, 11 and 13 were transported to Auburn University and analyzed for N content, as described by Isaac et al. (2003b, 2004).

Photo 6: *Workers separating leucaena prunings into leaves, small and large stems before drying to determine dry weight yield of each.*

In order to determine the effects of hedgerow management on soil C and N, soil samples were collected following 3 1/2 years of cropping from three depths (0-5 cm, 5-10 cm, 10-20 cm) in each plot and analyzed for organic N and C content, as described by Isaac et al. (2003b). Soil samples were incubated at 25 C for 30 days to determine C and N mineralization.

Data Analysis

Analysis of variance was carried out for all variables each cropping season. The Statistical Analysis System (SAS) was used for all statistical analyses. Among treatments, orthogonal or balanced comparisons were determined using the contrast statements in the model. For each year, analysis of variance on maize was carried out using all 10 treatments in a simple randomized complete block analysis to permit comparisons of individual treatment combinations with a control. The data from the nine alley cropping treatments were also analyzed as a 3 x 3 factorial.

Pooled analyses of the long-term data were carried out by former graduate student Hua Kang (2004) using the general linear model (GLM) program of the Statistical Analysis System (SAS Institute Inc., 1999). Variances for maize grain yields were not equal among the 12 cropping seasons, separate GLMs were done to get the average yield for each season. To check the entire effects of "Pruning utilization" and "Pruning regime", the data were combined over the 12 seasons in which maize was harvested to carry out a pooled GLM analysis.

The data were also examined to assess the effect of pruning regime on maize yield during periods of drought (Kang, 2004). Rainfall records were examined, and periods of drought were identified in the 12 seasons. Analyses were carried out to compare seasons with and without drought during a given period. For row-by-row yield analysis, 12 individual seasons were analyzed separately using the Mixed Procedure of SAS. Block was considered a random effect while treatment and row were fixed effects, as well as the combined seasons with or without drought. Among treatments, orthogonal comparisons were determined using one-degree-of-freedom contrasts. All variables were tested using F-tests for main effects and their interactions. Sources of variation were considered significant at a 95% confidence limit.

RESULTS

The presence of either hedgerows or rock walls resulted in rapid development of terraces within the plots. This may be attributed to a combination of sheet and rill erosion as well as tillage erosion.

Yields were generally low, as would be expected from low input agriculture on an eroded, shallow soil that is subject to drought events. In Seasons 8 and 9 (1996-B and 1997-A) we experienced total crop failure due to drought and no maize yield data were collected. In the remaining twelve seasons, data were collected on both maize and leucaena. Data tables are presented in the appendix.

Figure 3 provides an overview of the hedgerow management effects averaged over 12 seasons for maize and 13 seasons for leucaena hedgerows. (In Seasons 11-13, all plots were split, with half of each plot receiving a low dose of P and K. Data presented represents means of fertilizer and no fertililizer treatments. While fertilizer increased yields, it did not alter the trends presented.)

Application of leucaena prunings to the soil approximately doubled maize yields compared to removal of prunings and also increased leucaena biomass yields. Pruning three times per season at

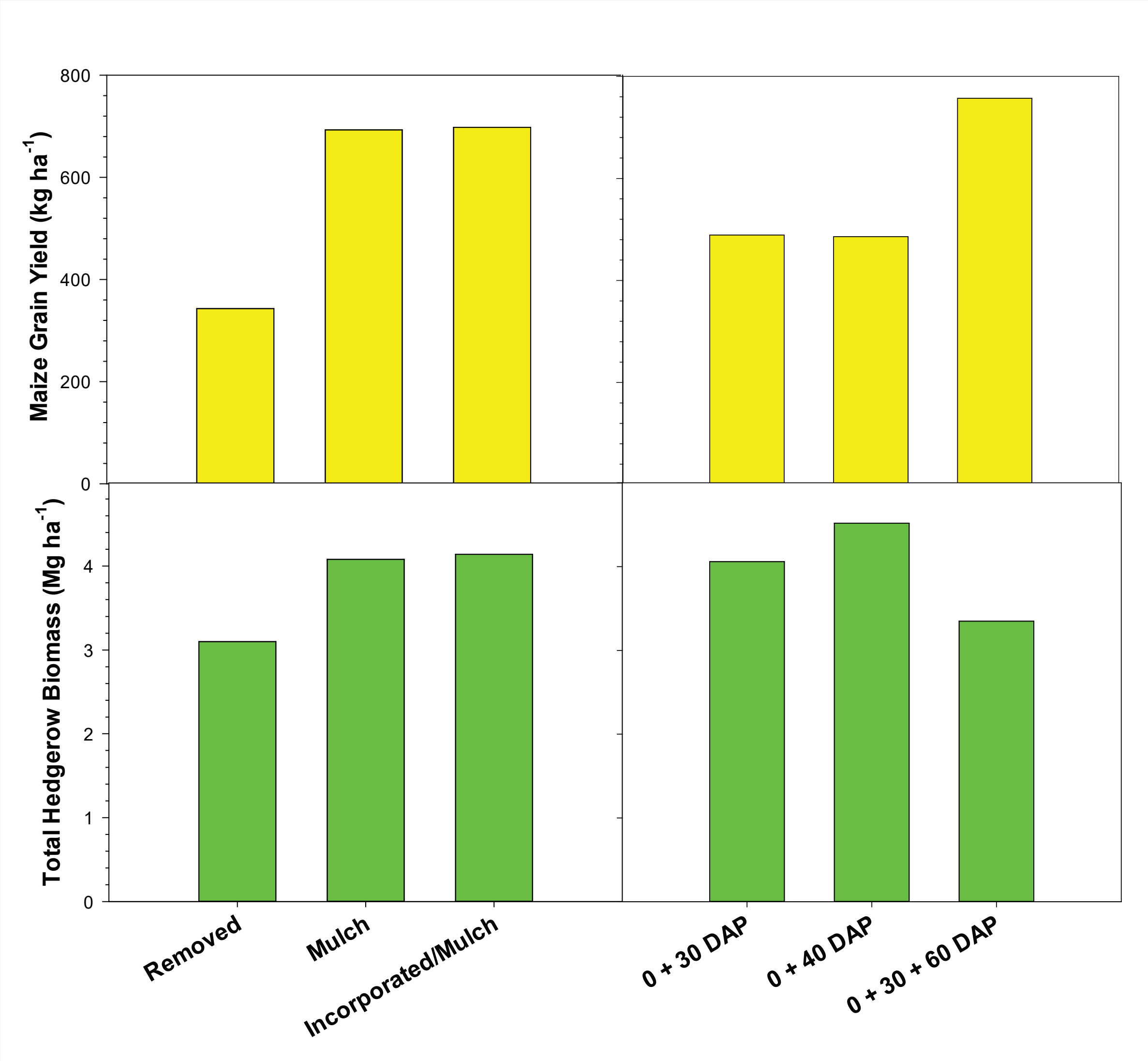

Figure 3. *The effects of pruning management on yield of continuously cropped maize and pruning biomass yield without fertilizer averaged over 12 seasons for maize and 13 seasons for hedgerow biomass. Bois Greffin, Pernier, Haiti.*

approximately 30-day intervals increased maize yields by about a half compared to two prunings per season.

Hedgerow biomass yields were lowest with three prunings per season and highest with two prunings at planting at 40 DAP (Figure 3). Removal of prunings from the plots resulted in lower hedgerow biomass yields averaged over 13 seasons.

Season by season trends and comparisons with the rock wall control treatment are discussed in the following sections.

Maize Grain Yield

We will first examine pruning management effects before comparing these treatments with the control. Application of leucaena prunings as mulch or incorporated at planting resulted in consistently higher grain yield than removal of prunings over all seasons (Appendix Table 3). Incorporation of the first pruning at planting did not improve yields compared to surface-applied prunings. Frequency of prunings had a greater effect on maize grain yields than timing of second pruning. Three prunings per season resulted in significantly higher yields than two-pruning in every season except for seasons 10, 11 and 14 where pruning regimes did not test significant, but the trend was consistent in all seasons.

No significant differences were observed between the two-pruning regimes except in Season 12 and 13 (Table 3) but the trends were opposite in the two seasons. The interaction between pruning regime and pruning application was also significant in season 12. In Season 12, yields were exceedingly low, and some plots had no yield (Table 4). Interactions of pruning application by pruning regimes were also significant in Seasons 1 and 3 (Table 3). These related mainly to inconsistencies between the 30 vs 40 DAP pruning treatments with and without application of prunings to the soil (Table 4). In all three seasons, when prunings were removed from the plots, pruning at 0+40 DAP gave higher yields than did pruning at 0 + 30 DAP. The reverse was true when the prunings were applied to the soil.

When considering only the plots where the prunings were applied to the soil, no interactions between pruning use and pruning frequency were significant (Kang, 2004). Pruning at 0+30 yielded significantly higher maize grain than 0+40 DAP in seasons 1, 6 and 12 (Appendix Table 5). In remaining seasons, differences between the two two-pruning regimes did not test significant.

Kang (2004) carried out pooled analyses of the data over the 12 seasons in which a maize crop was harvested. There was no significant difference in maize yield when the second pruning was at 30 or at 40 DAP when the full data set was considered (Kang, 2004; Figure 4). When prunings were applied to the soil, pruning at 0+30 DAP resulted in significantly higher yields than pruning at 0+40 DAP in three seasons (Table 5). The reverse trend was true when prunings were removed (Figure 4). Higher maize yield when the second pruning was carried out at 30 DAP rather than at 40 DAP in plots where prunings were applied suggests that scheduling the second pruning earlier served to reduce competition from the hedgerows. An examination of the hedgerow biomass yields, presented later in this document, may provide an explanation as to why the results were different when prunings were removed from the plots.

Comparisons among individual treatment combinations showed varying responses over the seasons (Appendix Table 4). Highest yields among alley cropping plots were generally observed with three prunings applied to the soil as either mulch or when first pruning was incorporated, followed by mulch. During Season 6 (1995-B), the mulch treatment with pruning at planting and 30 DAP gave the same maize yield as did the three pruning regime. The highest single yield with alley cropping occurred in Season 13 with three-pruning regimes with prunings applied to the soil (Figure 5,

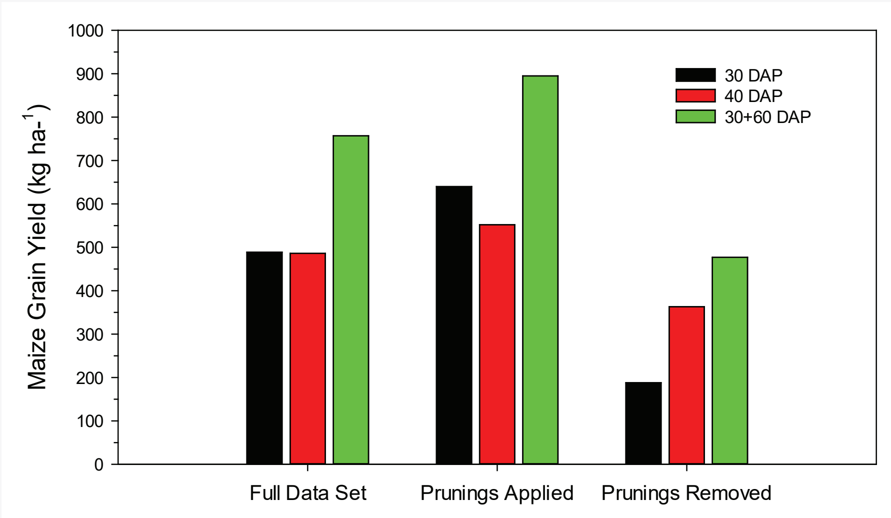

Figure 4. *Comparison of pruning regime on maize yield effects averaged over 12 seasons considering all treatments and considering separately where prunings were applied to the soil or removed from the plots.*

Adapted from Kang (2004).

Appendix Table 4), which highlights the effectiveness of this treatment combination at sustaining yields over time. Over the seasons, the two-pruning treatment with prunings removed at planting and 30 days later (0+30 DAP) was predominantly the least productive (Figures 5 and 6, Appendix Table 4), followed by the 0 + 40 DAP treatment with prunings removed.

Trends Over Time

The trends over time are illustrated in Figures 5. For simplicity, the curves showing trends with and without applications of prunings to the soil are shown in separate graphs. We combined both mulch treatments (mulch only and incorporated followed by mulch) in Figure 5 since the two mulch treatments did not differ significantly (Appendix Table 3). The rock wall control is included in both graphs. Data shown are for unfertilized subplots in seasons 11-13. We will consider fertilizer effects later in the document.

The control plot with rock wall barriers initially gave the highest yields but yields rapidly declined during the first eight seasons, after which they appeared to stabilize at a low yield level. This may be attributed to loss of soil fertility over time. The initial advantage of the rock wall plots may be attributed to the fact that the control plots contained more maize plants, and that there were no trees to compete with the maize as was the case in the alley cropping plots.

In alley-cropped plots where prunings were removed, a similar decline in yield was observed over the first eight seasons (Figure 5) and yields remained extremely low during the remainder of the trial. Yields in the control plots were almost double that in alley-cropped plots where prunings were removed throughout this period. From the standpoint of maize yields, the farmer practice of removal of prunings from the field was worse than having no hedgerows and only rock wall conservation structures.

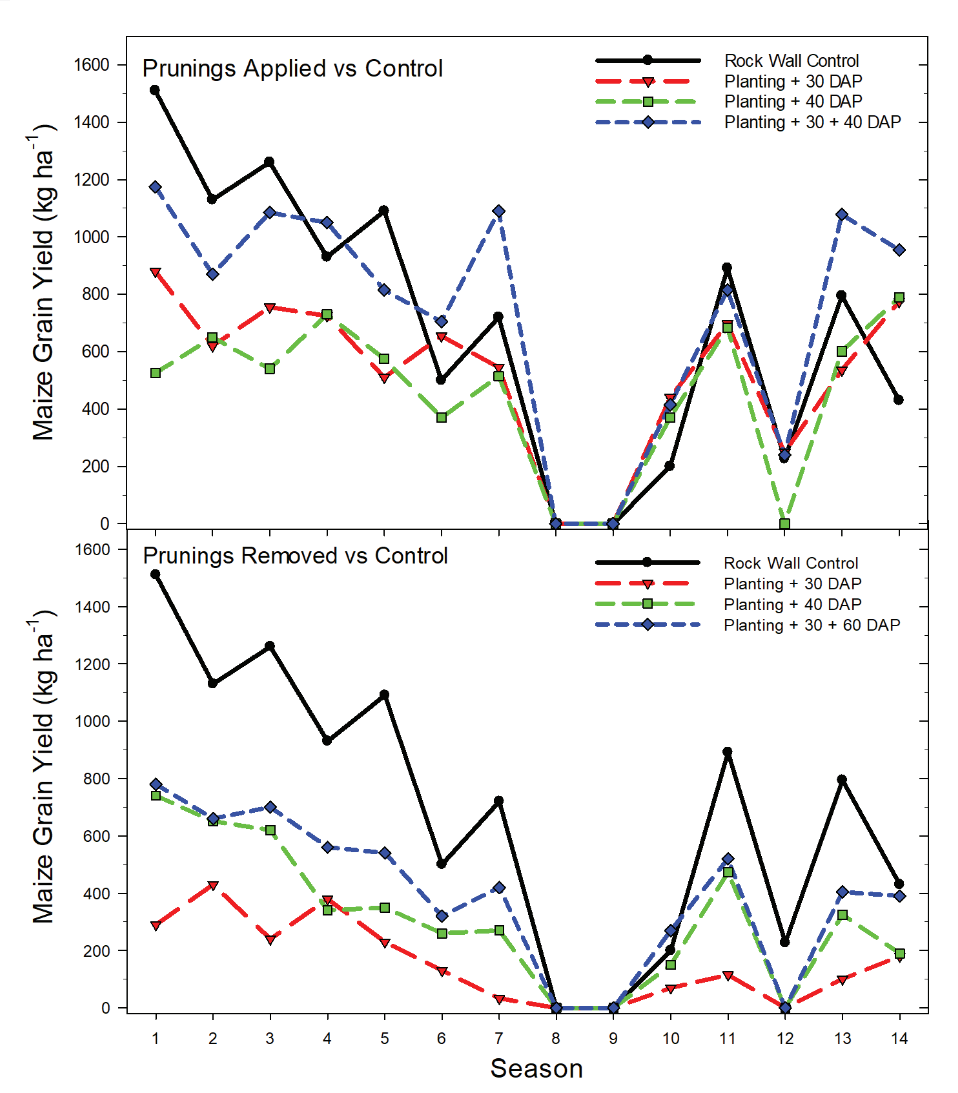

Figure 5. *Long-term trends in maize grain yield under different pruning regimes in plots where leucaena prunings were applied to the soil and plots where prunings were removed in alley cropped plots compared to rock wall control.*

Bois Greffin, Pernier, Haiti. 1993-1999. Top: Prunings applied to the soil; Bottom: Prunings removed from plots. Data for seasons 11-13 are for unfertilized subplots.

Where the prunings were applied to the soil, the downward slope over time for these treatments is less apparent than for the rock wall treatment (Figure 5). By the fourth season and the sixth and following seasons, although not always significant, treatments of three-pruning regimes with prunings applied to soil consistently yielded equal or higher than the control despite the fact that there were fewer rows of maize in the alley-cropped plots than in the control. (Appendix Table 4). In the last two seasons, pruning three times with prunings applied to the soil averaged higher than the rock wall control (Figure 5 and Appendix Table 4).

Comparison of Alley Cropping with Rock Wall Control

Figure 6 provides another way to look at the data pooled across seasons. When averaged over all seasons and all treatments, the two-pruning regimes with prunings removed averaged only

36% maize grain yield compared to the rock wall control while the three-pruning regime with prunings removed from the plots averaged 58% of rock wall control. This is because during four of the first five seasons, highest maize yields were observed in the control plots with rock walls (Figure 5). This initial advantage for the rock wall control was partly because the control plots had 25% more plants. Competition between the leucaena and the trees likely also played a role. When considering only plots where prunings were applied to the soil, the 2-pruning regime averaged 72% of the control whereas the 3-pruning regime averaged 8% higher maize yields than the rock wall control. If one ignores the first season during which time there was no residual benefit from previous pruning applications, the 2-prunings applied treatments averaged 77% of the control, whereas the 3-prunings applied treatments averaged 13% higher than the control.

The second and third parts of Figure 6 compare means of the first six seasons with the means of the last six seasons for which the crop was harvested. In the first six seasons, the only alley cropping treatment that came close to the control was the 3-pruning regime with prunings applied to the soil. Between seasons 7 and 14, when it may be assumed that the soil in control plots was significantly depleted of nutrients, the 2-prunings applied treatments averaged 97% of the control, whereas the three prunings applied averaged 42% higher than the rock wall control (Figure 6). The difference between this treatment and the control was significant in four of the six seasons (Table 4).

This clearly shows the importance of pruning regime and application of hedgerow prunings to the soil if alley cropping is to be is to be successful and provide a yield superior to that obtained with rock wall conservation practices. The longer that alley cropping is practiced, the greater the benefit of the three pruning regime compared to the control (Figure 6). The treatments with prunings applied to the soil were also the treatment that remained the most stable over time (Figures 5, 6).

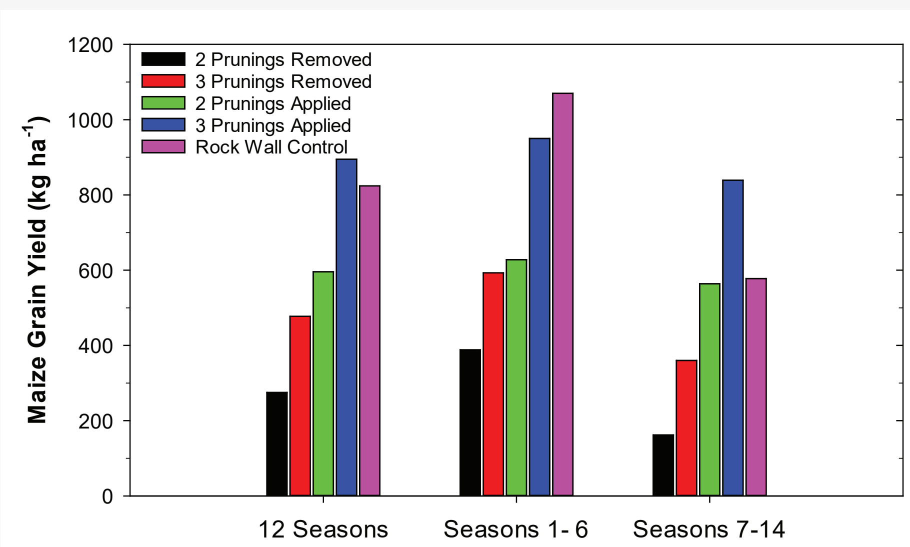

Figure 6. *Average maize grain yields over the 12 seasons for which plots were harvested compared to yields in the first and the last six seasons for which a crop was harvested, for two and three prunings with prunings removed from plots, two and three prunings with prunings applied to the soil, and for the rock wall control.*

Hedgerow Biomass Yield

Total biomass yield includes woody stems, small, mostly green stems and leaves. In season 1, mean total biomass yields recorded ranged between 13 and 17 Mg (metric tons) ha^{-1}, whereas in subsequent seasons, total biomass yields ranged between 1 and 6.2 Mg ha^{-1} (Figure 7). The data from Season 14 is not available. The reason for the higher yields in the first season is that the hedgerows had grown to be small trees by the start of the experiment with trunks measuring up to 7 cm in diameter (Photo 3). In subsequent seasons, there was much less woody material as regrowth was harvested several times a year. Total biomass yields fluctuated from season to season but was mainly in the 2 to 5 Mg ha^{-1} range (Figure 7).

A better assessment of the potential benefit of alley cropping to the associated crop is the amount of biomass in leaves and small green stems. The leaves decompose very rapidly and within two weeks of application of the prunings to the soil, the leaves are no longer visible on the soil surface. These leaves contain significant amounts of nitrogen (N) as well as phosphorus (P), potassium (K) and other plant nutrients that are readily available to the crop. The amount of leaf biomass averaged over treatments varied between 1.2 and 2.9 Mg ha^{-1} with the exception of Season 10, which was the second of two seasons of extreme drought that resulted in total failure of the maize crops (Figure 7). The fluctuations in hedgerow leaf yield likely reflect seasonal variations in rainfall. Each biomass harvest reflects growing conditions since the preceding harvest, including the end of the previous cropping season, and the preceding dry season

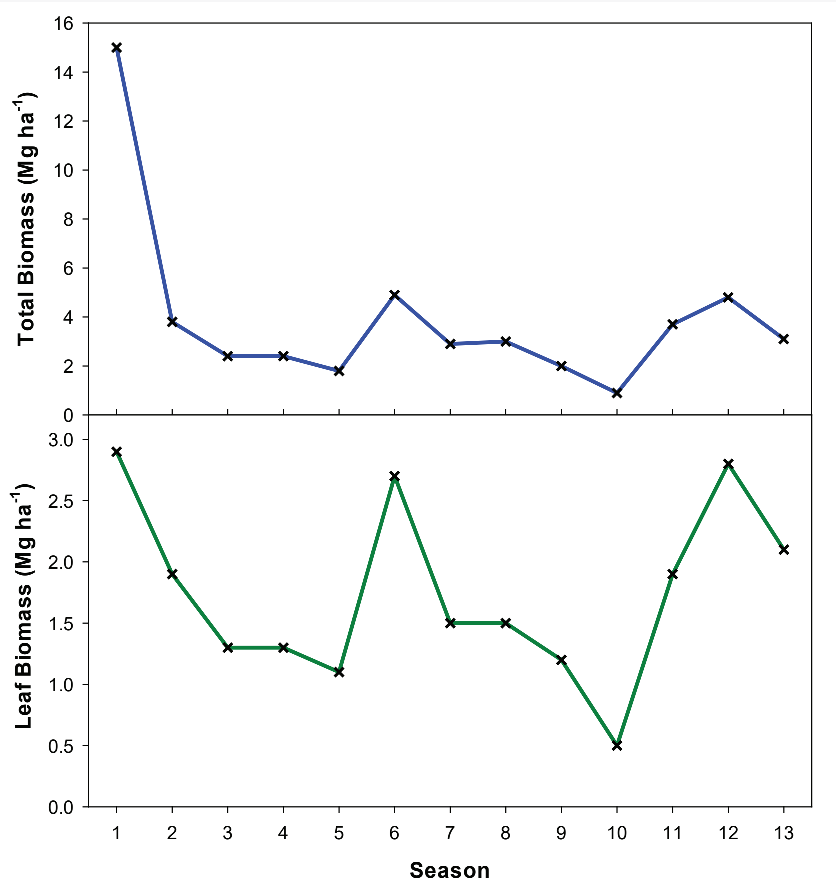

Figure 7. *Mean total and leaf dry weight biomass in hedgerow management trial over 13 seasons in Pernier, Haiti (1993-1999).*

in the case of the first harvest. The peaks in Season 6 and 12 reflect good rainfall following the last harvest in Seasons 5 and 11, respectively, as well as good rainfall distribution during the first parts of Seasons 6 and 12, including a hurricane in the middle of Season 12 (Appendix Figure A1). Seasons 9 and 10 had very poor rainfall, resulting in total loss of the maize crop, hence the dip in leaf yield in those seasons, especially in Season 10, the second season with severe drought.

Although not always significant, the trend of lower biomass yield with removal of prunings was consistent across 13 seasons for total biomass (Appendix Table 6) and 11 seasons for leaf biomass (Appendix Table 8). When averaged over 12 seasons, excluding the first and last seasons, removal of prunings from the plots resulted in 12% reduction in total biomass yield and 10% lower leaf yield than did application of the prunings to the soil (Figure 8). This is expected because removal of prunings means that nutrients in the harvested leaves and small stems were not available to the hedgerows or to the maize crop. One might have expected greater differences but perhaps the leucaena benefited from less competition from the maize in plots where prunings were removed from the plots, thus partially compensating for the negative effect of removal of nutrients from the plots.

Across the thirteen seasons, pruning twice gave significantly higher total biomass yield than pruning three times during ten seasons and the trend was consistent but non-significant for an additional three seasons (Table 6). Pruning twice gave significantly higher leaf biomass than pruning three times during six seasons, but a similar trend was observed for an additional three seasons (Table 8). Among the two-pruning regimes, a trend of greater leaf biomass with the later pruning was observed in eleven of thirteen seasons but the difference was significant for only three seasons (Appendix Table 8). Similar results were recorded for total biomass (Table 6).

However, if biomass yields are broken down into prunings applied vs prunings removed, a different trend is evident (Figure 8). When prunings were applied to the soil, there was little

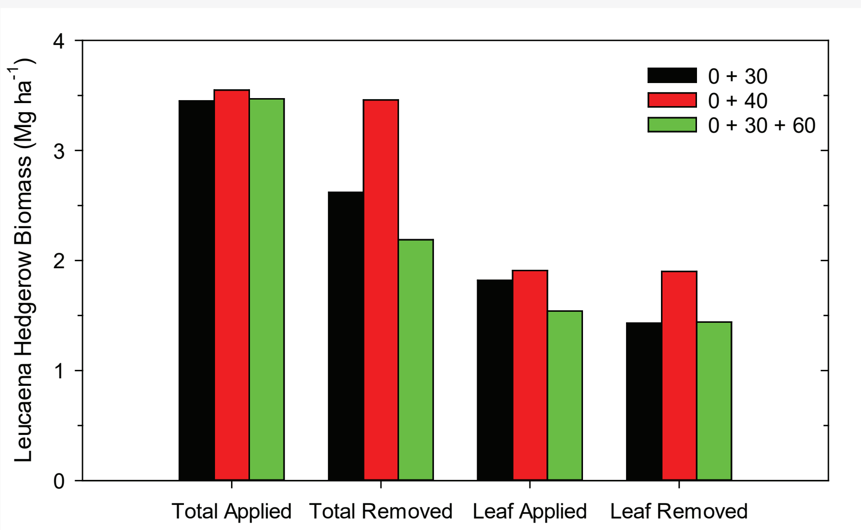

Figure 8. *Total and leaf dry weight biomass from leucaena prunings harvested from plots where prunings were applied to the plots and plots where prunings were removed during the second through thirteenth season from hedgerow management trial. Pernier, Haiti. 1993-2001.*

difference in total biomass between the three pruning regimes averaged over 12 seasons, but when prunings were removed from plots, pruning at 0 + 40 DAP gave 33% more total biomass than the 0 + 30 DAP regime and 58% more than the three-pruning regime. The trend is somewhat similar for leaf biomass but less pronounced (Figure 8). An interesting anomaly is that removal of prunings from the plot seemed to have little effect on total and leaf biomass with the 0 + 40 DAP treatment. It is also interesting that the third pruning had no effect on average leaf biomass yields compared to pruning at 30 DAP.

More biomass with the later pruning may explain why when prunings were removed from plots maize yielded more with the later pruning, whereas maize yielded more with the earlier pruning when prunings were applied to the soil. This may be a nutrient response from greater biomass with the later pruning. Defoliation of legumes has been shown to result in release of N from N-fixing nodules and roots into the soil (e.g. Whitney and Kanehiro, 1967). More above-ground biomass with second pruning at 40 DAP is likely reflected in more root and nodule biomass underground, which provides nutrients to the maize as roots and nodules decompose.

Hedgerow Biomass Contribution to Nitrogen Fertility under Varying Management

Isaac et al. (2004) analyzed leucaena biomass and N content in leaves and small stems (< 1cm diameter) and N concentration in maize ear leaf and grain from seasons 6 (95-B), 7 (96-A), 11 (98-A) and 13 (99-A) for N concentration and yield. These seasons were selected in part because they were less affected by drought than the intervening seasons (Figure 5, Appendix Figure A1). The leaf and small stem data reported by Isaac et al. (2004) follows a similar trend to the leaf data presented in Figure 8. Removal of prunings from the plots resulted in a 15% reduction in leaf and small stem

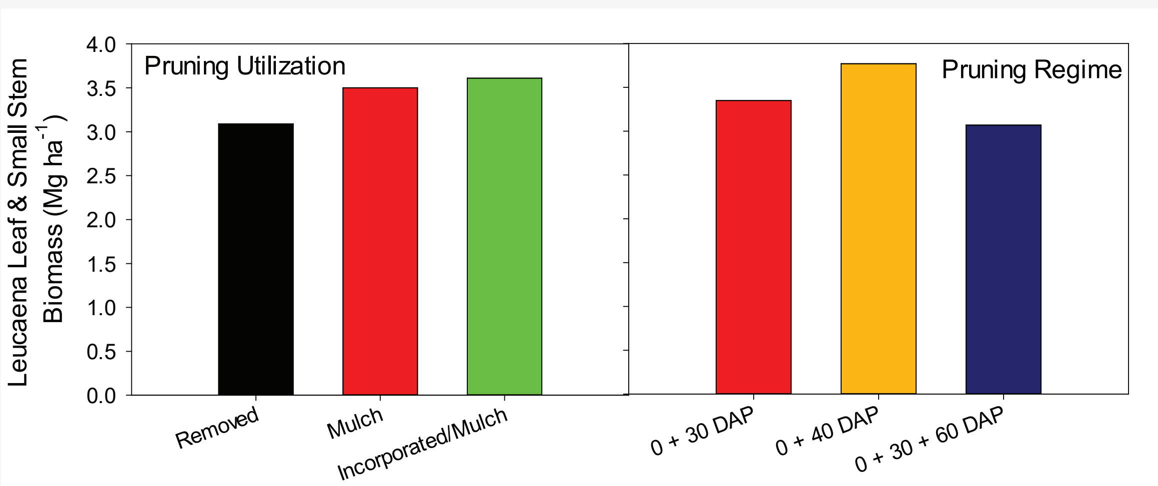

Figure 9. *The effect of hedgerow pruning use and pruning regime on leaf and small stem (< 1 cm) biomass harvested from leucaena hedgerows averaged over four seasons.*

(Seasons 6 (95-B), 7 (96-A), 11 (98-A) and 13 (99-A)). Pernier, Haiti. (Adapted from Isaac et al., 2004).

biomass harvested in the four seasons (Figure 9). The reduction was significant at the 2% level in Season 11 and at the 9% level in season 6 but did not test significant in Season 7 and Season 13.

Pruning twice per season resulted in significantly more leaves and small stems than did pruning three times in three of the four seasons (Isaac et al., 2004; Figure 9). These differences tested highly significant in Seasons 6, 7 and 13. Among the two 2-pruning regimes, carrying out the second pruning at 40 DAP resulted in higher leaf and small stem biomass than carrying out the second pruning at 30 DAP in all four seasons (Figure 9) and the difference was significant in three of the four seasons (Isaac et al. 2004).

Nitrogen Harvested in Leucaena Leaves and Small Stems

Similar results with respect to pruning utilization were observed with N contained in the harvested biomass (Isaac et al., 2004). Removal of prunings from the plots resulted in less N harvested in the leaf and small stem biomass (Figure 10). This trend was consistent in all four seasons and was significant in all but Season 13. There was no significant effect from incorporation of the first application on harvested leucaena N.

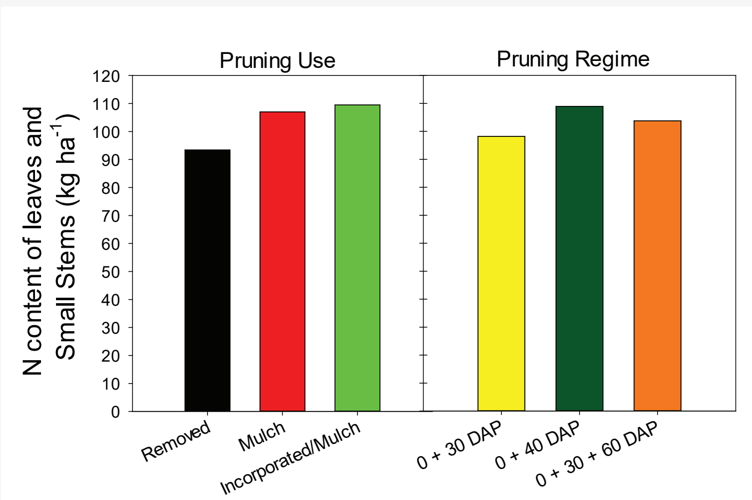

Figure 10. *The effect of hedgerow pruning use and pruning regime on N content in leaf and small stem (< 1 cm) N harvested from leucaena hedgerows averaged over four seasons.*

(Seasons 6 (95-B), 7 (96-A), 11 (98-A) and 13 (99-A)). Pernier, Haiti. (Adapted from Isaac et al., 2004).

There was less consistency in the data with respect to the effect of pruning regimes on N content of leucaena biomass over the four seasons compared to the data on biomass harvested (Isaac et al., 2004). Pruning three times resulted in less N harvested than pruning twice in seasons 6, but the reverse was true in Season 11. However, if one looks at the data from only the plots where prunings were applied to the soil, there was little difference between the pruning regimes averaged over the four seasons (Figure 11).

When prunings were removed from the plots, pruning at 30 DAP resulted in 27% less N harvested than when pruned at 40 DAP (Figure 11). The trend was consistent across the four seasons and the difference was significant in two. This is to be expected because more biomass harvested with the 0 +

40 regime would be expected to result in more N harvested.

Less can be made in terms of the comparison between the three-pruning regime and the two-pruning regimes because of inconsistencies across seasons, but the 3-pruning regime consistently ranked higher than the 0 + 30 DAP treatment in all four seasons (averaging 27% higher) and the difference was significant in season 11. It is doubtful that the difference between the three pruning treatment and the 0 + 30 DAP treatment would be important given the long-term trend in leaf yield which gave similar average yields across seasons (Figure 9, Table 8). The important point to note is that when prunings are applied to the soil, leucaena hedgerows provided on average more than 100 kg N ha^{-1} to the maize crop each season, or over 200 kg N ha^{-1} per year.

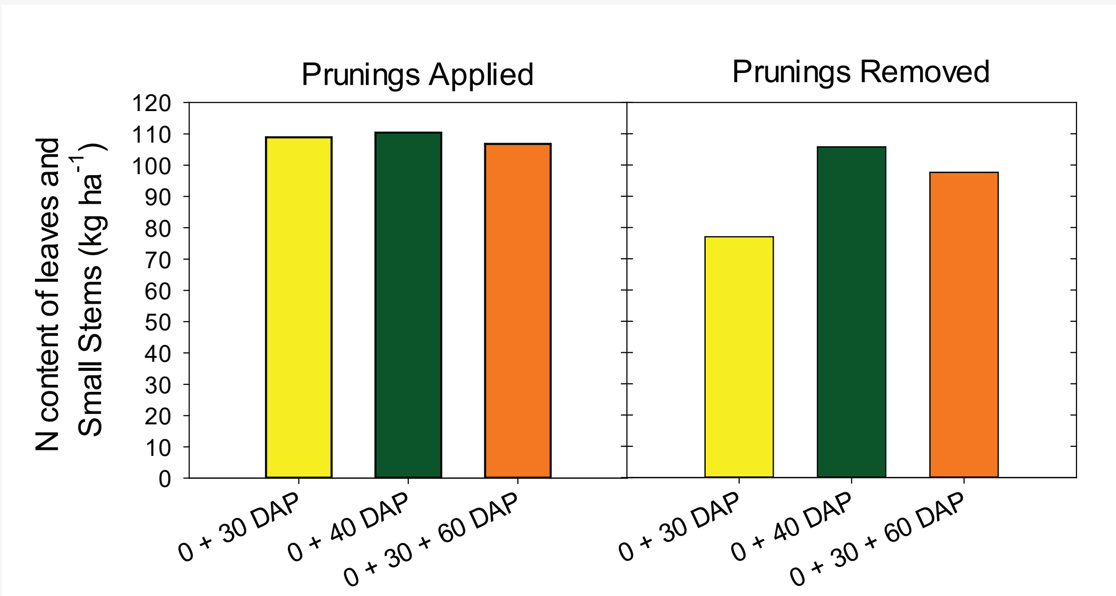

Figure 11. *The effect of hedgerow pruning regime with and without prunings applied to the soil on N content in leaf and small stem (< 1 cm) N harvested from leucaena hedgerows averaged over four seasons.*

(Seasons 6 (95-B), 7 (96-A), 11 (98-A) and 13 (99-A). Pernier, Haiti. (Adapted from Isaac et al., 2004).

The effectiveness of leucaena prunings as a N source that is readily available to the crop was demonstrated by an *in situ* decomposition study conducted by Isaac et al. (2000) on a similar calcareous soil at Bergeau in southern Haiti. Leaves and small stems were placed in nylon mesh bags that were placed on the soil surface and removed at intervals to determine the N remaining in the leaf and stem residues. Based upon the hedgerow biomass yields, they determined that close to 50 kg N ha^{-1} was released within two weeks and over 70 kg N ha^{-1} was released within four weeks (Figure 12). About 45% of the N contained in leucaena leaves was released in two weeks, whereas the stems released N at a much slower pace. Leucaena leaves were also shown to accelerate mineralization of N in the soil (Isaac et al., 2003a), thus further increasing N available to the plant. This shows that leucaena prunings applied to the soil at 30 or 40 DAP serve as an effective side dress of N that is available while the maize is actively growing, much as nitrogen fertilizer would.

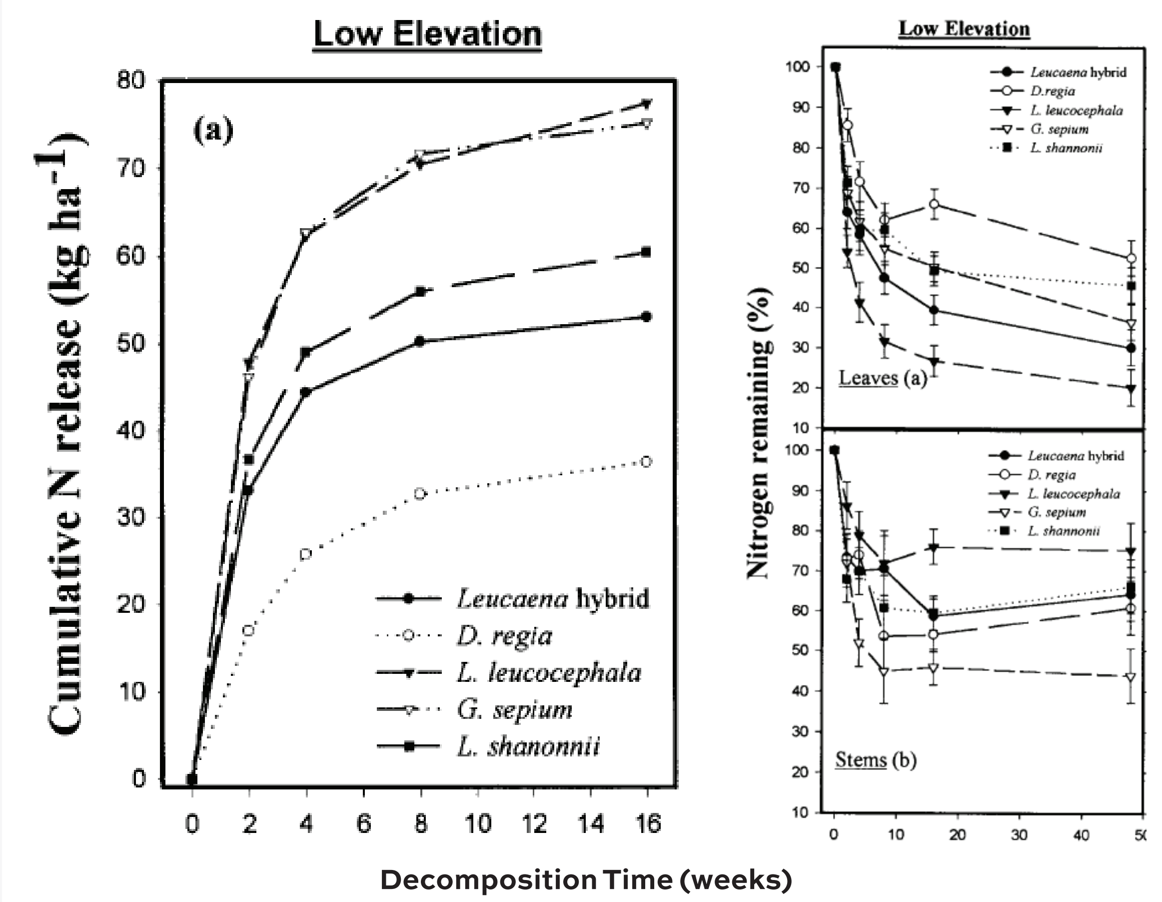

Figure 12. *Cumulative N release and percent N remaining from leucaena leaves and small stems in a decomposition study carried out in Bergeau, Haiti.*

(Adapted from Isaac et al., 2000).

N Uptake in Maize

Ear leaf N concentration provides an indication of N status in maize. Application of prunings to the soil significantly increased N concentration in maize ear leaves in each of the four seasons by an average of 15% compared to removal of the prunings (Isaac et al., 2004; Figure 13). Compared to the rock wall control plots, the prunings applied treatments averaged over pruning regimes were significantly higher than the control only in Season 6, but the trend for higher ear leaf N concentration was consistent in all four seasons. There was little difference between the prunings removed treatment and the control in ear leaf N.

For comparison purposes, Isaac et al. (2004) included data from a treatment in an adjacent alley cropping trial in which a low dose of fertilizer (37.5 kg each of N, P_2O_5 and K_2O ha^{-1}) was applied in addition to leucaena prunings (Shannon et al., 2003). In this trial, leucaena hedgerows were pruned three times per season at approximately 0 + 30 + 60 DAP with prunings applied to the soil as mulch. Addition of a low dose of compound fertilizer significantly increased ear leaf N by 11% in Season 7 compared to plots where prunings were applied to the soil without fertilizer (Isaac et al., 2004). Although not significant in the other three seasons, the trend was consistent in all four seasons. When averaged over the four seasons, the fertilizer increased ear leaf N by 8% (Figure 13). Because the basal application of N fertilizer was small and there was no side dress application of N fertilizer, one would not expect a large difference in ear leaf N content.

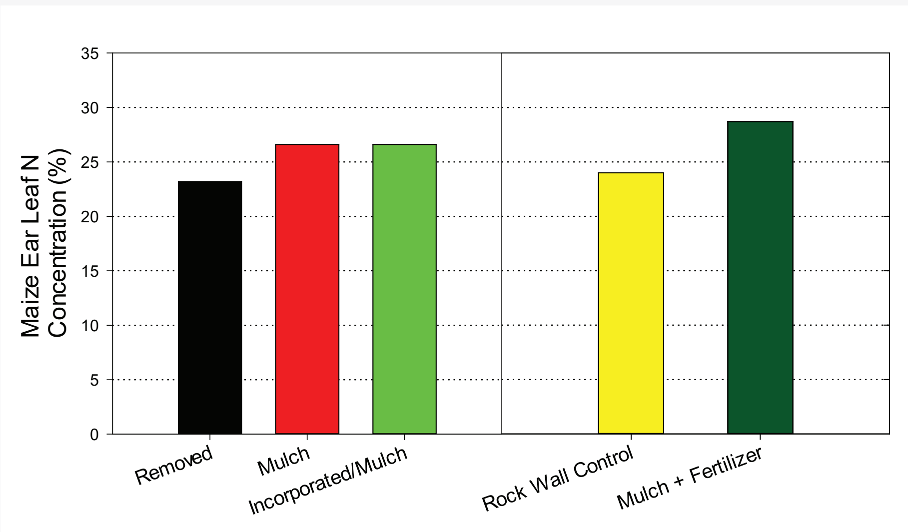

Figure 13. *The effect of hedgerow pruning use on maize ear leaf N concentration averaged over four seasons (Seasons 6 (95-B), 7 (96-A), 11 (98-A) and 13 (99-A)), compared to control plots with rock walls and alley cropping with a low dose of N, P and K. Pernier, Haiti.*

(Adapted from Isaac et al., 2004).

Pruning three times gave significantly higher ear leaf N than pruning twice in Seasons 6 and 7 (Isaac et al., 2004), but this did not hold true in Seasons 11 and 13. When averaged over the four seasons, pruning three times or pruning twice at planting and 40 DAP averaged 7% higher ear leaf N compared to pruning at planting and 30 DAP (Figure 14). When considering only the plots in which prunings were applied to the soil, the differences among pruning regimes were very small. The three prunings applied treatment averaged 13% higher ear leaf N than the rock wall control treatment. Addition of fertilizer significantly increased ear leaf N over the equivalent three-prunings applied treatment without fertilizer in Season 7, but the trend was consistent in each season (Isaac et al., 2004), giving an average increase of 6% due to addition of a low dose of compound fertilizer.

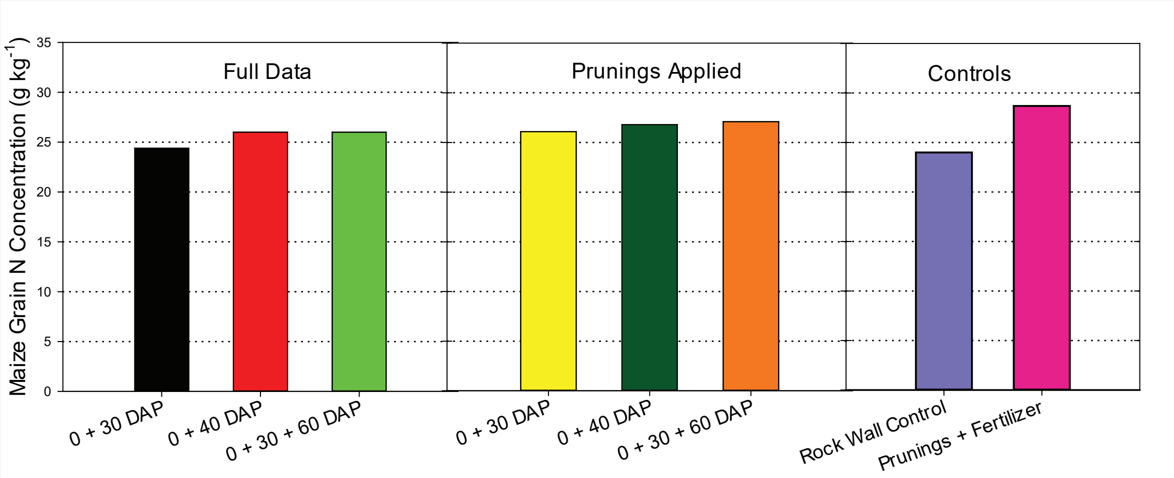

Figure 14. *The effects leucaena hedgerow regime on maize ear leaf N concentration. Pernier, Haiti.*

Average over seasons 6 (95-B), 7 (96-A), 11 (98-A) and 13 (99-A). Adapted from Isaac et al., 2004).

Much larger treatment differences were evident in N uptake in maize grain (Figure 15). Averaged over the four seasons, application of prunings to the soil resulted in 2.6 times more N taken up in the grain compared to removal of prunings (Isaac et al., 2004). Nitrogen uptake in the rock wall control plots averaged 2.3 times that in the "prunings removed" plots (Figure 15). Higher N uptake in the control than in the "prunings removed" treatments was significant by the $LSD_{0.05}$ method in season 13 and significant for all but the 3-prunings treatment in season 7, but the trend was consistent throughout. Higher N uptake in control plots than in the "prunings removed" treatments may be attributed to more maize plants harvested in control plots than in alley cropped plots and to the lack of competition for nutrients from leucaena hedgerows in the control plots.

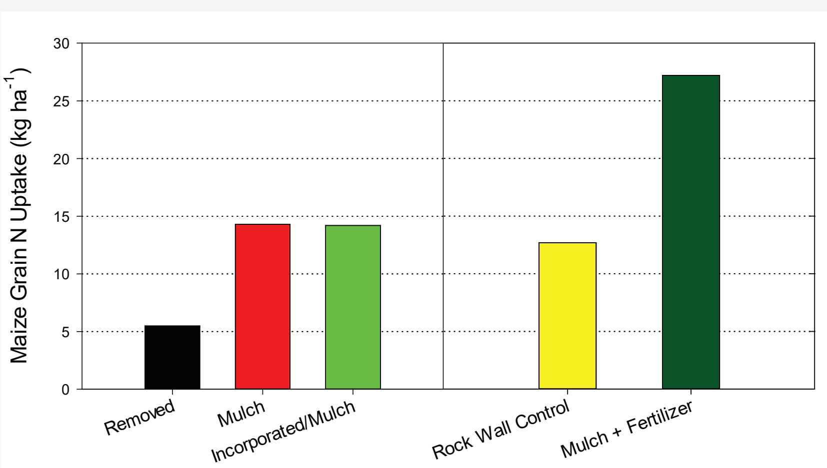

Figure 15. *The effects of leucaena hedgerow pruning use and application of fertilizer N, P and K with hedgerow prunings on maize grain N uptake.*

Average over seasons 6 (95-B), 7 (96-A), 11 (98-A) and 13 (99-A). Pernier, Haiti.

(Adapted from Isaac et al., 2004).

Application of a low dose of compound fertilizer nearly doubled N uptake in the grain compared to application of prunings only (Figure 15). Higher grain N uptake is primarily related to increased grain yield from application of a combination of leucaena prunings and chemical fertilizer.

Pruning three times increased grain N uptake by an average of 60% over pruning twice (Figure 16). The difference was significant in three of four seasons (Isaac et al., 2004). Pruning twice showed little difference compared to the rock wall control, even when considering only plots in which prunings were applied to the soil (Figure 16). The lack of benefit from alley cropping with two prunings may be attributed to loss of cropping area to the hedgerows, as well as possible competition for water and nutrients from leucaena hedgerows. However, when the hedgerows were pruned three times with prunings applied to the soil, grain N uptake was 48% higher than in the rock wall control. This suggests that there was a better utilization of N from leucaena prunings with the three-pruning regime than with pruning twice per season and that some of the N released from the pruning at 60 DAP likely was taken up by the maize. Addition of a low dose of compound fertilizer further increased grain N uptake by an additional 45% over pruning three times without fertilizer. This data clearly shows the advantage pruning three times at an interval of 30 days over pruning twice, and the benefit of combining alley cropping with a moderate application of fertilizer.

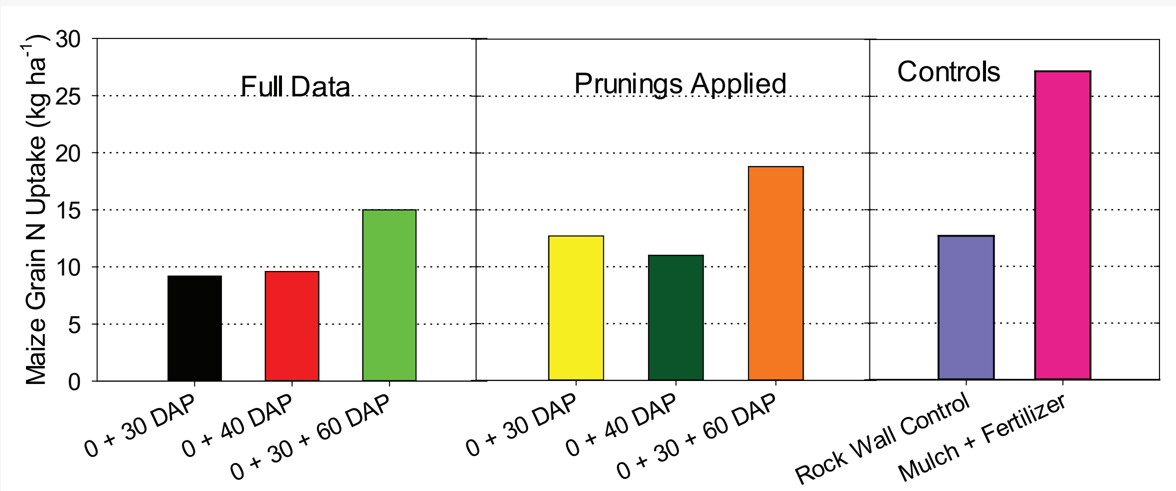

Figure 16. *The effects of leucaena hedgerow pruning regime on maize grain N uptake. Average over seasons seasons 6 (95-B), 7 (96-A), 11 (98-A) and 13 (99-A). Pernier, Haiti.*

(Adapted from Isaac et al., 2004).

Soil organic N and C

Isaac et al. (2003b) measured organic N and C in the soil following 3.5 years of alley cropping. They also measured organic N and C in the plots in the previously mentioned trial in which a low dose of fertilizer (37.5 kg each of N, P_2O_5 and K_2O ha^{-1}) was applied in addition to leucaena prunings

(Shannon et al., 2003). Application of prunings to the soil significantly increased soil organic N in the 0 – 20 cm depths compared to removal of prunings (Figure 17). Application of prunings significantly increased soil organic N in the surface 5 cm compared to the rock wall control, but a similar trend in lower profiles did not test significant. Application of prunings with added fertilizer did not increase organic N compared to the control or prunings removed treatments. Isaac et al. (2003b) attributed this to higher mineralization rates in the presence of fertilizer. Pruning regimes had no effects on soil organic N.

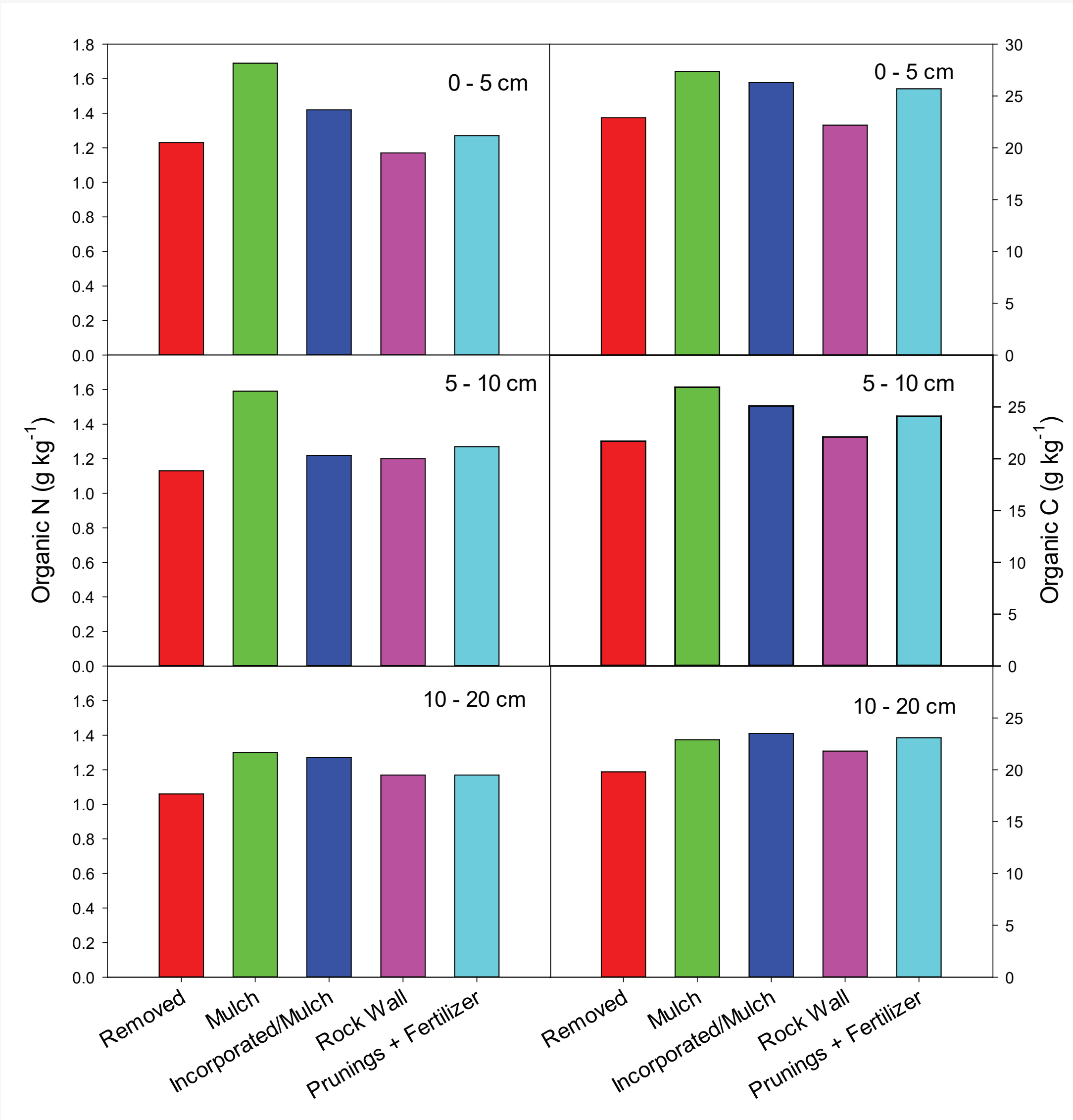

Figure 17. *The effects of leucaena hedgerow pruning applications on soil organic N and C content at three depths in the soil profile after seven cropping seasons (3 1/2 years). Pernier, Haiti. (Adapted from Isaac et al., 2003b).*

Application of prunings to the soil significantly increased soil organic C at all depths compared to removal, although compared to the rock wall control, the difference was significant only in the surface 5 cm (Isaac et al., 2003b; Figure 17). Surface application of prunings as mulch resulted in 18% higher organic C in the soil profile than did incorporation of the first pruning in each season, which was significant, and 34% higher than removal of prunings. The authors attributed the lower organic matter with incorporation of first pruning than surface application to more rapid mineralization when incorporated. Tillage is known to accelerate decomposition of soil organic matter due increased microbial activity in response to increased oxygen availability in the soil. In this case, incorporation of leucaena prunings required an additional tillage that was not carried out in the mulch treatments.

Application of a combination of prunings and fertilizer increased soil organic C compared to the rock wall control at the 0-5 cm depth and compared to prunings removed at the 10-20 cm depth, but other differences did not test significant (Isaac et al., 2003b; Figure 15). Addition of fertilizer did not significantly affect soil organic C. Alley cropping with leucaena increased soil organic C and N when prunings were applied to the soil, but not when prunings were removed from the plots. Pruning regimes had less effect than pruning use on soil C and N (Isaac et al., 2003b). Pruning at planting and 40 DAP had the most soil organic C at 0 – 20 cm soil depth. The authors associated this with greater biomass harvested with this regime, together with lower N and higher polyphenol concentrations in the leaves with later harvest, which can slow decomposition.

The important point for practitioners of alley cropping is that application of prunings to the soil not only increased N uptake by the maize, resulting in higher crop yields, but also maintained soil organic C and N in the soil at a higher level than continuous cropping with removal of prunings or not having hedgerows at all. The yield benefit of a low dose of compound fertilizer was 68% over hedgerow prunings alone, averaged over 14 seasons in an adjacent trial (Shannon et al., 2003). There was no benefit in terms of soil organic N or organic matter from planting hedgerows when hedgerow prunings are removed from the plot as would be the case when they are used to feed livestock, or from using a soil conservation practice such as rock walls that don't contribute biomass to the soil. Application of a low dose of inorganic fertilizer did not increase soil organic N and C but did benefit the crop.

Phosphorus and Potassium Effects on Alley Cropped Maize

This alley cropping experiment was originally carried out without the use of fertilizer in order to simulate the prevalent conditions of most low resource farmers. However, during seasons 11, 12 and 13, former graduate student Jean René Bossa split each of the plots and applied 60 kg P_2O_5 and 40 kg K_2O ha^{-1} as triple superphosphate and muriate of potash to one half of each plot at planting, while the other half was not fertilized. Maize was harvested from both halves of each plot in order to assess the additional effect of added fertilizer P and K in conjunction with alley cropping. Nitrogen fertilizer was not applied because it was assumed that N would be supplied by the leucaena prunings. Isaac et al. (2004) reported that prunings contributed an average of over 100 kg N ha^{-1} per season, which enabled the crop to respond to added P and K.

The data was analyzed for each season and pooled analyses over the three seasons was also conducted. Factorial analysis of the alley cropped treatments are presented in Table 3b and an analysis comparing treatment combinations with the rock wall control is presented in Table 4b. Application of P and K in the presence of hedgerow prunings significantly increased maize yield, but had no significant effect in alley-cropped plots where prunings were removed and no or minimal effect in the rock wall control plots (Tables 3b, 4b) (J.R. Bossa, unpublished data).

Season 12 was characterized by drought (Appendix Figure 1) and no grain was harvested in some plots. In Figure 18 - 20, the data are plotted using average yields from Seasons 11 and 13. (The analysis was adjusted for missing data in season 11 in two of the plots containing the 3-pruning applied treatments in one replicate which resulted in adjusted means close to 50 kg ha^{-1} below the arithmetic means of the remaining plots in the same treatments, but the adjusted means are shown) Yields were lower when each of the three seasons were included but the general conclusions remain unchanged. In the "prunings removed" treatments, and to a lesser extent in the control plots, the ability of the maize to respond to added P and K (Figure 18) was likely limited by N deficiency in the soils, which had been continuously cropped to maize for 10 seasons without fertilizer. On the other hand, in plots where prunings were applied to the soil, application of P and K increased yield by 36% in Seasons 11 and 13, or 37% averaged over the three seasons. The lack of significant response to added P and K in the absence of leucaena prunings is consistent with Liebig's law of the minimum, which states that crop yield is limited by the nutrient element that is least available relative to the plant's nutrient requirements. The residual effect of P and K fertilization in Seasons 11 – 13 was readily visible in Season 14, even though fertilizer was not applied in Season 14 (Photos 7, 8, 9, 10). We did not harvest each subplot separately in Season 14 because of the extra labor required, but the pictures tell the story.

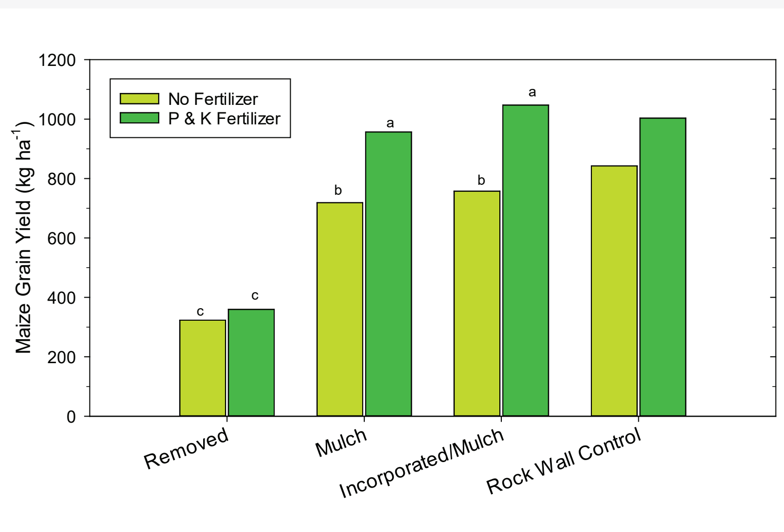

Figure 18. The main effects of added P and K in plots with and without leucaena biomass and in rock wall control in seasons 11 and 13. Pernier, Haiti.

(J.R. Bossa, unpublished data). Data were adjusted for missing plots in Season 11 using the least squares method (LSMEANS). Bars having the same letter were not significantly different at the 5% level by the LSD method. The rock was control was not included in the factorial analysis, but yields are presented for comparison purposes.

Photo 7: *Residual effect of P and K fertilizer in Season 14 in alley cropped plot with prunings removed. Agronomist Carine Bernard stands between fertilized and unfertilized area of plot. Fertilized subplot is on left. Note stunted growth of maize. October 1999.*

Photo 8: *Residual effect of P and K fertilizer in Season 14 in alley cropped plot in which prunings were applied to the soil. Carine Bernard is standing in fertilized subplot, Mr. Delva in unfertilized subplot. Note difference in height and color of maize compared to preceding photo.*

Photo 9: *Residual effect of P and K fertilizer in control plot in Season 14. Fertilized area is on left, unfertilized on right. October 10, 1999.*

Photo 10: *Residual effect of P and K fertilizer in Season 14 in alley cropped plot with three prunings per season applied to soil. Fertilized area is on left. Note soil buildup above hedgerows enhanced by branches.*

Application of P and K increased maize grain yield irrespective of pruning regime (Table 4b). Figure 19 shows the response to P and K application with respect to pruning regimes averaged over season 11 and 13 in plots where prunings were applied to the soil. Highest yields with alley cropping were obtained with P and K fertilizer in the 3-pruning regime, with P and K fertilizer increasing yield by 29% in Seasons 11 and 13 (Figure 19), or 33% averaged over the 3 seasons (Table 4b). Similar percentage yield percentage increases with P and K were observed with the other two pruning regimes.

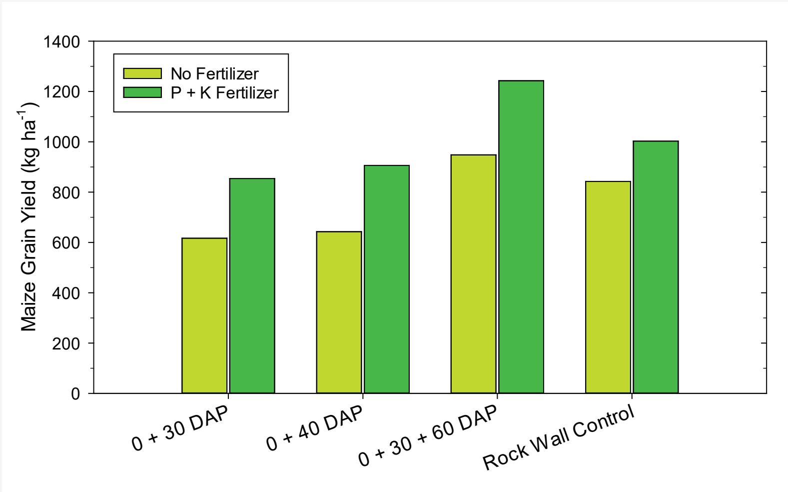

Figure 19. *The effects of pruning regime and added P and K fertilizer on average maize grain yield in seasons 11 and 13 in plots where prunings were applied to the soil. Pernier, Haiti.*

(J.R. Bossa, unpublished data). Data were adjusted for missing plots in Season 11 using the least squares method (LSMEANS).

It is worth noting that the two-pruning regimes with prunings applied to the soil were not superior to the control plots (Figure 19, Table 4b). This is because the benefit from application of prunings to the soil was not sufficient to compensate for the loss of cropping area to the hedgerows in addition to competition from the trees. This provides further evidence that for alley cropping to be superior to no alley cropping in terms of crop yields, hedgerows should be pruned three times per season.

When the control is compared to the best treatment combinations, a different picture emerges (Figure 20). Alley cropping with hedgerows pruned three times and prunings incorporated followed by mulch gives significantly higher yield than the rock wall control and the respective mulch treatment approached significance at the 5% level of probability. However, because of a missing plot

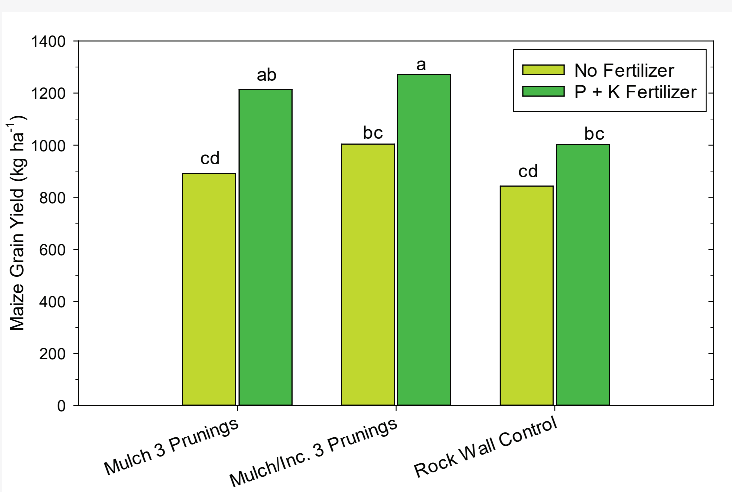

Figure 20. *Comparison of best alley cropping treatments with rock wall control, averaged over Season 11 and 13.*

Bars with the same letter are not significant at the 5% level based upon standard errors of the mean.

in the mulch treatment and an unfertilized subplot in the incorporated/mulch treatment, we did not attain the same level of separation from the control. Nevertheless, it does show the superiority to the control of the 3-pruning regime with prunings applied to the soil. Fertilization with P and K significantly increased yield in the alley cropping plots but the apparent increase in yield in control plots was not significant.

A significant interaction was observed between seasons and treatments (Tables 3b and 4b). Because of severe drought, in season 12 no grain was harvested in plots where prunings were removed, regardless of whether fertilizer was applied or not, and also when the prunings were applied to the soil at 0 + 40 DAP. Figure 21 shows an interaction between the effects of the 2-pruning regimes at 30 DAP vs pruning at 40 DAP when prunings were applied to the soil with respect to seasons. In Seasons 11 and 13, there was little difference between the two two-pruning regimes, whereas in season 12, the 10-day delay in the second pruning resulted in no yield. This is undoubtedly the result of competition between the hedgerows and maize for limited water. The interactions between pruning regimes and drought are discussed in greater detail in the next section.

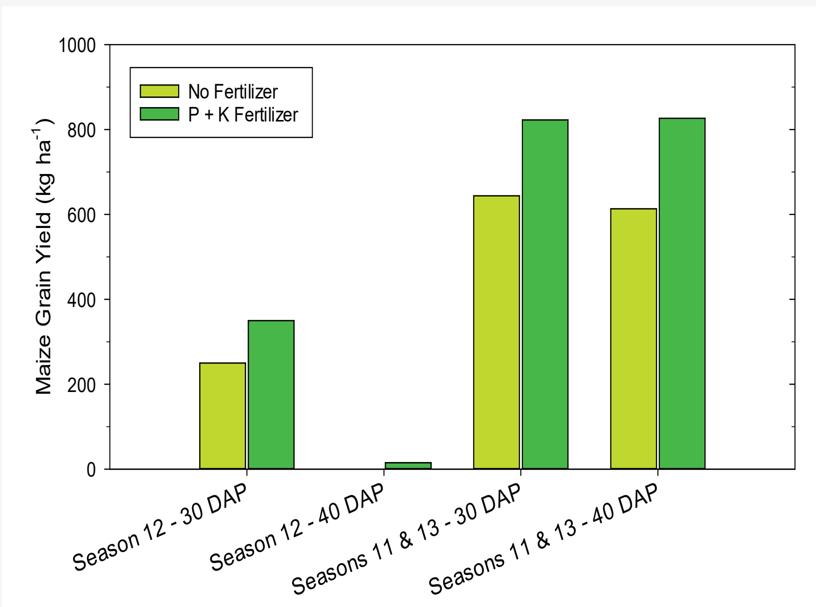

Figure 21. *Comparison of the effects of a 10-day delay in pruning on maize yield and fertilizer response in a season of extreme drought (season 12) and seasons where drought was less severe.*

Data shown are least square means for plots where prunings were applied to the soil. Although the adjusted means show a minimal yield for pruning at 40 DAP with fertilizer, no maize was harvested from these plots.

In a leaf decomposition study carried out at Bergeau, Haiti, on a soil similar to that of Pernier, 43% of leaf P and 52% of leaf K was released after 4 weeks (Bossa et al., 2005a). After 32 weeks, 70% of P and 96% of K was released for a total of 4.9 kg P and 24 kg K ha^{-1}. This demonstrates that alley cropping recycles plant nutrients in addition to adding N to the system. However, the amount of K and especially P was not large and if a soil is deficient in these elements, the amount of P and K contained in leucaena leaves may not be sufficient to meet the demands of the crop. In this case, application of chemical fertilizer or an organic source containing P and K might be in order as was observed in the trial at Pernier. In a separate study at other sites, Bossa et al. (2005b) reported increased maize yield with application of leucaena prunings with or without fertilization with P and K.

In conclusion, application of P and K fertilizers will increase yields in absence of added N fertilizer when prunings are applied to the soil. Farmers who have limited resources to purchase fertilizer should focus on addressing soil deficiencies in P and K. A major portion of the N requirement by maize can be met by the N contained in the leucaena prunings (Isaac et al., 2004).

A Note on Zinc

The Pernier site is situated over limestone bedrock and consequently has a high pH. Several micronutrients including zinc (Zn) have reduced availability to plants on alkaline soils. Phosphorus also known to compete with Zn for uptake by plants. Thus, when Zn availability is low, as is the case on high pH soils, fertilization with P can induce Zn deficiency in plants. In a literature review, Garcia et al. (1995) reported a median value of 169.5 mg Zn kg^{-1} leucaena forage consisting of both leaves and stems. If one assumes four metric tons of leaves and small stems, this is equivalent to 0.7 kg Zn ha^{-1}. This suggests that leucaena prunings may have the potential to mitigate the detrimental effects of P application on alkaline soils.

On a site adjacent to the hedgerow management study, Dr. Bossa compared application of 10 kg Zn ha^{-1} in addition to 60 kg P_2O_5 and 40 kg K_2O ha^{-1} with application of P and K alone in absence of leucaena prunings. Although the treatments did not test significant because of high heterogeneity in the trial, maize yield increases of 22%, 32% and 35% over P and K alone were observed due to Zn application in the three seasons (J.R. Bossa, unpublished data). Similar yields were observed with application of P and K together with hedgerows but without Zn. While this study was inconclusive, the potential of alley cropping to mitigate micronutrient deficiencies through recycling of nutrients merits further study.

Management of Competition for Water in Alley Cropping

Haiti's climate and weather patterns are a function of its mountainous terrain and its location in the northern part of the Caribbean Sea, resulting in highly variable climate and vegetation within small distances. The experimental site in Pernier was located at approximately 250 m elevation on the northern foothills of the La Selle mountain range, whose highest peaks surpass 1800 m elevation. Since prevailing winds are from the southeast, Pernier lies in a partial rain shadow of the mountains located to its south and southeast. Although the mean annual rainfall of over 1300 mm over the period of the trial would be considered satisfactory for maize production, we encountered gaps in rainfall distribution resulting in visible drought stress on the maize. In addition, the shallow depth of soil to bedrock and the steep slope of the field limited the capacity of the soil to store water following major storms. Consequently, drought stress was a factor at some period during most seasons and resulted in total crop loss in two seasons. This location was therefore an ideal location for assessing whether pruning regime can mitigate drought stress in an alley cropping system.

Graduate student Hua Kang (2004) analyzed maize yields over the twelve seasons in which a crop was harvested to assess the effects of hedgerow management in relation to occurrence of drought. Since data on soil moisture or plant measurements were not available, drought incidences were determined by examination of rainfall records. Appendix Figure A1 provides rainfall information in conjunction with pruning operations and tasseling and silking of maize. While there is an element of subjectivity to this analysis, it is possible to identify large gaps in the rainfall record in which drought stress was likely. We considered amounts and timing of rainfall in relation to pruning dates and in relation to tasseling and silking dates and the grain filling period, during which times maize grain yield is most vulnerable to drought stress.

Seasons 3, 6, 7 11, 12 and 13 were found to have drought between 30 and 40 DAP. Figure 22 compares the two-pruning regimes with a second pruning occurring at 30 or at 40 DAP in the six seasons without drought during that period and the six seasons with drought during that period. In this case, only plots where the prunings were applied to the soil were considered. In the six seasons when there was not significant drought stress between 30 DAP and shortly after 40 DAP, there was no significant difference between a second pruning at 30 DAP and pruning at 40 DAP. In the six seasons in which there was drought during the same period, a 10-day delay in pruning resulted in a 19% loss in maize yield, which was statistically significant (Figure 22).

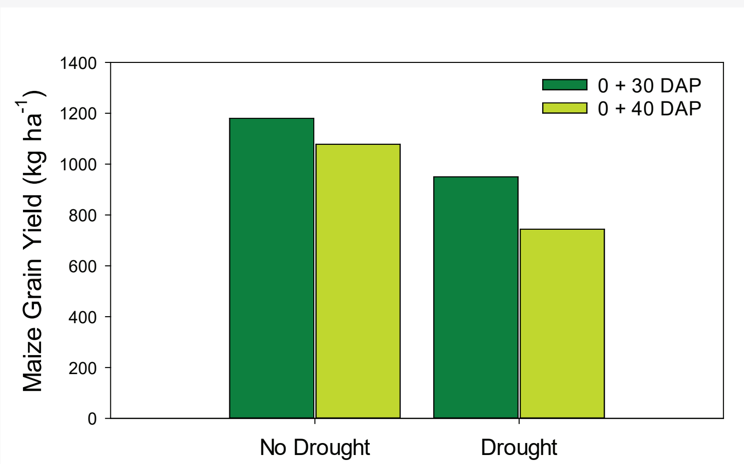

Figure 22. *The effects of second pruning at 30 DAP and at 40 DAP in the two-pruning regime during six seasons with drought during the period of 30 DAP to shortly after 40 DAP compared to no drought during the same period. Pernier, Haiti.*

(*Kang, 2004*)

Seasons 7, 12 and 13 were selected as having severe drought during and immediately following silking and tasseling, when maize yield is most vulnerable to drought stress. In season 4, maize may have also suffered drought stress during part of the tasseling period, but abundant rainfall occurred at the end of that period, therefore it was not included in this analysis. Pruning three times resulted in 40% higher maize yield than pruning twice when drought was absent during and following silking, but 79% higher in the three seasons when there was drought during or after silking (Figure 23).

What this long-term data suggests is that pruning the hedgerows immediately prior to or during periods of drought reduced competition for water between the leucana and the maize. This is a reasonable assumption because removal of most of the leaf area of the trees removes the ability of the trees to transpire and take up moisture from the soil. If drought occurred early in the season, pruning at 30 DAP was superior to pruning at 40 DAP. If drought occurred during the reproductive period, pruning a third time at 60 DAP gave a proportionally higher advantage over pruning twice than during periods when drought was absent during that period.

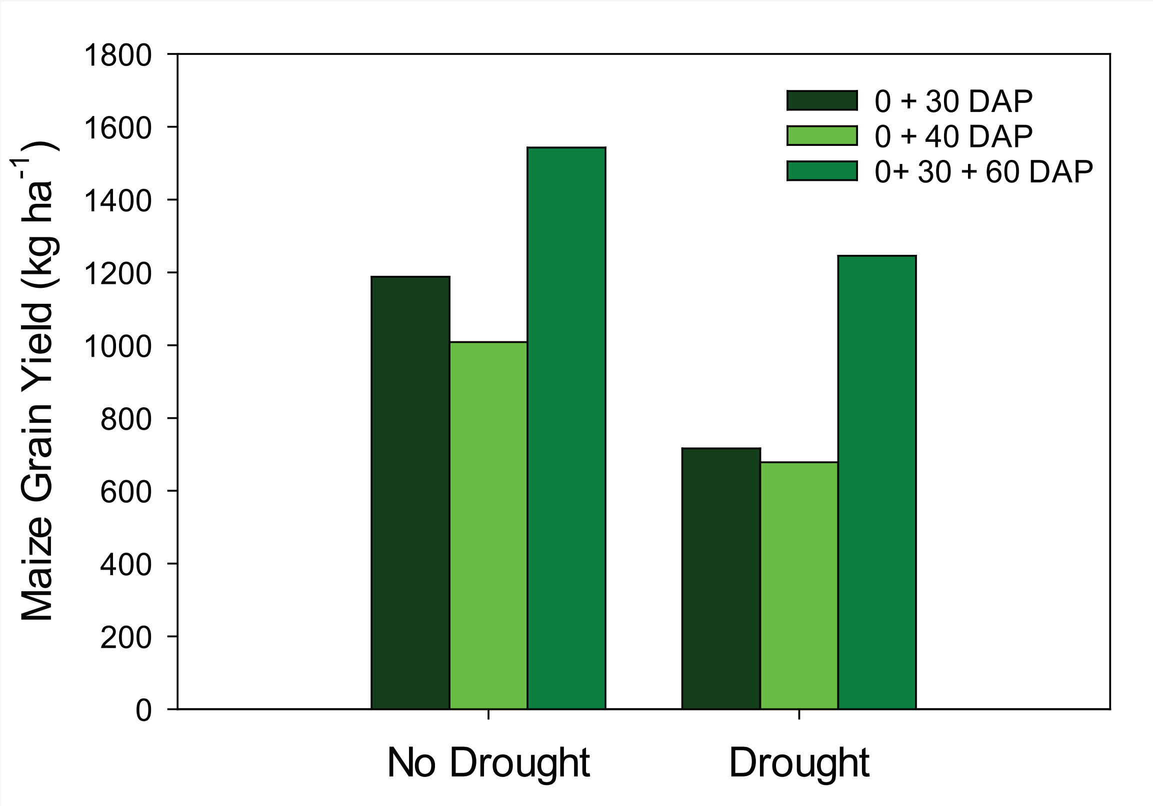

Figure 23. *The effects of drought during and following tasseling and silking on the relative advantage of pruning three times compared to pruning twice. Pernier, Haiti.*

(Kang, 2004). Data shown are for plots in which prunings were applied to the soil.

It is worth pointing out at this point that for convenience we have talked about the first pruning taking place at planting, but operationally the first pruning of the seasons took place prior to planting. Under erratic rainfed conditions, once pruning was completed, we sometimes had to wait for rain before planting the maize. Consequently, during the twelve seasons, the first pruning preceded planting by a range of two to eighteen days, with an average of nine days (Appendix Tables A1, A2).

Effect of Row Position and Drought

When barriers are established on contours on a steep slope under cultivation, terraces rapidly form as soil moves from upper positions on the terrace and accumulates above the barrier due to both water erosion and tillage. This was observed in both plots with rock walls and leucaena hedgerows. In each terrace (plot), the soil was deepest above barriers and shallowest below the uphill barrier. This was generally reflected in the row yields, with highest yields in the rows lowest on the terrace and lower yields in the rows progressively higher in the terrace (Photo 11). That is to be expected because the greatest volume of soil for retaining water and nutrients occurred directly above the rock wall or hedgerow. These observations are also consistent with surveys conducted by Bannister and Nair (1990) of hedgerows of leucaena and other tree species in farmers' fields.

Photo 11: *Terrace formation with soil buildup behind lower hedgerow on slope due to soil movement within the plot. This results in larger maize plants above hedgerows whereas plants are stunted below upper hedgerow where soil is shallow. In front of Agronomist Carine Bernard is a plot where prunings were removed. Plants are stunted and N deficient. Behind her is a plot where prunings were applied to the soil. Plants are taller and greener. Residual effect of P and K fertilizer is also visible in foreground. October 1999.*

Kang (2004) statistically analyzed row-by-row yields as affected by the position on the slope and proximity to hedgerows in relation to drought. Figure 22 shows maize yield in the four rows within alley-cropped plots in six seasons in which drought was observed during the 30 – 40 DAP period and those seasons in which drought stress was not observed during the same period. During the six seasons in which no drought was experienced during this period, highest yield was observed in the rows lowest on the terrace (row 4), with each row position higher on the slope yielding significantly lower than the yield of the row lower on the terrace. In the seasons where drought was observed, there was no statistical difference between rows 3 and 4 (Figure 24).

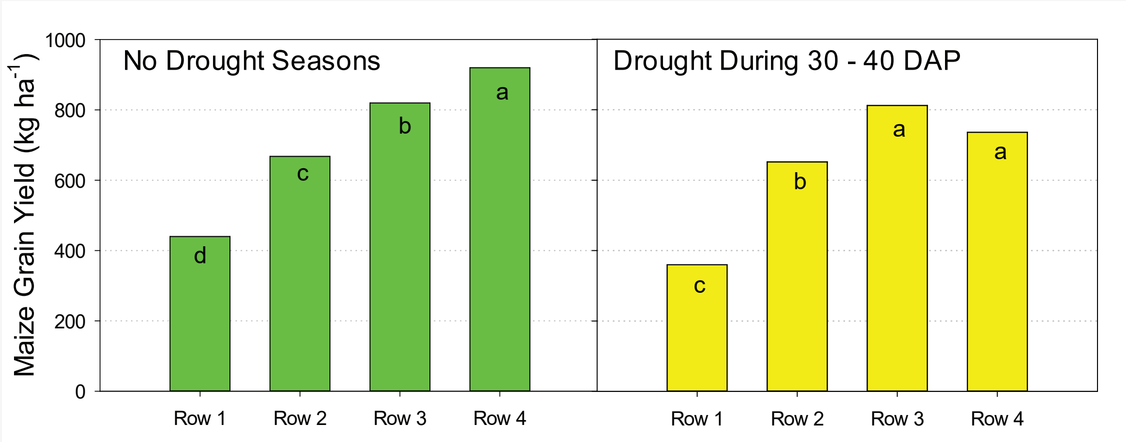

Figure 24. *Maize row yields during six seasons without drought during the 30 – 40 days after planting maize and six seasons with drought during the same period.*

(Adapted from Kang, 2004. Data shown are for plots in which prunings were applied to the soil. Row 1 is row highest on the terrace slope and immediately below a hedgerow. Row 4 is lowest on the terrace and immediately above a hedgerow.) Columns with the same letter do not different at the 5% level of probability as determined by the LSD method.

A similar effect is evident when examining the effect of drought during and immediately following tasseling and silking (Kang, 2004). In the seasons where no major drought was observed during and following tasseling, highest yields were in the rows lowest on the terrace (Figure 25). In this case, the difference between row 3 and row 4 was not significant for plots where prunings were applied to the soil, but if all alley cropping plots including those where prunings were removed from the plots were considered, row 4 yielded significantly higher than row 3. When one considers the three seasons where drought was observed in that same period row 3 yielded higher than row 4.

What this row-by-row analysis suggests is that maize in rows immediately above the leucaena hedgerows benefited from the higher volume of soil and the greater availability of nutrients and water, but during periods of drought, the maize rows closest to the hedgerows suffered more from competition from the hedgerows than maize in position 3. Under drought, row position 3 had the highest yields despite having less soil volume to retain water than row 4, presumably because they were farther away from the hedgerows. This is consistent with data published by Odhiambo et al.

(2001) who reported soil moisture and maize yields were lowest in maize rows closest to pruned *Gliricidia sepium* or *Grevelia robusta* trees.

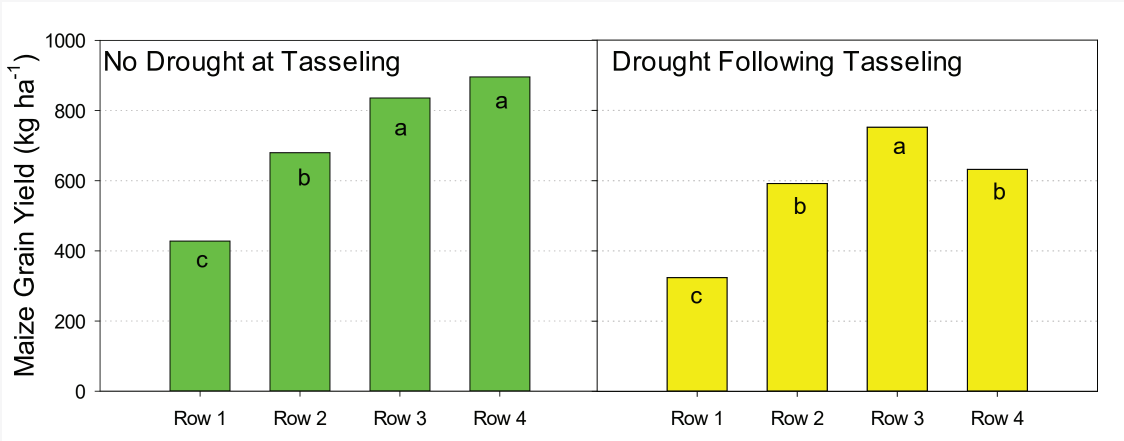

Figure 25. *Maize row yields during nine seasons without drought during and following tasseling and silking and three seasons in which drought occurred during and immediately following tasseling and silking.*

(Kang, 2004). Data shown are for plots in which prunings were applied to the soil. Row 1 is row highest on the terrace and immediately below a hedgerow. Row 4 is lowest on the terrace and immediately above a hedgerow. Columns with the same letter do not different at the 5% level of probability as determined by the LSD method.

The plots with rock walls showed similar position effects as the plots with hedgerows (Hua Kang, unpublished data). However, when drought occurred during the 30-40 DAP period, the rock walls tended not to show higher yields in position 3 than position 4 unless drought also occurred during the tasseling and silking period. During the early period of drought, the maize plants would have been smaller and of course not having trees to compete with, so the controlling factor was soil volume. A possible explanation for the opposite effect when drought occurred during and following tasseling may be that the soil may have dried out more quickly at the porous rock wall face and with maize plants being larger and consuming more water than earlier in the season, plants in position 3 may have had an advantage.

The observations based upon rainfall records and crop yields presented above are circumstantial. We did not measure drought stress directly on the maize plants. In addition, all three seasons that were determined to experience severe drought stress during the reproductive stage of maize were also determined to have drought stress during the 30 to 40 DAP period. However, they do suggest that an important effect of hedgerow pruning is to mitigate competition for water. By pruning the branches and leaves, evapotranspiration by the trees mostly ceases, leaving most of the water in the soil to the maize in the alleys.

In order to quantify the effect of pruning on moisture status in maize, Hua Kang (Kang et al., 2008) carried out a study in central Alabama where she measured stomatal conductance (CD), leaf transpiration (TR) as well as photosynthetically active radiation (PAR) in maize rows planted adjacent to hedgerows of *Albizia julibrissin* Durazz., known locally as "mimosa". Mimosa is a nitrogen fixing leguminous tree adapted to the Southeastern United States and very tolerant of pruning, much like leucaena. The trial included three pruning regimes of mimosa and two pruning heights. She found that pruning at the time of a drought resulted in reduced CD and TR and increased maize grain and stover yields, suggesting that there was less competition for soil water because of pruning of the hedgerows. There was also a row position effect for CD, TR and PAR, suggesting greater competition for water and light in the rows closest to the hedgerows. This confirms the observations made at Pernier that pruning of hedgerows during periods of drought reduced competition for limited soil water in the rooting zone.

SOME FINAL THOUGHTS ON ALLEY CROPPING

Implication of this Research for Haiti

Haiti is a very mountainous country with a high population density. Consequently, many farms are located on very steep slopes, not amenable to mechanization. In many developed countries, cultivation of annual crops would not be allowed on these slopes, while in parts of Asia, such fields would be terraced. Many Haitian farmers lack alternatives to cultivating steep slopes and terracing with rock is limited primarily to high value crops on land where rock is readily available to construct walls. Much of crop production on steep slopes is carried out on land that is not terraced. How can low resource farmers cultivate these lands sustainably without incurring severe soil erosion, depletion of soil nutrients and loss of productivity? The problem is not simply how to prevent soil erosion, but also how to maintain soil fertility and crop productivity.

Alley cropping addresses both of these issues. Carine Bernard and Agricultural Engineer Dr. Kyung Yoo measured runoff and sediment loss in three plots on a 30% slope using flumes and Coshocton wheel samplers in a trial adjacent to the experiment described in this document (Shannon et al., 2002). Compared to a control plot with no erosion control barriers, tree barriers reduced runoff and sediment loss from nine-year old hedgerows by 41% and 92%, respectively, in the second season of 2000, and by 4% and 40%, respectively, in the first season of 2001. During the same seasons, rock walls, spaced the same 4 m distance apart as were hedgerows, reduced runoff and sediment loss by 73% and 90% in second season 2000 and 53% and 69% in first season 2001. Although both practices helped to reduce runoff and soil loss, only the alley cropped plots sustained maize yields over 17 seasons of continuous cropping (Shannon et al., 2003).

The impetus for this research on alley cropping was based upon the fact that planting of hedgerows on contours was already being promoted for soil conservation to counter severe land degradation on steep slopes. In areas where the bedrock is limestone, construction of rock walls on contours is an alternative soil conservation measure, albeit labor intensive. However, soil conservation with rock wall terraces cannot sustain crop yields under continuous cropping without supplemental fertilization (Shannon et al., 2003). In areas where stone is not available, tree or grass hedgerows are more viable alternatives for soil conservation. But grass conservation barriers cannot provide the N needed by crops and competes with the crop for water, N and other nutrients. In a trial comparing various soil conservation practices with alley cropping (Shannon et al., 2003), plots with grass conservation barriers gave lower maize yields than did rock walls or tree hedgerows.

Small land holdings often do not generate sufficient revenue to invest in a significant amount of commercial inputs. Trees that provide fixed N to the crop while reducing runoff and soil erosion provide a low-cost alternative to farmers.

One of the objections that some farmers have had to planting leucaena is that the trees produce lots of seed and the resultant seedlings can pose a weed problem. However, when the trees are pruned on a regular basis in an alley cropping system the trees seldom flower and do not produce seed.

The problem from a soil fertility standpoint is that most Haitian farmers that have conservation hedgerows do not apply the prunings from hedgerows to the soil. Our data show that removal of prunings from alley-cropped plots without addressing the fertility needs of the crop is not sustainable. One of the constraints that Haitian farmers who practice mixed farming face is a shortage of fodder for livestock, especially during the dry season. Most farmers may own some goats, and those who are better off may own a donkey or horse for transportation, and one or more head of cattle. During the cropping season, livestock are prevented from entering cropped fields, but once the harvest is over, free grazing is practiced. The hedgerows, which remain green during the dry season when fresh fodder is in short supply, are often heavily grazed by livestock, leaving little new growth for mulching at the start of the growing season. Sometimes the hedgerows are destroyed due to overgrazing. During the cropping season, when farmers prune the hedgerows they normally practice cut and carry, removing the leaves and small stems from the field to feed livestock. This makes economic sense because the opportunity cost to applying hedgerow prunings to the soil is high. Livestock are more valuable to farmers than commonly grown subsistence crops such as maize or sorghum. Agricultural Economist Zach Lea estimated that "marketing the forage through an animal produces nearly four times the revenue-minus-labor expense" than a maize and bean crop (John Dale (Zach) Lea. 1993. Initial Financial Evaluation of Hedgerows. Unpublished working document for the USAID/Haiti PLUS Project). However, the practice is detrimental to sustainable crop production and subsistence farmers will plant food crops for their own consumption and sale.

One partial solution to address the fodder shortage is to plant fodder trees such as leucaena together with forage grasses on sites unsuitable for food crops (Dean Treadwell, personal communication, 1991). This would provide livestock with an alternative to browsing hedgerows in cropland. When combined with confinement of livestock in a cut and carry system, or tethering in the field, fodder gardens would reduce browsing on the hedgerows while benefiting livestock production. Mr. Treadwell was able to incentivize farmers to confine goats and to adopt a cut and carry practice by providing a breeding service using superior breeds.

Another strategy would be to focus on increasing the profitability of crops grown within the alleys. Farmers more readily change their behavior when there are economic incentives to do so. For example, farmers who grow vegetables for the urban market are willing to construct rock wall terraces and apply fertilizer and pesticides on their crops because of their high value. In 1998, we visited farmers in Bannate in southern Haiti who were growing tomatoes in alleys between hedgerows of leucaena for a factory in Les Cayes. The farmers were very enthusiastic about applying hedgerow prunings as mulch to the tomato crop.

In 1999, Budry Bayard (Bayard et al., 2004, 2007) carried out a survey on adoption and management of hedgerows in alley cropping in Bannate and a neighboring village of Gaïta. Factors leading to adoption and management of the hedgerows included group membership, training in soil conservation practices and per capital income. He indicated the need for economic incentives to promote adoption and management of alley cropping.

In 2010, Dr. Bayard and I visited Bannate again. The tomato factory had closed, and the farmers had reverted to growing traditional crops and allowing the livestock to heavily graze the hedgerows. This shows that the farmers were responding to market conditions. Anything that increases revenue from an alley cropping system will increase willingness to adopt proper management practices. Interventions that result in better market access and higher farm-gate prices, as was the case in Bannate when the factory purchased their tomato production, will also increase farmer willingness to invest in proper management of hedgerows to benefit the crops grown. The introduction of high value crops or practices and varieties that increase yields will enhance the attractiveness of alley cropping to farmers.

Alley cropping is not a panacea, but it can enable farmers with limited ability to purchase inputs to sustainably and continuously crop sloping land while also conserving soil and water. Development workers and extension agents should include alley cropping as one of practices offered to farmers.

The Place of Alley Cropping in the Tropics

Alley cropping is one of several solutions proposed to enable low resource farmers in the tropics to maintain soil fertility through N fixation and maintaining organic matter in the soil. Replenishing of soil organic matter is especially important on very sandy or highly weathered soils with low cation exchange capacity to retain plant nutrients, where a significant portion of plant nutrients is held in soil organic matter. The choice of how to sustain soil fertility and crop production will depend upon advantages and disadvantages of different practices within the context of existing farming systems and agro-ecological environments.

Alternatives to alley cropping include rotation with legumes or legume-grass cover crops, application of mulch or farmyard manure, intercropping with legume crops or legumes grown uniquely to supply N and organic matter, such as *Canavalia*. One interesting practice that is being promoted in eastern and southern Africa consists of planting holes or basins, where tillage and application of manure, fertilizer and/or compost is limited to restricted areas occupied by the crop, thus minimizing tillage and making better use of limited farmyard manure, mulch and fertilizer, if available (anonymous, 2007). Another interesting system is the *tapato* slash/mulch system used traditionally in parts of Central America, where a velvet bean (*Mucuna puriens* (L.) DC.) cover is grown together with maize. Each alternative has certain advantages, requirements and limitations.

All practices that involve the introduction of non-food crops into a cropping system for soil fertility purposes entail costs to the farmer that do not bring an immediate benefit. Rotations with cover crops require taking a field out of food production and investing in land preparation, planting and cover crop establishment without an obvious return unless livestock grazing is an important part of the farmer's system. A perennial cover crop must be terminated by turning the soil, not an easy task without mechanization, or by applying herbicides, which may not be accessible to the farmer. Annual legumes such as velvet bean reseed themselves and can become weeds in the subsequent crop. Alley cropping, by contrast, does not take an entire field out of production, and once established, the hedgerows do not require replanting for many years. Weeds tend to be less under alley cropping than in open fields. When leucaena trees are left unpruned they produce significant amounts of seed, but the trees do not flower or produce seed when regularly pruned. While pruning of hedgerows requires labor, it probably does not compare with clearing fallow land. Pruning hedgerows in research plots is a very tedious endeavor because it entails meticulously separating prunings into woody stems, small stems and leaves in order to get good hedgerow production data, but that is not the case under normal production. While the first pruning in the season may entail cutting woody stems, the second and third prunings in a season should go quickly with a sharp machete.

A concern raised about alley cropping is low adoption rate. The same could be leveled against alternative practices promoted to restore soil fertility and sustain crop production. During the colonial period in Africa, considerable effort was placed on research into legume cover crops, but without significant adoption. Research on cover crops and green manures were being conducted in Nigeria as far back as 1925 (Faulkner, 1934) and studies on the effects of legume management on soil nutrient status followed shortly thereafter (Doyne, 1937), but farmers there did not adopt cover crops. Cover crops were a subject of research in the initial years at the agricultural experiment station in Gandajika, Democratic Republic of Congo, founded in the 1930s, but no farmers were employing cover crops when the first author was posted there in the 1985. One exception is the use of velvet bean by farmers in Benin as a cover crop to suppress infestation by the grass weed, *Imperata cylindrica* (L. Capo-Chichi, personal communication).

Rotations with cover crops require sufficient land to continue to grow crops and continued access to the land following fallow. Rotations with grain legumes provide limited benefit to subsequent crop, since much of the N fixed by the crop is removed in the harvested grain, especially if the harvest index is high. Any system that involves interplanting of annual legumes with a crop has the same issues of interspecies competition for water, light and nutrients as does alley cropping. This competition must be well managed, or crop yields will be reduced. Although the legumes such as *Canavalia* that are interplanted with a crop may fix N, very little of that N will be available to the crop until the following season. The exception is alley cropping, where the trees, once established, are pruned before the crop is planted and again while the crop is actively growing, thus providing N directly to the associated crop. Farming systems in which livestock play a limited role and especially where animals are not confined cannot provide the amount of farmyard manure needed to sustain soil fertility on a large scale.

Secondary benefits are important considerations. In the case of velvet bean cover crop in Benin, suppression of a noxious weed was a secondary benefit not related to soil fertility. Alley cropping has an advantage over other systems on sloping lands where soil and water conservation are important for sustaining crop production. Alley cropping also has the secondary benefit of providing a source for firewood. In savanna areas of the tropics, and even in densely populated forest zones, much time can be spent collecting firewood for cooking because of its scarcity. Alley cropping provides a ready source of firewood, especially in the first pruning of each season after the dry season. This viewpoint is confirmed by a study conducted in southwest Cameroon, where adoption of alley cropping was higher in areas where firewood were in short supply (Adesina et al., 2000).

All of these systems involve some level of management, as well as labor. Not all farmers will want to pay attention to proper timing of hedgerow pruning. But as discussed earlier, it may be possible to incentivize this behavior if it can be shown to be economically profitable. Thus, alley cropping has a greater chance of adoption if crops that bring a high return in the market are grown rather than subsistence crops.

As a system for low resource farmers to maintain soil fertility and productivity, alley cropping has a comparative advantage over other alternatives where land is limited and where there are secondary benefits, such as soil conservation on sloping land or provision of firewood in savanna. The inclusion of high value crops or practices that increase profitability will help to promote its adoption.

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APPENDIX

Figure A1. *Rainfall distribution pattern at Pernier, Haiti, and time of planting (P) and pruning (Pr) operations with respect to rainfall and tasseling (T) and silking (S) dates in the experiment.*

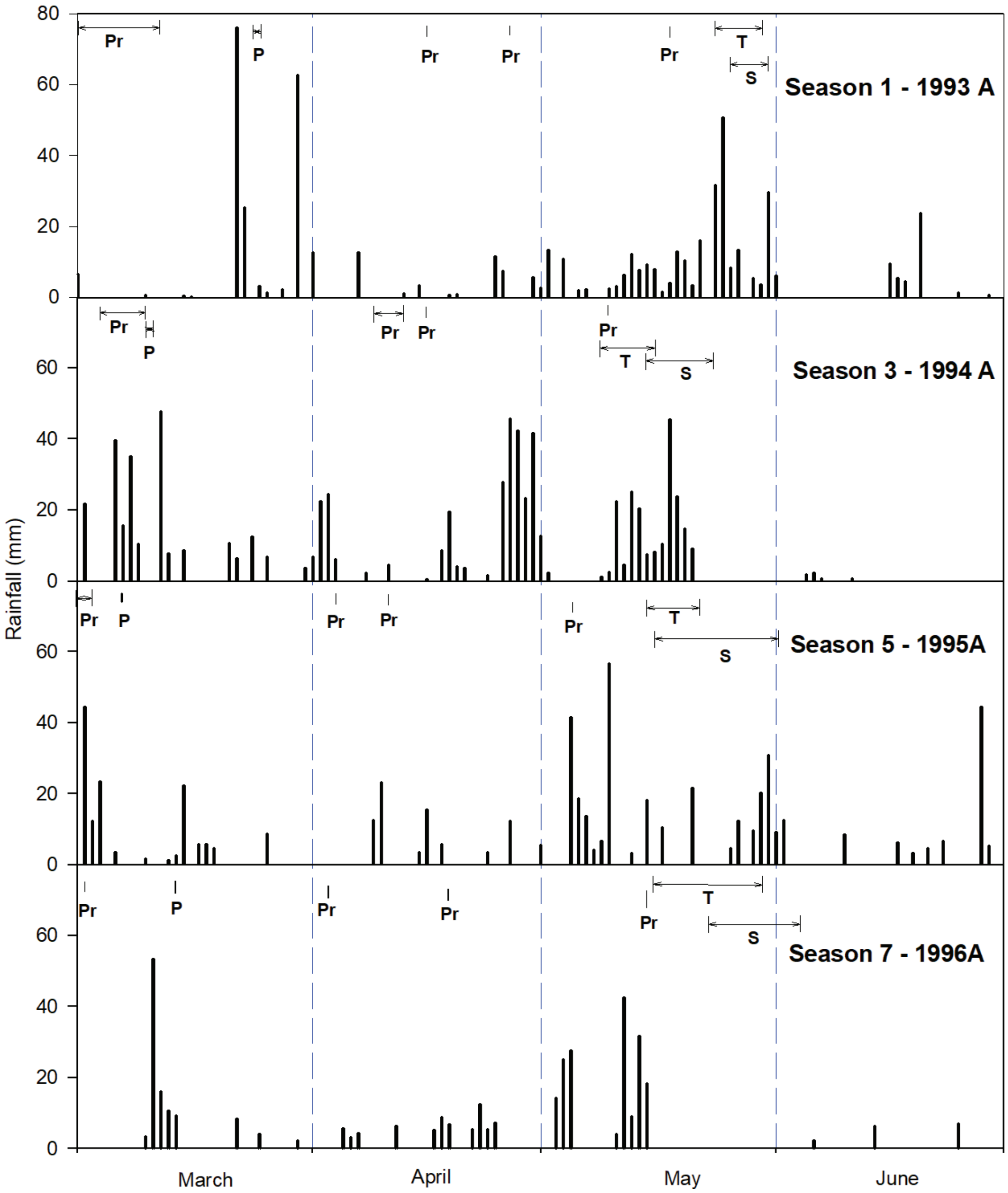

Figure A1, *continued. Rainfall distribution pattern at Pernier, Haiti, and time of planting (P) and pruning (Pr) operations with respect to rainfall and tasseling (T) and silking (S) dates in the experiment.*

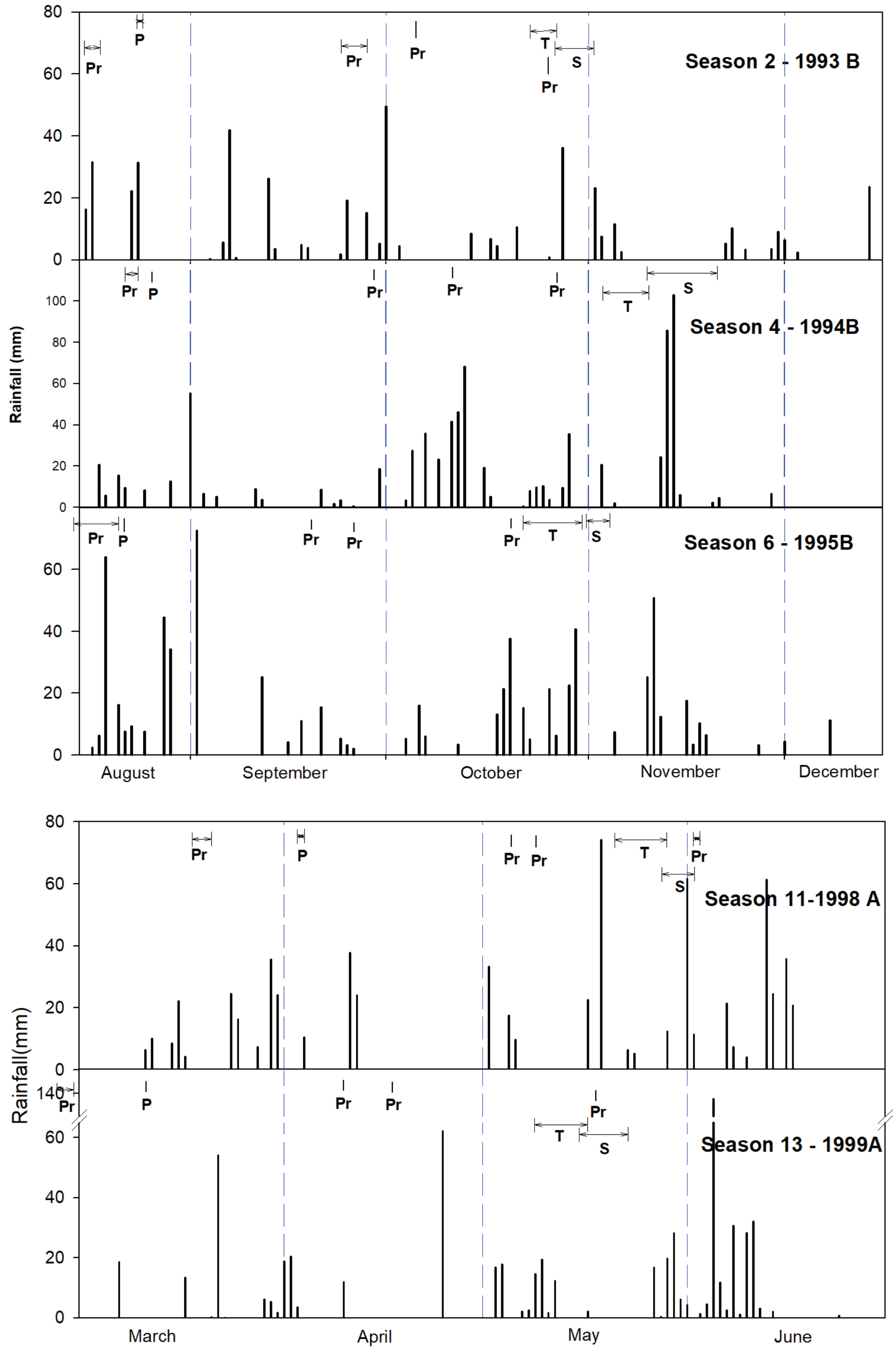

Figure A1, *continued. Rainfall distribution pattern at Pernier, Haiti, and time of planting (P) and pruning (Pr) operations with respect to rainfall and tasseling (T) and silking (S) dates in the experiment.*

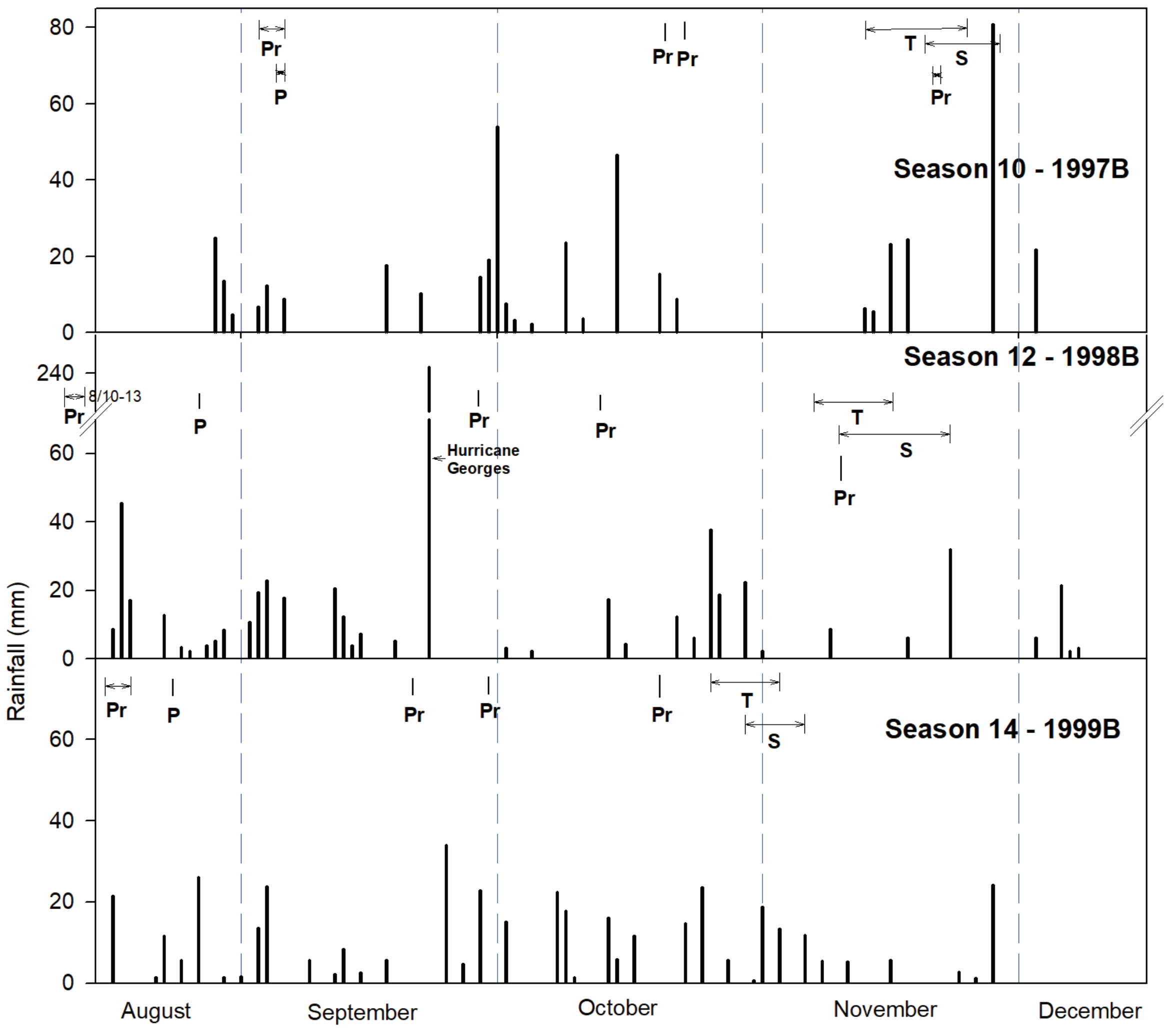

Table 1. *Timetable of field operations on hedgerows & growth stage of maize.*

SEASON	Field Operations					Maize Stages			
	FINAL Tillage	1ST Pruning	30 DAP Pruning	40 DAP Pruning	60 DAP Pruning	(D/M/Y) Plant	50% Tassel	50% Silking	Harvest
1 (1993-A)	8-12/2	1-11/3	15/4	26/4	17/5	23-24/3	23-29/5	25-30/5	14-15/7
2 (1993-B)	2-9/8	16-18/8	24-28/8	4/10	25/10	24-25/8	22-26/10	26/10-1/11	14-15/12
3 (1994-A)	22-25/2	3-9/3	8-12/4	15/4	9/5	9-10/3	8-15/5	14-23/5	7-8/7
4 (1994-B)	10-16/8	22-24/8	26/9	11/10	27/10	26/8	2-10/11	10-21/11	3-4/1
5 (1995-A)	6-10/2	23/2-2/3	3/4	10/4	4/5	6/3	15-22/5	16-30/5	5/7
6 (1995-B)	24-26/7	14-21/8	20/9	26/9	20/10	22/8	24-29/10	30/10-3/11	18-19/12
7 (1996-A)	5-9/2	26/2-1/3	2/4	18/4	14/5	13/3	15-28/5	22/5-3/6	15-16/7
10 (1997-B)	1-6/9	2-5/9	20/10	22/10	20-21/11	4-5/9	12-24/10	19-28/10	14/1
11 (1998-A)	16-20/3	17-20/3	4/5	8/5	1-2/6	2-3/4	20-28/5	27/5-1/6	21-23/7
12 (1998-B)	3-7/8	10-13/8	28/9	12/10	9/11	27/8	6-15/11	9-22/11	22/12
13 (1999-A)	1-5/2	22-26/2	9/4	16/4	17/5	10/3	8-16/5	15-22/5	14/7
14 (1999-B)	9-18/8	16-19/8	21/9	30/9	19/10	24/8	25/10-2/11	28/10-5/11	3/1

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

Table 2. *Timing hedgerow management operations and growth stage of maize with respect to planting date.*

SEASON	Field Operations					Maize Stages		
	(D/M/Y) Plant	1ST (0 DAP) Pruning	30 DAP Pruning	40 DAP Pruning	60 DAP Pruning	50% Tassel	50% Silking	Harvest
1 (1993-A)	23-24/3	-13	21	32	53	61	63	111
2 (1993-B)	24-25/8	-8	32	39	60	60	64	110
3 (1994-A)	9-10/3	-4	31	35	60	63	56	118
4 (1994-B)	26/8	-3	30	45	61	66	70	128
5 (1995-A)	6/3	-9	27	34	58	73	77	119
6 (1995-B)	22/8	-4	28	34	58	65	74	117
7 (1996-A)	13/3	-11	20	35	61	68	74	122
10 (1997-B)	4-5/9	-2	45	47	76	43	45	129
11 (1998-A)	2-3/4	-14	31	35	59	51	56	100
12 (1998-B)	27/8	-16	32	46	74	73	78	115
13 (1999-A)	10/3	-18	30	37	68	62	68	124
14 (1999-B)	24/8	-7	28	37	56	64	68	129

Note: *When operations involved multiple dates, value was mean of differences between start and finish dates of each operation.*

Table 3. *Maize grain yields over 12 cropping seasons as affected by leucaena pruning management in alley cropping. Pernier, Haiti.*

	CROPPING SEASON†											
	1 93-A	2 93-B	3 94-A	4 94-B	5 95-A	6 95-B	7 96-A	10 97-B	11 98-A	12 98-B	13 99-A	14 99-B
Factors	kg ha^{-1}											
PRUNING APPLICATION (PA)												
Removed	600	580	520	430	380	240	240	160	380	30	300	250
Mulch	870	690	780	850	600	630	740	430	830	210	840	840
Incorporated/Mulch‡	860	740	820	820	670	530	690	390	850	240	960	810
Orthogonal Comparisons												
Removed vs Applied	***	**	***	***	***	***	***	**	***	***	***	***
Mulch vs Incorporated	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	0.07	ns
PRUNING REGIME (PR)												
Planting + 30 DAP§	680	550	580	610	420	480	370	320	570	200	500	580
Planting + 40 DAP§	600	650	570	600	500	330	430	300	650	10	630	560
Planting + 30+60 DAP	1040	800	970	890	720	580	870	370	830	260	980	770
Orthogonal Comparisons												
3 vs 2 prunings	***	***	***	***	***	*	***	ns	**	***	***	ns
30 vs 40 DAP	ns	ns	ns	ns	ns	ns	ns	ns	ns	***	*	ns
PA	**	*	***	***	***	***	***	*	***	***	***	***
PR	***	**	***	**	***	*	***	ns	***	***	***	ns
PAxPR	**	ns	*	ns	ns	ns	ns	ns	ns	***	ns	ns

†Season A refers to the first cropping season of the year, which generally starts in March, depending upon the onset of rains, with harvest during the dry season in July. Season B refers to the second cropping season, which runs from August through December. Data for Seasons 11 – 13 represent means of fertilized and unfertilized subplots.
‡/ Pruning incorporated at planting, mulch thereafter;

*§/ DAP=Days after planting. ns, *, **,*** Not significant, significant at the 5%, 1% and 0.5% level of probability.*

Table 3.b. *Maize grain yields in seasons 11 – 13 as affected by fertilization with phosphorus and potassium and leucaena pruning management in alley cropping. Pernier, Haiti.*

CROPPING SEASON†

	11 98-A		12 98-B		13 99-A		Pooled Analysis	
	No PK	PK	No PK	PK	No PK	PK	No PK	PK
Factors	---------- kg ha^{-1} ----------							
PRUNING APPLICATION (PA)								
Removed	370b	390b	0c	50c	280c	330c	220c	260c
Mulch	740a	930a	190b	230ab	700b	990a	540b	710a
Incorporated/Mulch‡	740a	950a	180b	300a	780b	1140a	560b	800a
Orthogonal Comparisons								
Removed vs Applied	**		***		***		***	
Mulch vs Incorporated	ns		ns		0.07		ns	
PRUNING REGIME (PR)								
Planting + 30 DAP§	500b	640b	170b	240ab	390e	600cd	350d	490c
Planting + 40 DAP§	610b	690b	0c	22c	510de	760bc	370d	490c
Planting + 30+60 DAP	730ab	930a	200b	320a	850b	1100a	590b	790a
Orthogonal Comparisons								
3 vs 2 prunings	**		***		***		***	
30 vs 40 DAP	ns		***		*		ns	
PK	610	760	120	190	580	820	440	590
Season							***	
PA	***		***		***		***	
Season x PA							***	
PR	**		***		***		***	
Season x PR							***	
PA x PR	ns		***		ns		***	
PK	*		**		***		***	
Season x PK							0.06	
PA x PK	ns		ns		*		*	
PR x PK	ns		ns		0.07		ns	
PA x PR x PK	ns		ns		ns		ns	

*†Season A generally starts in March, with harvest during the dry season in July. Season B runs from August through December. ‡/Pruning incorporated at planting, mulch thereafter; §DAP=Days after planting. ns, *, **,*** Not significant, significant at the 5%, 1% and 0.5% level of probability. Means followed by the same letter for the same factor same season not different at the 5% level of probability. 3 and 4-way interactions with Seasons were not significant.Least square means presented in Season 11 and pooled because of missing values.*

Table 4. *Pruning application and pruning regime treatment effects on maize grain yields compared to control over twelve cropping seasons.*

	CROPPING SEASON†											
	1 93-A	2 93-B	3 94-A	4 94-B	5 95-A	6 95-B	7 96-A	10 97-B	11 98-A	12 98-B	13 99-A	14 99-B
Treatment	kg ha^{-1}											
REMOVED												
Planting + 30 DAP‡	290	430	240	380	230	130	33	70	140	10	120	180
Planting + 40 DAP	740	650	620	340	350	260	270	150	450	20	310	190
Planting + 30+60 DAP	780	660	700	560	540	320	420	270	550	50	480	390
MULCH												
Planting + 30 DAP	940	600	750	740	550	760	620	510	840	310	630	710
Planting + 40 DAP	440	600	410	720	500	360	460	470	710	0	730	930
Planting + 30+60 DAP	1220	870	1150	1080	740	760	1150	300	930	320	1180	880
INCORPORATED/MULCH§												
Planting + 30 DAP	820	640	760	710	470	550	470	370	740	290	740	840
Planting + 40 DAP	610	700	670	740	650	380	570	270	800	10	860	650
Planting + 30+60 DAP	1130	870	1020	1020	890	650	1030	530	990	420	1280	1030
CONTROL (Stone Wall)	1510	1130	1260	930	1090	500	720	200	940	280	900	430
Significance (F test)	***	***	***	***	***	***	***	ns	***	***	***	**
$LSD_{0.05}$	358	256	393	333	314	259	279	324	277	138	215	449
CV %	25	19	30	27	30	32	28	60	32	70	28	42

*†Season A: first cropping season of the year, which generally starts in March with the onset of rains, with harvest during the dry season in July. Season B: second cropping season from August through December. Data for Seasons 11 – 13 represent means of fertilized and unfertilized subplots. ‡DAP=Days after planting; §Pruning incorporated at planting, mulch thereafter. ns, *, **,*** Not significant, significant at the 5%, 1% and 0.5% level of probability; LSD0.05 Smallest difference between two means that is significant at 95% confidence level; CV%: Coeficient of variation, a measure of the degree of precision in the experiment.*
Note: Least square means used where missing data.¶ Use for all except treatments 6 and 9. LSD to compare 6 vs 9: 311; 6 vs rest: 299; 9 vs rest: 281

Table 4.b. *Effects of application of phosphorus and potassium, pruning application and pruning regime on maize grain yields compared to rock wall control over twelve cropping seasons.*

	CROPPING SEASON†							
	11 98-A		12 98-B		13 99-A		Pooled Analysis	
	No PK	PK	No PK	PK	No PK	PK	No PK	PK
Treatment	---------- kg ha^{-1} ----------							
REMOVED								
Planting + 30 DAP‡	120h	170gh	0f	20f	100j	140j	70i	110hi
Planting + 40 DAP	470e-h	420f-h	0f	40ef	330ij	300ij	270gh	260gh
Planting + 30+60 DAP	520-g	570d-f	0f	90d-f	400h-j	550g-i	310e-g	400e-g
MULCH								
Planting + 30 DAP	780a-f	900a-c	310a-c	300a-c	510g-i	740e-g	530de	650cd
Planting + 40 DAP	670b-f	760a-e	0f	0	560g-i	900c-f	410e-g	550de
Planting + 30+60 DAP	750a-f	1110a	250b-d	380a-c	1030b-e	1320ab	680cd	940ab
INCORPORATED/MULCH§								
Planting + 30 DAP	620b-f	860a-e	190c-f	400ab	560g-i	910c-f	460ef	720c
Planting + 40 DAP	700a-f	900a-c	0f	30f	640f-h	1070b-d	450ef	660cd
Planting + 30+60 DAP	880a-e	1100a	350a-c	490a	1120bc	1440a	790bc	1010a
Control (Stone Wall)	890a-d	990ab	230b-e	340a-c	790d-g	1010c-e	640cd	780bc
Mean	640	780	130	210	610	840	460	610
Season	700		170		720			
Significance (F Test)								
Rep	**		ns		ns		ns	
Seasons							***	
Treatment	***		***		***		***	
Season x Treatment							***	
PK Fertilizer	*		*		***		***	
Season x PK							0.06	
Treatment x PK	ns		ns		ns		ns	
CV%	32		69		25		34	

†Season A generally starts in March, depending upon the onset of rains, with harvest during the dry season in July. Season B runs from August through December.

‡DAP=Days after planting; §Pruning incorporated at planting, mulch thereafter.

*ns, *, **,*** Not significant, significant at the 5%, 1% and 0.5% level of probability; Means followed by the same letter in the same season not different at the 5% level of probability. 3-way interactions with Seasons were not significant.*

CV%: *Coeficient of variation, a measure of the degree of precision in the experiment*

Table 5. *Maize grain yield over 12 cropping seasons as affected by leucaena pruning management in alley cropping. Treatment factor "pruning removed" was eliminated from analysis.*

	CROPPING SEASON†												
	1 93-A	2 93-B	3 94-A	4 94-B	5 95-A	6 95-B	7 96-A	10 97-B	11 98-A	12 98-B	13 99-A	14 99-B	Mean
Factors	---------- kg ha^{-1} ----------												
PRUNING APPLICATION (PA)													
Mulch	870	690	780	850	600	630	740	430	820	150	800	840	680
Incorporated/Mulch‡	860	740	820	820	670	530	690	390	840	210	1000	810	710
PRUNING REGIME (PR)													
Planting + 30 DAP§	880	620	750	730	520	650	550	440	790	250	750	770	650
Planting + 40 DAP§	520	650	540	730	580	370	520	370	760	10	790	750	550
Planting + 30+60 DAP	1170	870	1100	1050	810	700	1090	420	940	280	1160	950	870
Orthogonal Comparisons													
3 vs 2 prunings	***	***	***	***	***	*	***	ns	0.1	**	***	ns	**
30 vs 40 DAP	**	ns	ns	ns	ns	**	ns	ns	ns	***	ns	ns	ns
PA	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
PR	***	***	***	*	*	*	***	ns	ns	***	**	ns	***
PAxPR	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns

†Season A refers to the first cropping season of the year, which generally starts in March, depending upon the onset of rains, with harvest during the dry season in July. Season B refers to the second cropping season, which runs from August through December.

‡DAP=Days after planting;

§Pruning incorporated at planting, mulch thereafter.

*ns, *, **,*** Not significant, significant at the 5%, 1% and 0.5% level of probability*

Table 6. *Total dry weight biomass harvested from leucaena hedgerows in hedgerow management study. Main effect of factors. Pernier, Haiti. 1993-1999.*

	CROPPING SEASON†												
	1 93-A	2 93-B	3 94-A	4 94-B	5 95-A	6 95-B	7 96-A	8 96-B	9 97-A	10 97-B	11 98-A	12 98-B	13 99-A
Factors	---------------- Mg ha^{-1} ----------------												
PRUNING UTILIZATION													
Removed	15.13	3.72	2.27	2.25	1.79	4.52	2.57	2.73	1.82	0.89	3.39	4.32	2.78
Mulch	15.83	3.82	2.42	2.44	1.92	5.16	3.05	3.14	2.13	1.02	3.65	5.22	3.22
Incorporated/ Mulch‡	15.62	3.96	2.56	2.50	1.82	5.09	3.19	3.23	2.12	1.05	4.15	5.05	3.5
Orthogonal Comparisons													
Removed vs Applied	ns	ns	ns	ns	ns	*	*	ns	ns	ns	ns	*	*
Mulch vs Incorporated	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
PRUNING REGIME													
Planting + 30 DAP§	14.55	4.06	2.53	2.20	2.18	5.37	3.16	3.81	2.33	1.02	3.16	5.22	3.24
Planting + 40 DAP	16.53	4.44	2.86	3.16	2.09	5.88	3.46	3.75	2.00	1.02	3.85	6.02	3.69
Planting + 30+60 DAP	15.49	3.01	1.87	1.83	1.25	3.52	2.19	1.55	1.74	0.93	4.17	3.35	2.58
Orthogonal Comparisons													
3 vs 2 prunings	ns	***	***	***	***	***	***	***	ns	ns	*	***	***
30 vs 40 DAP	ns	ns	ns	***	ns	ns	ns	ns	ns	ns	*	*	ns

†Season A refers to the first cropping season of the year, which generally starts in March, depending upon the onset of rains, with harvest during the dry season in July. Season B refers to the second cropping season, which runs from August through December.

‡DAP=Days after planting; §Pruning incorporated at planting, mulch thereafter.

*ns, *, **,*** Not significant, significant at the 5%, 1% and 0.5% level of probability*

Table 7. *Total dry weight biomass harvested from leucaena hedgerows in hedgerow management study. Pernier, Haiti. 1993-1999.*

	CROPPING SEASON†												
	1 93-A	2 93-B	3 94-A	4 94-B	5 95-A	6 95-B	7 96-A	8 96-B	9 97-A	10 97-B	11 98-A	12 98-B	13 99-A
Treatments	Mg ha⁻¹												
PRUNINGS REMOVED													
Planting + 30 DAP‡	13.01	3.62	2.18	1.92	2.13	4.32	2.48	3.22	1.99	0.96	2.43	3.63	2.61
Planting + 40 DAP	18.31	4.55	2.89	3.08	2.11	6.02	3.26	3.57	1.81	0.82	3.84	6.23	3.29
Planting + 30+60 DAP	14.07	3.00	1.74	1.75	1.12	3.22	1.99	1.41	1.67	0.89	3.89	3.11	2.44
MULCH													
Planting + 30 DAP	16.86	4.29	2.81	2.54	2.54	6.13	3.76	4.22	2.72	1.08	2.95	6.38	3.78
Planting + 40 DAP	14.55	4.15	2.58	2.94	1.84	5.61	3.12	3.53	1.83	1.06	3.76	5.85	3.61
Planting + 30+60 DAP	16.07	3.02	1.87	1.84	1.38	3.72	2.26	1.66	1.83	0.93	4.25	3.42	2.28
INCORPORATED/MULCH§													
Planting + 30 DAP§	13.79	4.26	2.59	2.15	1.88	5.65	3.23	3.98	2.28	1.02	4.10	5.65	3.34
Planting + 40 DAP	16.74	4.61	3.09	3.46	2.32	6.01	4.01	4.14	2.36	1.17	3.96	5.98	4.18
Planting + 30+60 DAP	16.34	3.01	1.99	1.90	1.25	3.62	2.33	1.58	1.77	0.96	4.38	3.53	3.03
Significance (F test)	ns	*	***	***	ns	***	***	***	ns	ns	*	***	*
$LSD_{0.05}$	4.88	1.09	0.65	0.72	1.05	1.14	1.00	1.41	0.59	0.24	0.66	0.72	1.00
CV%	18.2	16.4	15.6	17.4	32.9	13.4	19.7	26.7	29.3	24.1	17.8	24.8	18.2

†Season A = 1st rainy season, Mar-Jul; Season B = 2nd rainy season, Aug-Dec.

*‡Pruning incorporated at planting, mulch thereafter; § DAP:Days after planting; ns, *, **, *** Not significant, significant at the 5%, 1% and 0.5% levels of probability, respectively. LSD0.05 Smallest difference between two means that is significant at 95% confidence level.*

CV%: *Coeficient of variation, a measure of the degree of precision in the experiment*

Table 8. *Leaf dry weight biomass harvested from leucaena hedgerows in hedgerow management study. Main effect of factors. Pernier, Haiti. 1993-1999.*

	CROPPING SEASON†												
	1 93-A	2 93-B	3 94-A	4 94-B	5 95-A	6 95-B	7 96-A	8 96-B	9 97-A	10 97-B	11 98-A	12 98-B	13 99-A
Treatments	Mg ha^{-1}												
PRUNING UTILIZATION													
Removed	2.90	1.91	1.37	1.25	1.11	2.65	1.46	1.42	1.08	0.51	1.80	2.50	2.02
Mulch	2.94	1.90	1.34	1.35	1.23	2.83	1.63	1.64	1.24	0.59	1.96	3.03	2.09
Incorporated/ Mulch	2.97	2.02	1.44	1.38	1.15	2.85	1.67	1.50	1.29	0.61	2.14	2.92	2.36
Orthogonal Comparisons													
Removed vs Applied	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	*	ns
Mulch vs Incorporated	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
PRUNING REGIME													
Planting + 30 DAP	2.67	1.88	1.32	1.12	1.31	2.89	1.52	1.64	1.26	0.57	1.68	2.99	2.14
Planting + 40 DAP	3.09	2.15	1.51	1.63	1.20	3.17	1.74	1.89	1.28	0.57	2.03	3.32	2.37
Planting + 30+60 DAP	3.06	1.79	1.31	1.23	0.98	2.27	1.49	1.03	1.07	0.57	2.23	2.14	1.96
Orthogonal Comparisons													
3 vs 2 prunings	ns	*	ns	ns	**	***	ns	***	ns	ns	*	***	ns
30 vs 40 DAP	ns	*	*	***	ns	ns	ns	ns	ns	ns	ns	ns	ns

†Season A = 1st rainy season, Mar-Jul; Season B = 2nd rainy season, Aug-Dec.

‡Pruning incorporated at planting, mulch thereafter; § DAP:Days after planting;

*ns, *, **, *** Not significant, significant at the 5%, 1% and 0.5% levels of probability, respectively.*

Table 9. *Leaf dry weight biomass harvested from leucaena hedgerows in hedgerow management study. Main effect of factors. Pernier, Haiti. 1993-1999.*

	CROPPING SEASON†												
	1 93-A	2 93-B	3 94-A	4 94-B	5 95-A	6 95-B	7 96-A	8 96-B	9 97-A	10 97-B	11 98-A	12 98-B	13 99-A
Treatments	Mg ha^{-1}												
PRUNINGS REMOVED													
Planting + 30 DAP	2.52	1.77	1.19	1.02	1.19	2.46	1.30	1.34	1.10	0.52	1.34	2.10	1.87
Planting + 40 DAP	3.27	2.16	1.65	1.55	1.24	3.22	1.68	1.96	1.12	0.47	2.01	3.44	2.30
Planting + 30+60 DAP	2.91	1.79	1.26	1.18	0.90	2.27	1.39	0.95	1.02	0.54	2.06	1.97	1.90
MULCH													
Planting + 30 DAP	2.94	1.92	1.39	1.25	1.50	3.15	1.81	1.97	1.45	0.61	1.53	3.66	2.40
Planting + 40 DAP	2.78	2.02	1.34	1.59	1.14	3.04	1.56	1.83	1.19	0.58	1.98	3.24	2.24
Planting + 30+60 DAP	3.09	1.75	1.29	1.21	1.06	2.30	1.53	1.12	1.09	0.58	2.37	2.18	1.64
INCORPORATED/MULCH§													
Planting + 30 DAP§	2.53	1.96	1.39	1.09	1.23	3.04	1.46	1.61	1.24	0.59	2.16	3.21	2.15
Planting + 40 DAP	3.21	2.28	1.55	1.76	1.23	3.25	1.99	1.87	1.53	0.66	2.01	3.27	2.57
Planting + 30+60 DAP	3.17	1.81	1.40	1.28	0.98	2.25	1.56	1.03	1.10	0.59	2.26	2.28	2.35
Significance (F test)	ns	ns	*	*	ns	***	ns	ns	ns	ns	*	***	ns
$LSD_{0.05}$	0.94	0.43	0.26	0.40	0.39	0.60	0.48	0.83	0.31	0.14	0.38	0.41	0.62
CV%	18.6	12.8	11.0	17.4	19.6	12.5	17.5	31.4	26.1	23.8	19.1	14.6	16.75

†Season A = 1st rainy season, Mar-Jul; Season B = 2nd rainy season, Aug-Dec.

‡Pruning incorporated at planting, mulch thereafter; § DAP:*Days after planting;*

*ns, *, **, *** Not significant, significant at the 5%, 1% and 0.5% levels of probability, respectively.*

LSD0.05 Smallest difference between two means that is significant at 95% confidence level

CV%: *Coeficient of variation, a measure of the degree of precision in the experiment*

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More publications on research carried out by Auburn University in Haiti can be found on the Global Programs website: ***agriculture.auburn.edu/outreach/global-programs/haiti***