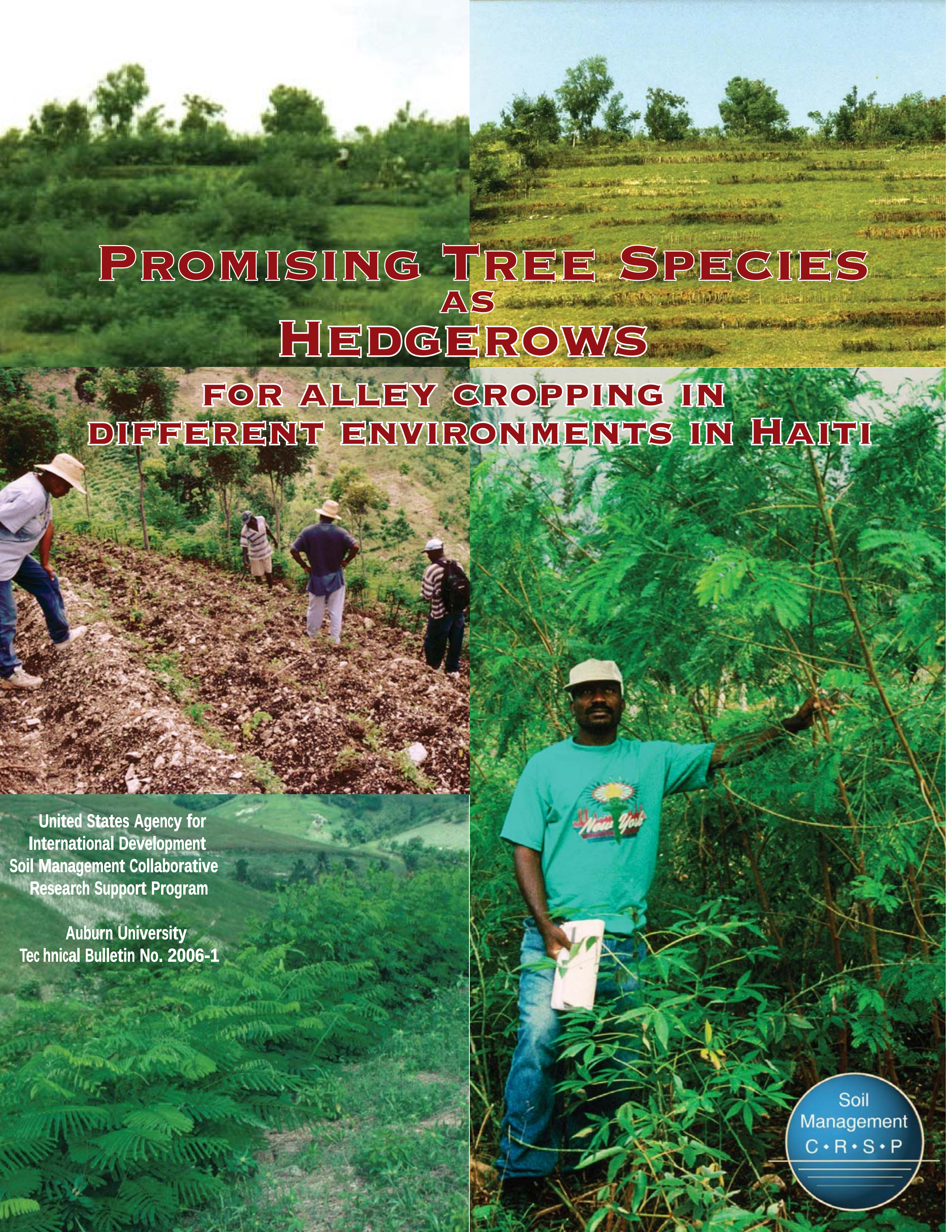

PROMISING TREE SPECIES AS HEDGEROWS

FOR ALLEY CROPPING IN DIFFERENT ENVIRONMENTS IN HAITI

United States Agency for
International Development
Soil Management Collaborative
Research Support Program

Auburn University
Tec hnical Bulletin No. 2006-1

Soil
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Front cover images, clockwise from top left:
1. Hedgerow species trial at Bergeau (calcareous site) prior to pruning of hedgerows. Note wide variation in growth of trees.

2. Hedgerow species trial at Bergeau following pruning to 50 cm height.

3. SECID technician Roswald Villefranche with leucaena hedgerow at Salagnac.

4. Hedgerows of *Delonix regia* (foreground) and a *Leucaena* species (rear) in the hedgerow species trial at the calcareous site at Bergeau.

5. On-farm trial at Bannate. Agronomist Carine Bernard, at left, examining cassava seedlings belonging to Sonson Augustin. Pruned hedgerows of *Leucaena leucocephala* and *Delonix regia* are behind the men in the background.

Back cover images, clockwise from top left:
6. Bannate was selected as one of the locations for the on-farm trial because farmers had already adopted alley cropping. Several leucaena hedgerows are visible on hillside in background. Cassava growing in foreground was from the control plot in the trial of Josette Gédeon.

7. Titanyen, site of semi-arid hedgerow species trial.

8. High-elevation site at Salagnac. An unidentified worker is standing next to one of the hedgerows in the trial. Note red color of soil, typical of many high-elevation locations.

9. High-elevation site at Fort Jacques. Hedgerows are scattered across mountain side.

10. Basaltic site at Saint Georges at start of experiment.

11. SECID technician Roswald Villefranche, on right, examining a pruned leucaena hedgerow belonging to farmer Madame Abraham, as farmer Larieux Borgella, left, and the local monitor, Etzer Fanfan, look on.

PROMISING TREE SPECIES AS HEDGEROWS FOR ALLEY CROPPING IN DIFFERENT ENVIRONMENTS IN HAITI

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Auburn University

Technical Bulletin No. 2006-1

The authors' views expressed in this publication do not necessarily reflect the views of the United States Agency for International Development or the United States Government.

This work was made possible through support provided by the Global Bureau, United States Agency for International Development (USAID), Soil Management CRSP Project, **Soil Management Practices for Sustainable Production on Densely Populated Tropical Steeplands** (Grant No. LAG-G-00-97-00002-00), and by the USAID/Haiti Mission through contracts with the South-East Consortium for International Development (SECID) in the Productive Land Use Systems (PLUS) Project (Contract No. 521-0217-C-00-5031-00) and the Agroforestry II (AFII) Project (Contract No. 521-0217-00-0004-00). The research was initiated under AFII (1991-1992), supported by PLUS (1992-1996), and assumed by the Soil Management CRSP in 1997. It continued to receive in-kind support from the PLUS Project, through the housing of Soil Management CRSP staff by SECID, which also provided administrative and logistical support. In 2001, in-country support was assumed by Development Alternatives, Inc. (DAI), with logistical and office support provided by the Pan American Development Foundation, as part of USAID's Hillside Agriculture Program. The authors would like to thank the USAID/Haiti mission for their support and the support of former SECID staff: Agronomist Patrick Condé; Mrs. Marilyn Louis, former SECID Administrator, for ensuring the survival of the trial during the year when support was suspended due to political unrest; Dr. Frank E. Brockman for his involvement and support as Chief of Party (1993-1996); and Dr. J.D. (Zach) Lea, SECID/Auburn Chief of Party from 1997 to 2001. Recognition is also given to the Center for Agricultural Research and Documentation (CRDA) from the Ministry of Agriculture, Natural Resources and Rural Development (MARNDR) for their participation in the work at Salagnac, Gaita, and Bannate and to the Pan American Development Foundation for assistance at Gaita and Bannate. Special thanks are due to Yves Carleau Roger of CRDA's Levy Farm and Chrysner Roche and Volmy Mérise at Salagnac for their participation in the trials, and to Gaspard Brice for PADF's assistance in the on-farm trials. We also thank Dr. Tom Thurow and Anthony Juo of Texas A&M for their collaboration and support as Project Leaders for the Soil Management CRSP Project, **Soil Management Practices for Sustainable Production on Densely Populated Tropical Steeplands.**

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PROMISING TREE SPECIES AS HEDGEROWS FOR ALLEY CROPPING IN DIFFERENT ENVIRONMENTS IN HAITI

INTRODUCTION

Alley cropping is a system whereby annual crops are planted between rows of trees, which are pruned during the cropping season and the prunings applied as mulch or green manure (Kang et al., 1984). During periods where no crop is grown, the trees are allowed to grow freely. Alley cropping has shown much promise during the past two decades as a technology suitable for small farmers in the third world. It improves soil by improving fertility and moisture retention, recycling plant nutrients, and reducing erosion (Kang et al., 1984). Alley cropping has promise on steeplands, where it can serve the purposes of sustaining crop production, while also doubling as a soil and water conservation barrier.

Successful implementation of alley cropping in a particular environment requires selecting the appropriate hedgerow species for that environment. Climate, soil, and tolerance to local pests and diseases must be considered when selecting suitable species for alley cropping. Management practices, such as the possibility of grazing by livestock, must also be considered. Systematic studies that assess a wide range of hedgerow species under different sets of environmental conditions are lacking in the scientific literature. Much of the research on alley cropping has been conducted using a single or very few hedgerow species. In some cases, researchers have concluded that alley cropping was unsuitable for a particular environment when, had they used an alternate species, their conclusions might have been different. Information on the contribution of different species to soil fertility improvement is also lacking. This research was originally undertaken because of the need to identify appropriate species under different conditions in Haiti, but the results have wider application within the tropics with similar climatic and soil conditions.

CONTEXT OF THE RESEARCH

Haiti (27,750 square kilometers [km^2]) shares with the Dominican Republic the second largest island in the Caribbean known as Hispaniola. With a population of approximately 8 million people, it has the eighth highest population density in the Western Hemisphere (CIA, 2005). The country is characterized by mountainous lands with moderate to steep topography. More than 60 percent of the Haiti land area is steeplands with slopes in most cases not appropriate for annual crops. Approximately 70 percent of the active population is supported by agriculture, and most count on their piece of land to produce staple food to meet their subsistence needs. The continuously growing population, combined with the scarcity of good agricultural land, force farmers to clear forests for crop production. Intensive exploitation of steep slopes with minimal inputs gives rise to increasing rates of erosion, soil degradation, and declining crop yields.

Efforts have been made to slow the deforestation process and to reduce soil erosion on sloping land. During the past two decades, conservation efforts have shifted from rock wall structures to contour hedgerows of trees. Even though some conservation measures appeared to be efficient in reducing soil losses, crop yields constantly declined under continuous cultivation. Although contour hedgerows may be managed for alley cropping by using the leaves as a nutrient- rich mulch, this was not generally practiced prior to the commencement of this research program. We hypothesized that by modifying the management of conservation hedgerows, it would be possible to stabilize yields and improve sustainability of production on steeplands.

In Haiti, limited data were available on which to base the choice of tree species as hedgerows for alley cropping. The most widely used species in contour hedgerows in Haiti is leucaena (*Leucaena leucocephala* Lam. De Wit). This species grows rapidly, fixes nitrogen (N), tolerates repeated pruning, and produces seed readily. The leaves are an excellent forage and the wood an excellent source of fuel and poles for construction and stakes. However, due to varying environmental conditions existing in Haiti, a single tree species is not the best choice for all locations. Haiti's topography and geologic history give rise to a range of climatic and soil conditions that make an ideal laboratory for testing species. Within a relatively small geographic area, it is possible to encounter a range in temperature, rainfall, and soil conditions characteristic of the tropics.

The research described in this report was initiated under the USAID/Haiti Agroforestry II Project and continued under the Productive Land Use Systems (PLUS) Project in order to adapt alley cropping to Haitian conditions. In 1997, the Soil Management Collaborative Research Support Project (SM-CRSP), **Soil Management Practices for Sustainable Production on Densely Populated Tropical Steeplands,** assumed responsibility for the research with continued support from the PLUS Project, and in 2001, the Hillside Agriculture Program of USAID/Haiti. In the first phase of this research (1991-1996), a large number of species were screened at three low-elevation sites differing in rainfall and soil conditions and at one high-elevation site. In the second phase (1997-2001), more intensive studies were carried out with the most productive species identified in Phase I, and field trials were carried out at a second high-elevation site and at two low-elevation sites where farmers tested a new hedgerow species that is not palatable to livestock.

STUDY AREAS

The initial studies were conducted at four sites where alley cropping is likely to be practiced in Haiti (Figure 1). Follow-up studies were located at three sites. These sites, which differed in terms of soil types, topography, farming practices, and climatic conditions, were representative of the dominant agro-ecological zones of the country. The soils were formed over basaltic rocks, limestone, and alluvial and colluvial sediments (Table 1). Elevations ranged from near sea level to 1,200 meters (m) and annual average rainfall from 700 millimeters (mm) to 2,600 mm. The topsoil depth ranged from more than 80 centimeters (cm) in lowlands to less than 30 cm on intensively cultivated steeplands.

HIGH-ELEVATION SITES

The first high-elevation site was located at Fort-Jacques (18˚ 29' N, 72˚ 15' W and 1,150 to 1,200 m above sea level), approximately 18 miles southeast of Port-au-Prince, Haiti (Figure 1 and Table 1). This zone is classified as low-elevation mountain humid forest (Organization of American States, 1972). Mean temperature is about 21˚C, with lows of 10˚C or lower expected in January. Annual rain-

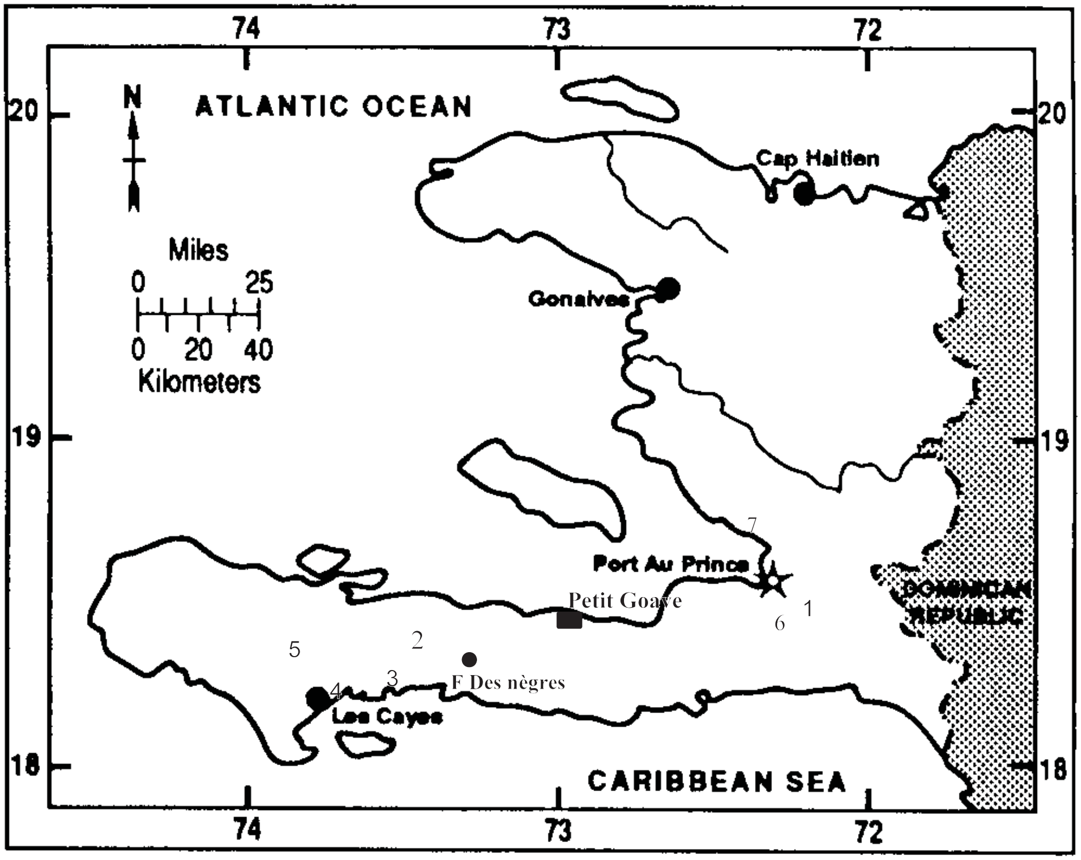

Figure 1. Research Sites for the Soil Managment CRSP Steeplands Project in Haiti: 1. Pernier, 2. Salagnac, 3. Saint Georges, 4. Bergeau, 5. Bannate and Gaita, 6. Fort Jacques, 7. Titanyen.

TABLE 1. CHARACTERISTICS OF SITES SELECTED FOR HEDGEROW SPECIES TRIALS IN HAITI

Site	Elevation	Slope %	Temp. °C	Rainfall mm	Parent material	Soil taxonomy†
1991 Trials						
Fort Jacques	1,200	30-45	21	1,160	Siliceous limestone	clayey-skeletal, kaolinitic, iso-hyperthermic Typic Hapludalfs
Bergeau	60	30	26.5	1,800	Limestone	loamy, mixed (calcareous), iso-hyperthermic TypicTroporthents
Saint Georges	80	25-45	26	1,600	Basalt	fine, mixed, isohyperthermic Typic Hapludalfs
Titanyen	87	5-8	28.5	780	Limestone	colluviumloamy, mixed, isohyperthermic Lithic Petrocalcic Calciustolls
1997 Trials						
Salagnac	900	3	21.4	2,514	Limestone	fine, kaolinitic, isohyperthermic Typic Rhodudalfs
Bannate	150	27-65	24	2,492	Limestone	not determined, probably Haplustolls
Gaita	300	15-35	24	2,033	not determined‡	not determined

†(Guthrie and Shannon, 2004) ‡Soil color suggested basalt, but contained rock fragments that appeared to be limestone.

fall, estimated at 1,160 mm, is distributed mainly between late February through June and September through early December. Grain crops are generally grown during the first rainy season, followed by vegetables in the cool season. The Fort-Jacques area is characterized by a steep topography with most land having slopes greater than 30 percent. Rock walls have been installed as a conservation measure to decrease soil and water losses on cropped fields. The experimental site has a steep north-facing slope of 30 to 45 percent on which were stone dry walls resulting in terraces with slopes varying from 15 to 25 percent. The red clay soil is derived from colluvium of siliceous limestone and argillaceous shale parent material (Guthrie and Shannon, 2004) and the depth varies with distance from rock walls.

In the previous year, beans, maize, cassava, and sweet potato had been planted in the first season, followed by carrot and lettuce in the second season.

A second high-elevation site was selected at Salagnac, (approximately 18˚E 23' N, 73˚E 30' W; Figure 1). Salagnac is located at approximately 900 m elevation on an upper slope of less than 5 percent in an area classed as low-elevation humid mountain forest (Organization of American States, 1972). Mean annual temperature is similar to that at Fort Jacques, despite the somewhat lower elevation (Table 1), due to frequent cloud cover. Mean annual rainfall for the period of the trial measured 2,585 mm. The soil is a deep red color, typical of aluminum and iron oxides, but the surface soil is neutral to slightly alkaline (Table 2; Guthrie and Shannon, 2004) owing to the presence of limestone fragments in the soil.

LOW-ELEVATION SITES

A low-elevation humid site on limestone parent material, hereby referred to as the calcareous site, was at Bergeau (18˚ 13' N, 73˚ 42' W) in the south region of Haiti (Figure 1). The area has varying topography with slopes ranging from less than 5 percent to more than 40 percent. Average annual temperature is 26.5˚C and mean rainfall is 1,800 mm, distributed mainly between late February through mid-June and late August through November. The bimodal rainfall pattern permitted the cropping of maize *(Zea mays* L.) or beans (*Phaseolus vulgaris* L.) or the association of maize and beans in rotation with sorghum (*Sorghum bicolor* L.). Generally, flat lands are cultivated with bean and maize in rotation with sorghum or sugar cane (*Saccharum officinarium* L.) while the hillsides are used mostly for vetiver (*Vetiveria zizanoides* L.), sorghum, or maize. The soil at this site is alkaline owing to the presence of limestone (Tables 1 and 2; Guthrie and Shannon, 2004). The site is on an east-facing slope at an elevation of about 60 m. Soil depth to bedrock is about 40 to 50 cm. The site was in pasture for the past four or five years. Previous to that, sorghum was cultivated in rotation with maize and bean.

A low-elevation site on basalt parent material, hereby referred to as the basaltic site, was at Saint Georges (18˚15' N, 73˚W and 80 m elevation), located also in the south region of Haiti (Figure 1). In this region, maize, sorghum, and peanut are primarily grown to meet the subsistence needs of the farmers. The continuous cultivation of peanut (*Arachis hypogea* L.) on steep slopes without soil conservation practices has resulted in a severely eroded landscape leading to abandonment of land in many cases. Rainfall, distributed between April and November, averages 1,600 mm. Average temperature is 26˚C. The slope of 25 to 45 percent faces north. The soil at the basaltic site is a loam with fine gravel, and neutral pH (Tables 1 and 2) (Guthrie and Shannon, 2004). The site has previously been in pasture and had a grass cover into which had been planted hedgerows of *Erythrina indica* and *L. leucocephala* spaced 2.5 to 3.5 m apart.

A low-elevation, semi-arid site was located at about 15 miles north of Port-au-Prince (18˚ 41' N, 72˚ W, 60 m elevation) on colluvium at the foot of a small mountain range (Figure 1). The soil is gravelly and excessively well drained and alkaline (Tables 1 and 2) (Guthrie and Shannon, 2004). Rainfall was estimated to average 780 mm, but with a highly erratic distribution pattern. This, together with high temperatures and drying winds, made the site more severe than would be suggested by the annual rainfall. The slope of 5 to 8 percent faces westward. The site had not been cultivated in recent years and contained a sparse cover of shrubs and grass.

In the second phase, on-farm trials were conducted at Gaita (18˚E 20' N, 73˚E 46' W) and Bannate (18˚E 19' N, 73˚E 50' W), two villages in which the Pan American Development Foundation had promoted alley cropping (Figure 1 and Tables 1 and 2). Soil descriptions were not carried out at the two sites. At Bannate, the trials were established on very steep slopes (27 to 65 percent) and the shallow soils were typical of many sites overlaying limestone: very dark, with fragments of limestone and alkaline reaction. At Gaita, slopes varied from 12 percent to 32 percent and the soils were light brown

TABLE 2. SOIL PROPERTIES AT EACH SITE

a. Chemical Properties

Site	pH (KCl)	pH (H_2O)	Extract-able P ppm	Ca†	Mg	K	Na	CEC	Organic matter %	Total N %	Soluble salts ppm
				Exchangeable cations							
				$cmol_c$ kg^{-1}							
1991 Trials											
High elevation	7.0	8.1	10.4	43.5	0.9	0.4	0.14	4.8	4.4	0.48	249
Calcareous	7.5	8.0	11.1	24.5	0.9	0.1	0.12	5.7	4.3	0.43	427
Basaltic	5.2	7.1	2.9	270.4	11.1	0.1	0.33	8.8	2.1	0.21	182
Semi-arid	7.6	8.1	21.1	28.0	1.9	0.3	0.13	0.3	5.6	0.45	319
1997 Trials											
Salagnac		7.0	4.9	11.4	0.5	3.8	na	15.7	6.1	0.33	299
Bannate		7.9	12.3	40.9	1.9	0.2	na	43.0	3.4	0.06	289
Gaita		5.3	5.7	4.2	0.5	0.1	na	9.1	1.2	0.02	141

b. Physical Properties

Site	Sand %	Silt %	Clay %	Texture	Electrical conductivity mmhos/cm
1991 Trials					
High elevation	10.9	38.2	50.9	Clay	0.18
Calcareous	23.8	56.3	20.0	Silt loam	0.31
Basaltic	43.4	34.1	22.5	Loam	0.13
Semi-arid	35.6	43.1	21.3	Loam	0.23
1997 Trials					
Salagnac	25.0	35.1	39.8	Clay loam	0.23
Bannate	30.0	57.0	13.0	Silt loam	0.23
Gaita	39.9	18.5	41.6	Clay	0.11

† Obtained by subtracting Mg, K, and Na from CEC. For Gaita, exchangeable acidity (4.3 $cmol_c kg^{-1}$), estimated based on buffer pH, was also subtracted from CEC.

in color and mildly acidic, but with limestone fragments present. The parent material was probably basalt. Annual rainfall at Gaita and Bannate averaged 2,033 mm and 2,492 mm, respectively, for the nearly three years of measurement.

SOIL CHARACTERISTICS

Soil samples were taken to a 20-cm depth at each site and combined into composite samples for physical and chemical analyses. Subsamples of each composite were analyzed by the Soil Testing Laboratory at Auburn University. The phosphorus (P), potassium (K), calcium (Ca), and magnesium (Mg) concentrations were determined using the Mississippi Extract (Lancaster, 1970). Cation exchange capacity was determined by extraction with pH 7.0, 1 M ammonium acetate, and organic matter was determined by Walkley-Black method (Soil Survey Staff, 1991). Soil pH was determined in water and in KCl, total N was determined in a LECO CHN 600 analyzer, and electrical conductivity was used to determine soluble salts. Particle size was determined by the pipette method and dry sieving.

Soils had neutral or basic pH values ranging from 7.0 to 8.1, with the exception of Gaita, which was mildly acidic (Table 2). The cation exchange capacities of the soils were generally high, with Ca occupying a large portion of the exchange sites. Mean CEC values for the top 20 cm of soil varied from 9 (Gaita) to 45 centimoles of charge per kg ($cmol_c kg^{-1}$) soil (high-elevation site). The soil textures ranged from clay to silt loam with an organic matter content ranging from 1.2 to 6.1 percent. Soils at the high-elevation site of Fort Jacques and at Gaita were high in clay content; at the calcareous site and Bannate, high in silt; and at the semi-arid and basaltic sites, high in silt and sand. The organic matter content was lowest at the basaltic site and Gaita but was high at the other sites, ranging from 3.5 to 6.1 percent. Calcium content was very high. Magnesium content was low (less than 2 $cmol_c kg^{-1}$) at all except the basaltic site; K was low at all sites except Salagnac. Sodium (Na) was higher at the basaltic site than other sites, perhaps due to its close proximity to the sea. Electrical conductivity was highest at the calcareous and semi-arid sites, Salagnac and Bannate, indicating higher soluble salts at these sites than other sites.

The major limitations for these soils were low fertility and nutrient imbalance, resulting, at most sites, from high pH and low phosphorus (Table 2; Guthrie and Shannon, 2004). At the basaltic site, potassium was also severely deficient (Bossa et al., 2005). At the semi-arid site, nutrient imbalance is compounded by inadequate moisture. Soils at the other sites are typical of the soils at many of the locations where hedgerow technologies are likely to be applied.

CHOICE OF THE SPECIES

A total of 35 tree or shrub species (most legumes) of diverse origin were included in the hedgerow assessment trials established in 1991. Selections of the species were based upon previous experience in Haiti, performance in other countries, recommendations of colleagues, and a review of literature. Environmental adaptation of a species and its ability to withstand frequent prunings were the main criteria for its inclusion in the trial. The seed was obtained from seed banks and organizations within and outside of Haiti and from seed harvested from orchards in Haiti (Table 3). Some species had been successfully grown in alley cropping; others were deemed to have potential in alley cropping. *Leucaena leucocephala,* variety K636, was selected as the control at each site. Three other species—*L. diversifolia,* variety K156; *Gliricidia sepium*, variety HYB; and *Casuarina cunninghamiana*—were also planted at each site. The other species were distributed based upon expected adaptation. A total of 16 species were planted at the high-elevation and basaltic sites, 20 at the calcareous site, and 18 at the semi-arid site. A randomized complete block design with four replications was used at all the sites except the high-elevation site at Fort Jacques, where an incomplete block design with 16 blocks and four replications was used.

Fort Jacques is on a north-facing, leeward slope of the La Selle Mountain Range rendering it prone to drought stress because of the "rain shadow" effect. *Calliandra calothyrsus,* which was being used successfully for alley cropping at other high-elevation sites in Haiti, did not perform well at Fort Jacques. We hypothesized that the poor performance at Fort Jacques was related to inadequate rainfall and that this and other species might be better suited to high-elevation sites where rainfall was more bountiful. For that reason, a second high-elevation trial was established at Salagnac in October 1997 this time with five species—*Acacia angustissima; Calliandra calothyrsus; L. leucocephala,* variety K636; *Leucaena* hybrid KX2 (*L. leucocephala* X *L. pallida)*, variety Ohana; and *Albizia julibrissin*—together with a no-hedgerow control. The objective of this trial was to compare species with potential for high elevation at a more humid site than Fort Jacques, and also to assess their effect on crop yield. *Leucaena* hybrid KX2, developed by the University of Hawaii, was selected in Florida for cold tolerance, as well as psyllid tolerance, and therefore was thought to have potential for high-elevation sites. *Albizia julibrissin* has been tested in alley cropping in the southeastern United States and is native to the Himalayan region of the Indian subcontinent, so we thought it might tolerate the cooler temperatures at Salagnac.

One of the problems encountered with the use of leucaena in conservation hedgerows in Haiti is that overgrazing commonly results in their destruction. The on-farm trials in Gaita and Bannate were established to assess the suitability of *Delonix regia* as an alternative to leucaena where grazing by livestock was a problem to the survival of the hedgerows. *Delonix regia* is unpalatable to ruminants, and in the trial at the low-elevation calcareous site at Bergeau, gave biomass yields comparable to leucaena. The study was established in nine farmers' fields in Bannate and Gaita, Haiti, between October 1997 and March 1998 to compare performance of *Delonix regia* with leucaena, variety K636. The species were assessed based upon measured biomass yields and on the yield of associated crops compared to the control plots without hedgerows. Farmers at these two locations were already actively adopting alley cropping with hedgerows of leucaena, but were not familiar with alley cropping of *D. regia*.

MANAGEMENT OF THE TRIALS

LAND PREPARATION

1991 TRIALS

The first set of trials was established during the first rainy season of 1991. Three weeks before planting, shrubs and weeds were removed with hand tools, without disturbing the soil, and the plant residues left on the soil surface. Soil preparation was begun two weeks later. The rows were marked out on a contour by means of an A-frame level or a string level. The rows varied from 20 to 36 m in length and were spaced 3 to 4 m apart where possible. The soil was broken up to a depth of 20 to 30 cm in a 30-cm width along each row with a hoe or pick. At the high-elevation site, the walls were reconstructed at certain points to prevent soil loss. At the basaltic site, the rows were established mid-way between existing hedgerows of *Erythrina indica* and leucaena, which were pruned low to the ground to minimize competition to the trees in our trials. At the semi-arid site, large stones were removed and a shallow trench was formed with a ridge on the down-slope side to serve as water catchments.

Table 3. Seed Weight, Seed Treatment, and Seed Sources of Species Used in the Assessment Trials

Species (variety)	Seed number/kg	Seed treatment †	Seed sources ‡
Acacia ampliceps	46,000	A	CSIRO
Acacia angustissima	119,050	A	CATIE
Acacia colei	82,500	A	CSIRO
Acacia decurrens	60,600	A	CSIRO
Acacia holosericea	86,205	A	CSIRO
Acacia mearinsii	72600	A	PADF/CSIRO
Acacia melanoxilon	142,850	A	PADF/CSIRO
Acacia tumida	19,500	A	CSIRO
Albizia guachepele	23,000	B	PADF
Albizia lebbeck	8,145	B	PADF
Albizia procera	25,000	B	PADF
Calliandra calothyrsus	17,820	B	ORE
Cassia emarginata	51,020	A	PADF
Cassia (Senna) siamea	31,500	E	PADF
Casuarina cunninghamiana	1,297,400	E	Zimbabwe
Delonix regia Bojer	1,900	C	PADF
Desmodium gyroides	218,050	E	PST
Enterolobium cyclocarpum	1,120	C	PADF
Erythrina indica	1,500	D	PST/PADF
Erythrina poeppigiana	4,500	D	PADF
Flemingia macrophylla	52,900	E	IITA
Gliricidia sepium (HYB)	10,090	E	Nigeria
Grevillea robusta	44,000	D	Fermathe/Haiti
Inga vera	—	E	Cayes/Haiti
Leucaena diversifolia (K156)	50,000	B	ODH
Leucaena leucocephala (K636)	19,450	B	ODH
Leucaena leucocephala (Delin)	26,700	B	Blin/Haiti
Leucaena hybrid (KX3)	33,550	B	ODH
Leucaena salvadorensis	11,411	B	Honduras
Leucaena shannonii	37,965	B	Honduras
Mimosa scrabella	68,025	D	PADF
Paraserianthes falcataria	41,000	B	PADF
Piptadenia peregrina	12,000	E	Anana/Haiti
Pseudoalbizzia berteriana	70,000	A	Berthe/Haiti
Tephrosia candida	43,100	E	IITA

† Pre-seeding Treatment: A: Seeds immersed in boiling water for 30 seconds; B: Round end of seeds cut or scratched; C: Round end of seeds cut or scratched and soaked in water for 12 hours; D: Soaked in cold/tepid water for 12 hours; E: No treatment;
‡CSIRO: Australia; CATIE: Costa Rica; PADF: Pan American Development Foundation, Haiti; PST: Targeted Watershed Project, Haiti; ORE:Organization for Rehabilitation of the Environment, Haiti; IITA: International Institute of Tropical Agriculture, Nigeria; ODH: OperationDouble Harvest, Haiti; Honduras: COHDEFOR; Remaining locations are harvest sites in Haiti.

Plots consisted of single rows of hedgerows, 5 m long at the calcareous and basaltic sites and 6 m at the high-elevation and semi-arid sites. Plants were spaced 10 cm apart within the row except at the semi-arid site where plants were spaced 20 cm apart. The plots were arranged end-to-end in rows laid on the contour. The usual spacing between rows was 3 m, but this varied slightly due to the need to follow the contour and occasionally because of obstructions. Generally, the distance between hedgerow rows did not surpass 4 m. At the ends of rows, borders of 2 m in length were planted with various leucaena varieties. A randomized complete block design was used at all but the high-elevation site where variability in soil depth induced by terracing mandated the use of incomplete blocks of four plots each. Four replications were planted at each site.

1997 TRIALS

At the high-elevation site at Salagnac, the field was tilled prior to planting. Hedgerows were spaced 4 m apart, with two hedgerows per plot in order to allow testing the compatibility of the hedgerow species with crops. The trees were planted 10 cm apart within the row. The trial was a randomized complete block with three replications. Plots measured 8 m X 8 m. At Bannate and Gaita, three to four hedgerows each of *Delonix regia* and leucaena, variety K636, were planted on ridges on each farm in lengths of 10 to 12 m on contour. The ridges, spaced about 1 m apart, were constructed by the farmers using hand hoes, and were between 20 and 40 cm in height. Hedgerows were about 5 m apart. A third plot was left without hedgerows as a control plot.

SEEDING

In order for alley cropping to be cost effective, hedgerows should be established by direct seeding and not by transplanting of seedlings. Consequently, all trials were established by direct seeding. Transplanting of seedlings was used only where it was necessary to fill in gaps in rows where emergence failed, in order to maintain the integrity of the trials for biomass evaluation. However, both biomass yield and ease of establishment must be considered when choosing a hedgerow species for alley cropping.

1991 TRIALS

Seed pretreatment varied with species (Table 3). Seeding was done during the first rainy season of 1991 at each site. From 3 to 10 seeds were planted per hill depending upon laboratory germination test and seed size. Where emergence was poor, hills were reseeded approximately three weeks after the first seeding. The trees were thinned to one plant per hill at approximately five to six weeks after planting. Because of drought and the early onset of the dry season, water was supplied at approximately weekly intervals at a rate of about 2.6 liters (L) per linear meter of row. At the semi-arid site, irrigations were twice weekly for the first three months. These were later reduced to once weekly until the start of the next rainy season. At the onset of the second rainy season, 60-day-old seedlings of *Grevillea robusta, Casuarina cunninghamania, Desmodium gyroides, Pseudoalbizia berteriana, Flemingia macrophylla* (Willd.) O. Ktze*, Mimosa scrabella,* and *Erythrina poeppigiana* were transplanted to fill in gaps in rows. The first weeding took place three weeks after planting. Later weedings were done at 30- to 45-day intervals at each site.

1997 TRIALS

At the high-elevation site at Salagnac, hedgerows were planted in October 1997. Hedgerows were 8 m long and spaced 4 m apart, resulting in plots of 8 m X 8 m. Seed was soaked in hot water for 30 seconds and then soaked in tepid water for 12 hours prior to planting, and three seeds were planted per hill, spaced at 10 cm within the row. Seedlings were thinned to one per hill 55 days after planting. The seedlings of *Albizia julibrissin* died out during the winter months and the species was reseeded in March 1998. The second planting of *A. julibrissin* also died out. Sweet potatoes and cabbages were planted in plots. These were followed by maize and three crops of beans. The farmer was allowed to plant according to his traditional practices. The crops were planted in the entire cropping area of the control plots, whereas in alley plots, the crops occupied about 80 percent of the plot area.

The on-farm trials at Bannate and Gaita were planted in October 1997 and March 1998. The hedgerow species were evaluated both on the basis of biomass production and on crop yield. Most farmers initially planted cowpeas within plots. However, in subsequent seasons, farmers did not all plant the same crops in the following seasons, but in the second rainy season in 1999, all farmers planted cassava. The farmers were provided cuttings from the same variety, in order to ensure sufficient uniformity in the trial to obtain statistically verifiable results. In control plots, crops were planted on all ridges, whereas in alley plots, hedgerows occupied every fifth row, or 20 percent of the plot area.

HEDGEROW PRUNING

Hedgerow pruning management was similar in both series of trials. The first biomass harvest was made approximately one year following hedgerow establishment with most species having more than 1 m height, except at the semi-arid site at Titanyen, where it took three years to obtain sufficient trees greater than 1 m in height in order to harvest biomass. In the following years, hedgerows were pruned three to four times a year at each site (one or two prunings each rainy season), with the exception of Titanyen, where only one harvest per year was carried out in 1994 and 1995. At each harvest, trees were pruned with pruning shears and cut one by one to 50 cm above the ground. Data were collected from the central 3 m of plots at the calcareous and basaltic sites and the central 4 m at the high-elevation and semi-arid sites. Similar procedures were followed at Salagnac, Bannate, and Gaita, except that two hedgerows were sampled per plot at Salagnac and three at the other two sites. At each cut, the prunings were separated into leaves, stems less than 1 cm in diameter, and stems greater than 1 cm in diameter. Fresh weights of each component were determined in the field and subsamples of approximately 200 grams (g) taken for dry matter determination. Stems and branches were sectioned to accelerate the drying. Samples of leaves and stems were dried at 68˚C for 48 and 72 hours, respectively, for dry matter determination. The following section summarizes annual biomass production of the most promising hedgerow species over several years.

HEDGEROW ESTABLISHMENT

An initial evaluation of the first year of hedgerow establishment in 1991 revealed that satisfactory stands were obtained with most species. However, the small-seeded species appeared to be unsuitable for direct seeding in the field, which limits their usefulness as hedgerows for alley cropping. Generally, poor establishment and seedling survival was observed in small-seeded species (< 2.5 g 100^{-1} seed) and where there was drought stress during germination (Shannon et al., 1997). Some of the *Acacia* species were exceptions, having small seed but satisfactory germination. Dry conditions and irregular rainfall patterns at the semi-arid site were not conducive to direct seeding of trees, which raises the issue of whether alley cropping has any relevance to the hot and dry conditions represented by the semi-arid site. In the 1997 trials, all species established well, but *Albizia julibrissin* did not survive at Salagnac because of an unidentified disease that caused swelling at the base of the seedlings' stems. Only those species that gave satisfactory survival and biomass production are reported within the main text. Data on all species included in the 1991 experiments are reported in the Appendix.

SURVIVAL AND BIOMASS PRODUCTION OF PROMISING SPECIES

1991 TRIALS

At the semi-arid site, many seedlings did not survive despite irrigation provided during the first dry season, and growth of surviving trees was so slow that the site was abandoned after the second biomass harvest. Only two annual harvests of biomass production of the hedgerows were made at the semi-arid site before this site was abandoned. *Leucaena leucocephala,* variety K 636, far out-yielded the other species in total, leaf, and stem biomass (see Appendix). Other species that ranked second or third in total, leaf, or small stem biomass included the wild form of *L. leucocephala,* known locally as Delin, *Acacia ampliceps, Cassia emarginata,* and *L. diversifolia.* Information gained on adaptation and growth of the tree species at the semi-arid site can be used in the selection of tree species for windbreaks in this area.

The survival and mean annual biomass over five years of the highest yielding species at the three remaining sites in the 1991 trials are presented in Table 4. Plant survival at these sites is associated with tolerance to repeated prunings and adaptation to environmental conditions. Survival, expressed as percent of hills planted, was good for most of the species across sites. However, there was a 26 percent loss of existing plants for *L. leucocephala* at the high-elevation site and a 31 percent loss for *Delonix regia* (Bojer ex Hook) at the basaltic site. Plant loss occurred in a cumulative way following prunings of *L. leucocephala,* variety K636, indicating the low ability of this species to survive repeated prunings at higher elevations.

Although survival was similar for most of the species within sites, large differences in annual biomass production were recorded among species within and across sites (Table 4). Leaf and green stem biomass are important criteria in assessing hedgerow species for alley cropping. These materials decompose most rapidly and the nutrients they contain are most readily available to the crop. After five years, hedgerows of *L. leucocephala,* variety K636, and *Leucaena* hybrid, variety KX3 (*L. leucocephala* X *L. diversifolia*), produced highest biomass at the two lowland locations, regardless of rainfall and soil types (Table 4). At the low-elevation calcareous site, *D. regia* was the third most productive species in leaf biomass while *Gliricidia sepium* (Jacq.) Walp was the third most productive species at the low-elevation basaltic soils. At the high-elevation site, *Acacia angustissima* (Mill.) Kuntze gave the highest biomass yield followed by *Leucaena* hybrid, variety KX3, and *L. diversifolia,* variety K156. On average, the highest-yielding species at each site gave more than 5 metric tons per hectare per year (Mg ha^{-1} yr^{-1}) of dry leaf and stem biomass. These amounts of annual biomass were adequate to provide N and to sustain soil organic matter in alley cropping systems. Continuous supply of organic materials from hedgerows is of particular interest in maintaining alley cropping systems. Good survival and sustained biomass

Table 4. Summary of Five-Year Results (1992-1996) for the Best Performing Hedgerow Species at Three Sites in the 1991 Trials

Species (variety)	Survival %	Total biomass Mg ha^{-1} yr^{-1}	Leaf biomass Mg $ha^{-1}$$yr^{-1}$	Stem biomass † Mg ha^{-1} yr^{-1}
Low Elevation – Calcareous soil ‡				
Leucaena leucocephala (K636)	100	13.0	5.7	3.7
Leucaena hybrid (KX3)	94	12.4	5.5	3.1
Leucaena shannonii	98	7.9	2.6	2.4
Leucaena diversifolia (K156)	96	6.8	3.2	1.6
Delonix regia	96	6.4	3.8	1.3
Gliricidia sepium (HYB)	92	4.1	2.5	1.2
Low Elevation – Basaltic soil §				
Leucaena leucocephala (K636)	96	9.0	3.3	2.7
Leucaena hybrid (KX3)	97	8.1	3.5	1.9
Leucaena shannonii	96	4.3	1.8	1.7
Leucaena diversifolia (K156)	94	4.8	2.2	1.1
Delonix regia	69	1.7	1.0	0.4
Gliricidia sepium (HYB)	91	4.6	2.3	1.3
High Elevation Site ¶				
Acacia angustissima	96	8.6	5.2	2.1
Leucaena hybrid (KX3)	87	5.8	3.0	1.6
Leucaena diversifolia (K156)	94	5.6	3.1	1.3
Leucaena leucocephala (K636)	74	4.6	2.2	1.3
Flemingia macrophylla	96	2.9	1.9	1.0
Calliandra calothyrsus	85	2.5	1.6	0.8

†Stem < 1 cm diameter. ‡Bergeau. §Saint Georges. ¶Fort Jacques

yield under an intensive pruning regime are indices of good adaptation of the species reported here. The low performance of *L. leucocephala* at high elevations was probably due to the presence of the psyllid insects, which were observed on leucaena plants during the cool months of the year.

Because of the problem of destruction of hedgerows in farmers' fields due to overgrazing, the performance of *Delonix regia*, which has the unique characteristic of being unpalatable to ruminants, was of particular interest to us. Initially, the growth and productivity of the species was unimpressive. However, by the fourth year the yield of *Delonix regia* at the calcareous site was close to that of the highest yielding species (Figure 2).

1997 TRIALS

Albizia julibrissin did not survive the seedling stage because of disease, but survival was satisfactory for all remaining species at the three sites. Yields of total biomass at the high-elevation site at Salagnac are presented in Figure 3. As at the high-elevation site of Fort Jacques, *Acacia angustissima* yielded highest, and the yield increased over time. It was initially followed by *L. leucocephala* and *Leucaena* hybrid KX2, but *Calliandra calothyrsus*, which had very low yield in the first year, increased over time, such that in the fourth year, calliandra yields were double that of the *Leucaena* species. Similar results were observed for leaf biomass yield.

The on-farm study was initiated to determine if *Delonix regia* had potential as an alternative hedgerow to leucaena in areas where grazing by livestock resulted in destruction or serious damage to leucaena hedgerows. In the first six biomass harvests, *Delonix regia* yielded 64 percent and 69 percent higher leaf and total biomass, respectively, than did leucaena in four farmers' fields at Gaita and 79 percent and 74 percent higher, respectively, in five farmers' fields at Bannate (Figure 4.). The higher yield of *D. regia* compared to leucaena was contrary to the results in the previous trials at Bergeau and St. Georges and may be attributed to browsing of leucaena by free-ranging goats. Although a formal assessment by farmers was not conducted, some participating farmers preferred *Delonix* over leucaena because of its higher biomass yield.

YIELDS OF ASSOCIATED CROPS

Since hedgerows were being tested for possible use in alley cropping, no assessment could be complete without testing crops in an alley cropping configuration. The effects of the hedgerows on the

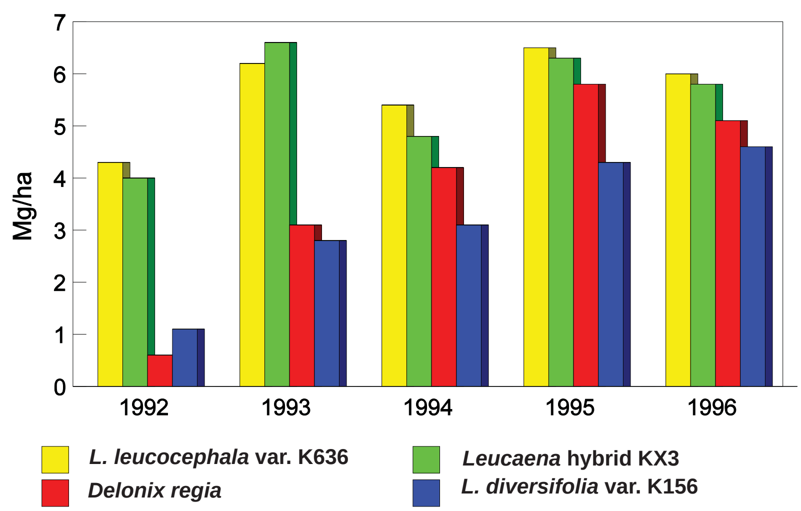

Figure 2. Increase in Leaf Yields of *Delonix regia* over Five-Year Period Relative to *Leucaena* Species. Bergeau, Haiti.

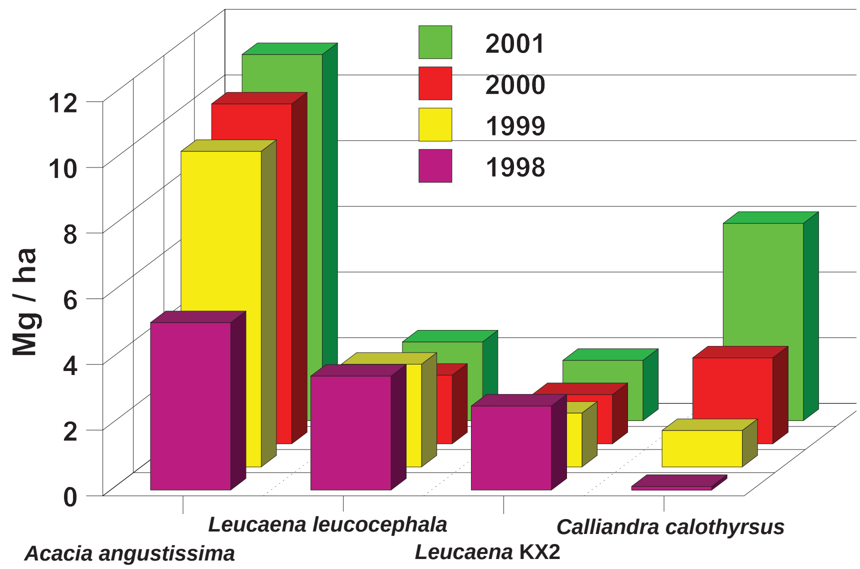

Figure 3. Total Biomass Yield of Hedgerow Species at Salagnac, Haiti, between 1998 and 2001.

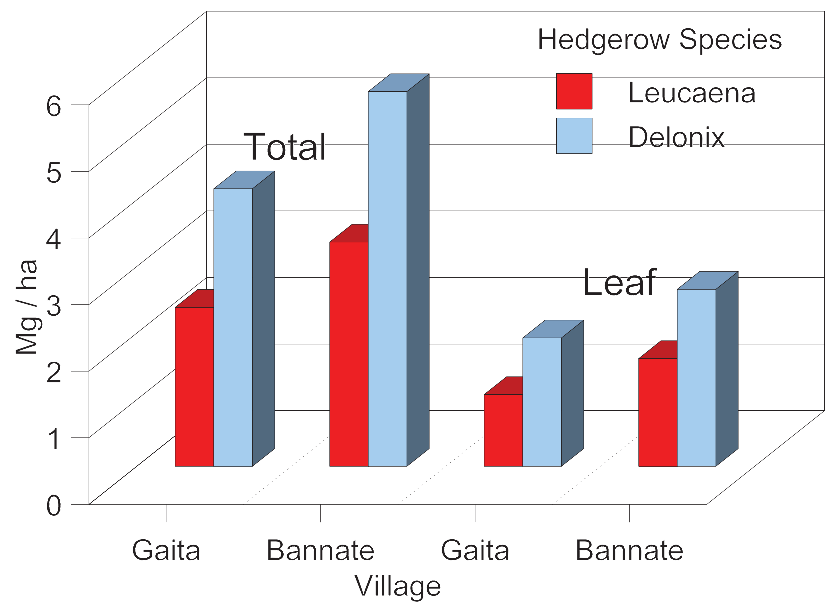

Figure 4. Biomass Yields of *Leucaena leucocephala* and *Delonix regia* Hedgerows in Farmer's Fields at Bannate and Gaita, Haiti.

associated crops in alley cropping are the result of competitive and beneficial effects, which are mitigated by moisture conditions as well as hedgerow management. The 1997 trials were designed to test a fewer number of species, but in alley cropping conditions. At Salagnac, Gaita, and Bannate, crops were grown between the hedgerows and in control plots in order to assess the effects of the alley cropping with different hedgerow species on crop yields.

At Salagnac, there were no significant differences in maize yields harvested in July 1998, although there was a tendency for higher yields in the control plots, reflecting the 25 percent greater number of maize plants in these plots. Four crops of beans were planted between 1999 and 2001. Bean yields were low and did not test significant for treatments, but highest yields tended to be in plots with the *Leucaena* species. If one considers only the area cropped to beans, yields did test significant for the September

1999 season, with beans grown with *Leucaena* species and with *A. angustissima* giving higher yields than beans in the control plots. Also, bean yields averaged over four seasons were 11 percent higher in *Leucaena* plots than in control (251 kilogram [kg] ha^{-1} vs 225 kg ha^{-1}), despite a reduced cropping area in alley-cropped plots, which illustrates that alley cropping was not detrimental to the crop at this site.

At Gaita and Bannate, cassava was harvested in December 2000 and January 2001. Cassava yields were low in Bannate and extremely low in Gaita, due to low fertility and drought stress. There was little difference in root yield for cassava grown between the two hedgerow species. At Gaita, cassava grown between hedgerows appeared greener than cassava grown in control plots, but when the yield calculation included the area lost to the hedgerows, there was a small, non-significant yield advantage for control plots (12.4 vs 11.3 Mg ha^{-1} fresh-weight roots). At Bannate, yields in control plots were approximately double that in alley-cropped plots (34.6 vs 16.8 Mg ha^{-1}). Soils at Bannate are very shallow and slopes are very steep, factors that create conditions favoring high runoff of rainfall and limited water storage capacity in the soils, rendering the sites very susceptible to drought. Both the cassava and the hedgerows grow throughout the dry season, competing for limited moisture in the soil. It is likely that competition from the hedgerows would be severe during the dry season, which would explain, in part, the lower yields in the alley plots than in the control plots. Also, because goats browsed the hedgerows, the contribution of organic matter and N to the soil from leucaena was limited, thus reducing the positive benefits anticipated from alley cropping with this species.

The disappointing results obtained with cassava at Bannate should not be taken to mean that alley cropping is not suitable at this site, as positive results have previously been obtained at Bannate. (Pierre et al., 1995). More frequent pruning of the hedgerows would likely have reduced competition and resulted in higher yields with alley cropping, as demonstrated by Isaac et al. (2004). Alley cropping clearly has a potential role to play in soil conservation at Bannate and Gaita because of the very steep slopes cropped. The important point is that no major differences were observed between hedgerow species with regards to their effect on crop yield. Thus, preliminary results suggest that *Delonix regia* may be used as a hedgerow in alley cropping so long as the crop's N requirements are met. Similarly, at Salagnac, the species of the hedgerows did not appear to affect crop yield. With abundant rainfall, competition for water did not appear to be a factor, and yields were not adversely affected by alley cropping, despite the loss in cropping area due to the presence of hedgerows.

HEDGEROW SPECIES AS SOURCE OF CARBON AND NITROGEN

DECOMPOSITION STUDY

Decomposition and N release from prunings of selected hedgerow species were monitored in the field using nylon mesh bags measuring 20 X 10 cm with 50 to 60 micrometer (µ) openings. The study was carried out from September 1995 through August 1996 using prunings from five of the most promising species at the low-elevation calcareous site and five at the high-elevation site, respectively. Promising species were selected based upon their mean annual biomass production and their percent survival over time. At each site, air-dried leaf and stem (less than 1 cm in diameter) prunings harvested from four-year-old hedgerows were sealed separately in litter bags and placed on the soil surface. Subsamples of each leaf and stem pruning were oven dried at 68^{o} C for 48 hours to account for moisture. The quantity of biomass included in the litter bags was calculated based upon the biomass yield of the species in Mg ha^{-1} and the surface area of the bag. The bags were arranged in a randomized block design with four replicates within each site. Following placement on the soil surface, four bags of each type of prunings per species were retrieved from the field at 2, 4, 8, 16, and 48 weeks. At each sampling time, soil and debris adhering on bag surfaces were carefully removed before drying the sample at 68^{o} C for 48 hours. Subsamples of 1 g were ashed in a muffle furnace at 400^{o} C for 12 hours and the data converted to an ash-free basis. Contents of each bag were weighed, ground to pass a 1-millimeter sieve, and analyzed for total C and N using a LECO CHN-600 analyzer (Leco Corp., St. Joseph, MI). Initial prunings were also analyzed for total C and N, lignin, cellulose, and polyphenol to estimate the importance of these elements on the decomposition process. Lignin and cellulose concentrations were determined via acid-detergent fiber analysis and polyphenol was extracted as soluble polyphenolics in aqueous methanol and determined colorimetrically (Isaac et al., 2000).

CARBON LOSS AND NITROGEN RELEASE FROM PRUNINGS

At both sites, pruning decomposition varied greatly among the species tested (Figure 5). At the low-elevation site, leaf C loss was highest (82 percent) in *G. sepium* and lowest (42 percent) in *D. regia* after 48 weeks (Isaac et al., 2000). Similarly, stem C loss was highest for *G. sepium* at the low-elevation site. At the high-elevation site, leaf prunings decomposed slower than at low elevation. Differences in temperature and relative humidity may be responsible for variations in pruning decomposition between the two sites. At the high-elevation site, C loss after 48 weeks was highest for *L. leucocephala* (48 percent) and lowest for *F. macrophylla*. At both sites, initial N concentrations of the leaf appeared to be the best parameter to estimate the decomposition rates of leaf prunings.

Nitrogen release from prunings resembled C loss within each site (Isaac et al., 2000). Nitrogen release was calculated by multiplying the percentage estimate of N release from the respective equations by the initial N content, and adding results for leaves and stems together according to species and sites.

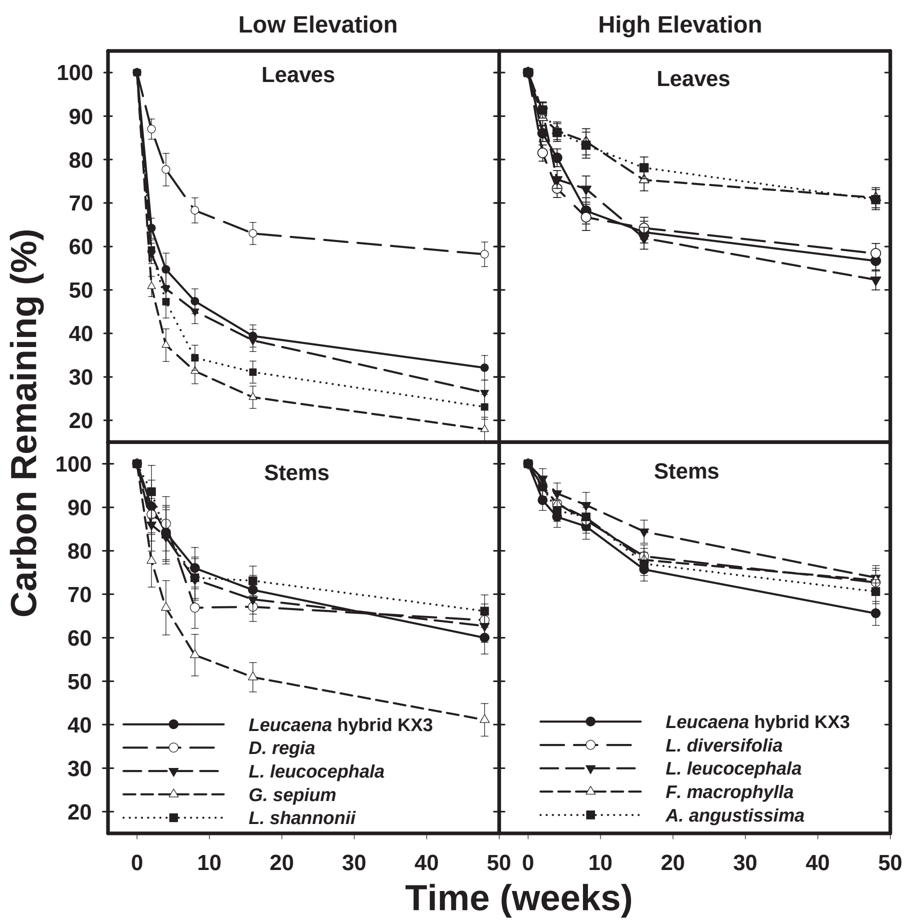

Figure 5. Carbon Remaining from Decomposing Leaves and Stems of Species Assessed for Alley Cropping at Low- and High-Elevation Sites in Haiti (Bars Are Standard Errors of the Means). Adapted from Isaac et al., 2000.

The equations were determined by fitting the single three-parameter or the double four-parameter model previously described by Weider and Lang, 1982. The equations were of the forms:

$$Y = A_0 + A_1 e^{-k1t} + Error$$

$$Y = A_0 e^{-k1t} + A_1 e^{-k2t} + Error$$

Cumulative N release during the first 16 weeks is shown in Figure 6. At the low-elevation site, *L. leucocephala* and *G. sepium* released more than 60 kg N ha^{-1} during the first four to six weeks, whereas at the high-elevation site, *A. angustissima* released approximately 40 kg N ha^{-1} during the same period. The low N content of *D. regia* (Table 5), combined with a slow rate of decomposition, resulted in less N released (36.4 kg N ha^{-1}) over 16 weeks at low elevation. At high elevation, the slow decomposition of the various species led to very limited N contributions to the soil, *A. angustissima* being the highest yielding species and *F. macrophylla,* the lowest N contributor (Figure 6). The rate of N release appeared to be related to the concentration of N as well as lignin and polyphenols in plant parts, the latter two reducing the rate of decomposition (Isaac et al., 2000).

It should be noted that the amount of N shown in Figure 6 comprises only the N release from the prunings from the first biomass harvest in a cropping season. In a real alley-cropping situation, one or two additional prunings would be made during the same season, contributing additional N, and N would also be released from decomposition of residues of prunings applied to the soil from previous cropping seasons. Thus the total amount of N available to the crop from alley cropping would be considerably more than the amounts shown.

The two species *L. leucocephala* and *A. angustissima* can be promoted as species for alley cropping at low and high elevations, respectively, to provide timely release of N for the associated crop. Because of the fast N release of leaf prunings of *G. sepium,* changes in hedgerow management may be necessary to prevent loss of the N before it can be taken up by the crop. *Delonix regia* is a poor source of N, but this species may have potential for soil conservation in areas where uncontrolled grazing prevents the successful use of leucaena.

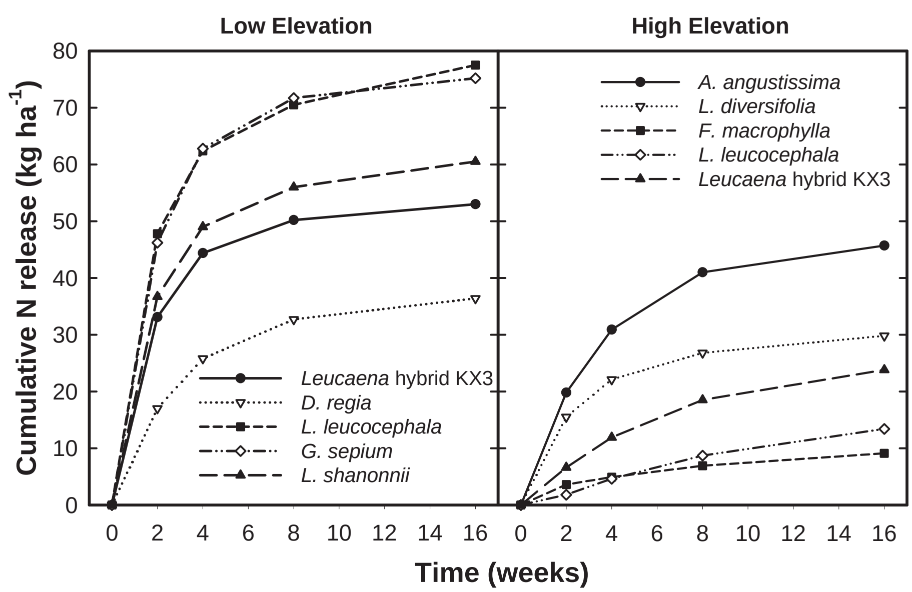

Figure 6. Cumulative N Release from Decomposing Hedgerow Prunings at a Low- and a High-Elevation Site in Haiti. Adapted from Isaac, et al., 2000.

TABLE 5. CUMULATIVE BIOMASS APPLIED OVER FIVE YEARS, LEAF N, AND SOIL ORGANIC C AND N AT THREE SITES IN THE 1991 TRIALS (1992-1996)

Species (variety)	Applied biomass † Mg ha^{-1}	Leaf N g kg^{-1}	Soil total N g kg^{-1}	Soil organic C g kg^{-1}
Low Elevation – Calcareous soil ‡				
Leucaena leucocephala (K636)	46.9	33.0	0.65	33.9
Leucaena hybrid (KX3)	42.9	33.2	0.58	31.3
Leucaena diversifolia (K156)	23.6	33.1	0.55	32.0
Delonix regia	24.4	24.5	0.60	35.1
Gliricidia sepium (HYB)	18.5	28.8	0.58	31.9
Control (No Hedgerows)	—	—	0.53	29.9
Low Elevation – Basaltic soil				
Leucaena leucocephala (K636)	29.6	23.5	0.25	16.2
Leucaena hybrid (KX3)	26.8	24.8	0.28	14.9
Leucaena diversifolia (K156)	15.9	24.9	0.25	13.4
Delonix regia	4.9	22.1	0.23	12.1
Gliricidia sepium (HYB)	17.5	23.0	0.25	12.7
Control (No Hedgerows)	—	—	0.25	12.3
High Elevation Site				
Acacia angustissima	25.9	41.2	0.55	30.1
Leucaena hybrid (KX3)	23.1	37.2	0.53	29.3
Leucaena diversifolia (K156)	22.3	37.9	0.48	26.0
Leucaena leucocephala (K636)	18.3	34.5	0.48	24.5
Flemingia macrophylla	14.1	30.9	0.48	24.3
Control (No Hedgerows)	—	—	0.48	22.1

†Total over 5 years (Leaf + stem < 1 cm diameter)
Adapted from Isaac et al. (2003)

HEDGEROW BIOMASS APPLICATION EFFECTS ON SURFACE SOIL CARBON AND NITROGEN

Five years after beginning the initial hedgerow species trials, soils under five of the most productive hedgerow species and in plots without trees were sampled at each site to determine effects of cumulative application of hedgerow prunings on surface soil C and N. At the low-elevation calcareous and basaltic sites, soils were sampled under *L. leucocephala,* variety K636; *Gliricidia sepium* (Jacq.) Walp., variety HYB; *L. diversifolia,* variety K156; *Leucaena* hybrid (*L. leucocephala* X *L. diversifolia*), variety KX3; and *D. regia* hedgerows, respectively. At the high-elevation site of Fort Jacques, soils were taken under *L. leucocephala,* variety K636; *L. diversifolia,* variety K156; *Leucaena* hybrid, variety KX3, *A. angustissima*; and *Flemingia macrophylla* hedgerows. Control plots were selected at least 4 m away from a hedgerow species or where a species failed to germinate. Soils were collected at the surface (0 to 5 cm) using a knife after digging holes (approximately 15 cm in diameter) with a machete in each plot from the alley above each hedgerow (beginning at 50 cm from the hedgerows). Soil samples were combined within plots before analysis. Soil organic C was determined after correction for carbonate C with 4 N H_2SO_4. Soil total N and organic C were determined using LECO CHN-600 analyzer (Leco Corp., St. Joseph, MI) (Isaac et al., 2003).

BIOMASS APPLIED AND SURFACE SOIL N AND C

Cumulative total biomass is provided in Table 5 to estimate the relation between amounts of biomass applied and surface soil C and N. Biomass yields were higher at the calcareous than at the other sites. Better soil quality and fairly abundant and well-distributed rainfall are probably the major reasons for higher yields at the calcareous site. Within sites, *L. leucocephala* and *Leucaena* hybrid were the most productive species at low elevations whereas *A. angustissima* yielded highest at the high elevation. *Delonix regia* yielded significantly lower at the basaltic than at the calcareous site, probably owing to poor stand establishment, poor soil fertility, and drought stress at the basaltic site. There were significant site-by-species interactions for total biomass of the *Leucaena* species. The highest yielding species at low-elevation sites *(L. leucocephala)* ranked fourth at high elevation.

The different species of hedgerows had varying effects on soil organic C and total N owing to amount and quality of prunings applied (Table 5). At the low-elevation, calcareous site, cumulative application of *L. leucocephala* and *D. regia* prunings to the surface increased soil total N by 23 and 13 percent, respectively, over the control soils without trees (Isaac et al., 2003). Low pruning quality of *D. regia* may have contributed to immobilization of N at the soil surface. However, high N concentrations of leaf prunings of *L. leucocephala* did not appear to increase soil organic matter decomposition, which would lead to mobilization of soil N. One possible explanation would be that a higher proportion of stems in the total biomass for *L. leucocephala* may have slowed the rate of the decomposition processes. At the basaltic and high-elevation sites, differences in soil total N were not significant, but highest soil N was recorded under *Leucaena* hybrid and *A. angustissima,* respectively.

Although not consistent, application of hedgerow prunings to the surface led to higher soil organic C than in the controls at all three locations, except in the case of *D. regia* at the basaltic site (Isaac et al., 2003). Biomass yields from *D. regia* at the latter site were probably not enough to positively impact surface soil organic C. Higher soil C was observed in soils under *D. regia* (calcareous site) and under *A. angustissima* (high-elevation site) than in the controls. Except for the calcareous site, the trends were for an increase in soil organic C in proportion to the amount of prunings applied. Linear relations were obtained by regressing amount of biomass applied on soil organic C at the basaltic (r^2 = 0.86) and high elevation (r^2 = 0.75) sites, respectively. This means that the more biomass that was applied, the higher the soil organic C content. A reverse situation occurred at the calcareous site, where prunings from *D. regia* (third most productive species at calcareous site) contributed to highest soil organic C after five years of mulching. In this case, the chemical composition of *D. regia,* rather than quantity may have contributed to slow the decomposition processes, leading to buildup of soil organic matter. Application of prunings had a greater effect on surface soil organic C than on soil N. Lower buildup of organic N than C may have resulted from a more rapid mineralization of the organic-N compounds formed.

CONCLUSIONS AND IMPLICATIONS

Choice of species is very important in alley cropping. A total of 37 hedgerow species were tested for biomass production under annual rainfall regimes ranging from 700 mm to more than 2,600 mm and from near sea level to 1,200-m elevation. At all low-elevation sites, regardless of rainfall amount or soil type, *Leucaena leucocephala* and related species were the most productive in terms of total and leaf biomass. *L. leucocephala* and *Gliricidia sepium* were the best sources of N. At both high-elevation sites, *Acacia angustissima* was by far the most productive species in terms of biomass production, and also the N supplied through decomposition. *Calliandra calothyrsus* appears to have potential at high-elevation humid sites but was not productive at the high-elevation site with moderate rainfall. Where grazing of hedgerows by ruminants is a major problem, *Delonix regia* was shown to have potential for low-elevation sites. However, because it does not fix N, another source of N should be supplied, such as from a leguminous cover crop or fertilizer N.

Major differences were not observed in the effect of different hedgerow species on crop yields, although there will likely be differences in crop growth over the long term due to the effects on soil C and N of hedgerow biomass applications differing in quality and quantity. Also, vigorously growing, competitive species may require more aggressive management than less vigorously growing species, especially on drought-prone sites, in order minimize competition to the crop.

This research program was one of the most comprehensive in terms of testing a large number of tree and shrub species for their potential in alley cropping in a range of environments and over several years. The results published herein should be of benefit elsewhere in the tropics where growing conditions are similar to those in Haiti. The importance of comparing species for at least four or five years is illustrated in the changes in relative yield over time of *Delonix regia* at Bergeau (Figure 2) and *Calliandra calothyrsus* at Salagnac (Figure 3). Both species initially appeared to be unproductive, but in later years were among the most productive species at those locations.

There is a need for research to identify the best hedgerows for elevations in excess of 1,200m. In Haiti, agricultural activities take place up to more than 1,700 m elevation, and some of these areas are highly vulnerable to soil erosion. Alley cropping in these areas with hedgerows adapted to the cooler temperatures of the high-elevation tropics would stabilize production and help to protect areas lower in the watersheds that are subject to flooding and sedimentation.

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APPENDIX: DETAILED INFORMATION ON 1991 TRIALS

Note on interpreting data: A significant F test indicates that there are differences among species. *** = significant at 0.1 percent level of probability (less than 1:1000 chance that there are no differences). $LSD_{0.05}$ = least significant difference at 95 percent level of certainty. If two species differ by greater than the $LSD_{0.05}$, it is assumed that the difference between species is not due to chance. The terms, SE and CV % are standard error of the mean and coefficient of variation, respectively, statistics useful in evaluating the data set. With respect to biomass harvests, only hedgerows more than 1 meter tall were harvested. Thus, for some less productive species, some plots were harvested and some were not, resulting in zero yield. The inclusion of yields of zero may explain the high coefficients of variation in some analyses. Species for which no plots were harvested were treated as missing values in the analyses.

TABLE A1. PERCENT EMERGENCE AND PLANT NUMBER AS PERCENT OF HILLS PLANTED FOR HEDGEROW SPECIES AT THE HIGH-ELEVATION SITE AT FORT JACQUES

Species (variety)	Emergence 35 DAP ‡	Plants† 35 DAP	Plants† 229 DAP	Plants† 348 DAP §	Plants† 727 DAP ¶
	%				
Leucaena leucocephala (K 636)	60.5	91.5	97.3	96.6	96.6
Calliandra calothyrsus	66.8	94.7	100.5	94.2	91.3
Leucaena diversifolia (K 156)	30.3	56.1	87.3	90.1	88.6
Leucaena hybrid (KX3)	46.3	94.3	89.9	90.8	88.4
Flemingia macrophylla	24.2	41.3	82.6	84.7	85.9
Acacia angustissima	42.4	79.7	5.7	84.7	83.6
Gliricidia sepium (HYB)	57.7	86.8	85.1	92.7	81.6
Casuarina cunninghamiana	0.0	3.0	91.2	84.8	77.2
Grevillea robusta	0.8	8.8	65.1	51.9	47.4
Albizia procera	12.3	41.5	42.8	43.8	40.5
Erythrina poeppigiana	13.5	28.1	27.9	25.2	18.8
Erythrina indica	22.6	66.4	74.7	52.4	15.7
Acacia decurrens	4.5	23.0	26.3	15.3	15.1
Acacia melanoxylon	2.9	10.4	40.8	36.6	14.3
Acacia mearnsii	22.1	59.5	23.9	16.8	11.6
Mimosa scabrella	9.4	31.1	26.7	16.4	7.1
Significance (F test)	***	***	***	***	***
$LSD_{0.05}$	10.8	17.5	23.6	24.2	20.8
SE	3.8	4.3	5.8	6.0	5.1
CV %	29.0	21.2	22.3	24.5	23.9

†Percentage of hills containing plants. Means adjusted for differences between blocks. Note: Increase in plant population for some species after 35 days may reflect seedling transplants.
‡ Days after planting. §Before first pruning. ¶Before third pruning
ns, *, *** = not significant, significant at 5% and 0.5% levels of probability, respectively.

TABLE A2. PERCENT EMERGENCE AND PLANT NUMBER AS PERCENT OF HILLS PLANTED FOR HEDGE-ROW SPECIES AT THE CALCAREOUS SITE AT BERGEAU

Species (variety)	Emergence 40 DAP ‡	Plants † 40 DAP	Plants † 105 DAP	Plants † 293 DAP §	Plants † 705 DAP ¶
			%		
Gliricidia sepium (HYB)	80.4	96.9	98.0	98.0	96.5
Albizia lebbeck	23.0	71.9	71.9	96.4	93.0
Leucaena leucocephala (K 636)	66.0	94.9	94.9	95.4	93.0
Albizia guachapele	73.5	97.4	96.9	94.9	93.0
Enterolobium cyclocarpum	71.8	98.5	99.0	99.0	91.5
Leucaena shannonii	76.6	93.9	89.3	90.8	88.5
Senna siamea	36.7	84.7	94.4	90.3	87.5
Erythrina indica	35.4	77.5	96.4	95.4	86.0
Leucaena hybrid (KX3)	54.3	89.3	87.8	87.7	84.5
Delonix regia	31.1	78.6	86.2	87.7	82.5
Inga vera	100.0	96.4	96.9	93.4	76.5
Casuarina cunninghamiana	0.0	0.0	0.0	80.1	62.5
Leucaena diversifolia (K 156)	41.8	79.1	77.0	69.4	68.0
Calliandra calothyrsus	74.9	94.9	87.8	68.4	53.0
Leucaena salvadorensis	71.8	95.4	90.3	57.6	52.5
Paraserianthes falcataria	21.5	61.2	49.5	86.2	50.0
Tephrosia candida	12.2	53.1	53.1	55.6	25.0
Acacia angustissima	11.3	52.6	60.2	88.8	18.0
Desmodium gyroides	0.0	0.0	0.0	51.0	0.0
Erythrina poeppigiana	6.5	25.5	8.2	0.0	0.0
Significance (F test)	***	***	***	***	***
$LSD_{0.05}$	9.2	9.6	10.3	12.3	14.4
SE	3.3	3.4	3.6	4.3	5.1
CV %	14.7	9.4	10.1	10.9	15.6

† Percentage of hills having plants. Note: Increase in population of plants for some species at 293 DAP reflects transplanting of seedlings. ‡ Days after planting. § Before 1st pruning. ¶ Before 3rd pruning
*** = Significant at the 0.1 % level of probability.

TABLE A3. PERCENT EMERGENCE AND PLANT NUMBER AS PERCENT OF HILLS PLANTED FOR HEDGE-ROW SPECIES AT THE BASALTIC SITE AT ST. GEORGES

Species (variety)	Emergence 40 DAP ‡	Plants † 40 DAP	Plants † 105 DAP	Plants † 293 DAP §	Plants † 705 DAP ¶
			%		
Leucaena leucocephala (K636)	68.96	91.84	91.8	86.5	86.0
Gliricidia sepium (HYB)	62.33	88.78	86.7	84.5	83.5
Enterolobium cyclocarpum	61.53	90.31	85.7	76.5	70.0
Leucaena salvadorensis	64.03	87.76	72.4	69.0	67.0
Leucaena hybrid (KX3)	41.69	89.80	74.0	68.5	66.5
Leucaena shannonii	52.38	76.53	61.2	57.0	55.5
Calliandra calothyrsus	38.99	72.96	63.3	54.5	53.5
Leucaena diversipholia (K156)	13.09	49.49	47.4	40.0	39.5
Delonix regia	16.63	48.47	56.1	45.0	35.0
Cassia siamea	17.03	59.69	42.3	31.0	29.0
Flemingia macrophylla	8.55	27.04	16.8	12.0	10.5
Cassia emarginata	7.91	26.02	15.3	6.0	4.5
Acacia angustissima	1.78	9.52	9.7	5.0	3.5
Casuarina cunninghamiana++	0.00	•	•	•	•
Desmodium gyroides++	0.00	•	•	•	•
Grevillea robusta++	0.00	•	•	•	•
Significance	***	***	***	***	***
$LSD_{0.05}$	12.12	22.76	16.4	18.4	18.8
SE	4.25	9.13	5.8	6.5	6.6
CV %	29.93	24.47	25.5	32.6	34.9

†Plant stands per hill. Survival is based upon percentage of plants remaining after thinning.
‡Days after planting. §Before 1st pruning. ¶Before 3rd pruning.
"•" No plants. Not included in analysis.
ns, *, *** = not significant, significant at 5% and 0.5% levels of probability, respectively.

TABLE A4. PERCENT EMERGENCE, PERCENT PLANTS AFTER THINNING, AND PERCENT SURVIVAL OF HEDGEROW SPECIES AT THE SEMI-ARID SITE AT TITANYEN

Species (variety)	Emergence 37 DAP ‡	Plants † 45 DAP	Plants † 108 DAP	Survival † 366 DAP
	%			
Leucaena leucocephala (Delin)	70.00	86.65	89.16	99.07
Leucaena leucocephala (K636)	61.66	91.66	90.83	95.87
Gliricidia sepium (HYB)	53.75	83.32	78.33	94.00
Cassia emarginata	38.54	71.66	80.85	93.19
Delonix regia	19.00	59.16	59.99	87.83
Albizzia lebbeck	21.07	57.50	58.33	87.39
Leucaena diverifolia (K156)	12.92	23.33	43.35	77.30
Acacia colei	63.54	73.33	79.17	67.24
Acacia ampliceps	18.85	68.33	77.49	63.71
Albizzia guachepele	43.47	69.16	56.66	56.13
Enterolobium cyclocarpum	79.16	95.83	95.83	45.10
Acacia holosericea	40.52	68.33	50.83	29.30
Cassia siamea	23.75	64.16	60.01	19.55
Piptadenia peregrina	13.33	33.33	20.83	10.71
Albizzia procera	42.86	57.50	51.66	5.83
Acacia tumida	31.98	77.50	29.99	0.00
Casuarina cunninghamiana++	0.00	•	•	•
Pseudoalbizzia berteriana++	0.00	•	•	•
$LSD_{0.05}$	15.88*	21.87***	27.03***	28.26***
SE	5.59	7.55	9.52	9.92
CV %	31.75	22.72	33.49	33.54

† Plants: plant population as percentage of hills planted. Survival: Percentage of plants present after thinning.
‡ Days after planting.
"•" No plants. Not included in analysis.
*,*** = Significant at the 5% and 0.5% levels of probability respectively.

TABLE A5. TOTAL AND LEAF DRY WEIGHT BIOMASS HARVESTED FROM TREE SPECIES IN FIVE YEARS AT THE HIGH-ELEVATION SITE

	Total biomass					Leaf biomass				
Species (variety)	1992	1993	1994	1995	1996	1992	1993	1994	1995	1996
	t/ha									
Acacia angustissima	8.87	8.15	6.49	10.76	8.55	4.41	5.38	4.52	6.50	4.74
Leucaena hybrid (KX3)	7.15	5.63	3.90	7.06	5.16	2.33	3.29	2.69	3.83	2.89
Leucaena diversifolia (K156)	5.14	3.82	3.74	9.03	6.15	2.09	2.47	2.67	4.87	3.52
Leucaena leucocephala (K636)	6.45	4.77	3.13	4.96	3.31	1.81	2.75	2.17	2.58	1.77
Flemingia macrophylla	0.88	3.22	2.57	4.31	3.52	0.50	2.02	1.90	2.66	2.19
Calliandra calothyrsus	1.00	1.99	2.27	3.58	3.80	0.52	1.34	1.69	2.15	2.43
Gliricidia sepium (HYB)	0.24	0.28	0.33	1.92	0.73	0.16	0.23	0.26	1.19	0.61
Albizia procera	•	•	0.09	0.43	0.81	•	•	0.07	0.31	0.65
Casuarina cunninghamiana	•	0.24	0.09	0.28	0.25	•	0.18	0.07	0.23	0.15
Erythrina poeppigiana	•	0.28	0.23	0.16	0.15	•	0.18	0.16	0.12	0.10
Grevillea robusta	•	0.09	0.06	0.19	0.12	•	0.08	0.06	0.18	0.09
Erythrina indica	0.02	0.01	•	•	•	0.01	0.002	•	•	•
Acacia decurrens	•	•	•	•	•	•	•	•	•	•
Acacia melanoxylon	•	•	•	•	•	•	•	•	•	•
*Acacia mearns*i	•	•	•	•	•	•	•	•	•	•
Mimosa scrabella	•	•	•	•	•	•	•	•	•	•
Significance (F test)	*	***	***	***	***	***	***	***	***	***
$LSD_{0.05}$	4.35	2.40	1.12	2.38	1.91	1.65	1.29	0.72	1.31	1.03
CV %	65.99	55.53	32.06	36.69	38.71	62.81	47.49	29.03	34.95	35.51

*, *** = Significant at the 5 % and 0.5 % levels of probability, respectively.
"•" indicates not harvested. Not included in analysis.

TABLE A6. BRANCH AND STEM DRY WEIGHT BIOMASS HARVESTED FROM TREE SPECIES IN FIVE YEARS AT THE HIGH-ELEVATION SITE

	Small stem biomass †					Large stem biomass ‡				
Species (variety)	1992	1993	1994	1995	1996	1992	1993	1994	1995	1996
	t/ha									
Acacia angustissima	1.61	1.79	1.75	2.87	2.35	2.86	0.98	0.22	1.40	1.45
Leucaena hybrid (KX3)	1.62	1.29	1.05	2.32	1.83	2.75	1.10	0.16	0.90	0.44
Leucaena diversifolia (K156)	1.01	0.70	0.89	2.35	1.70	1.94	0.66	0.14	1.78	0.93
Leucaena leucocephala (K636)	1.99	1.28	0.84	1.83	1.25	2.55	0.74	0.12	0.55	0.29
Flemingia macrophylla	0.27	1.00	0.67	1.54	1.33	0.01	0.21	•	0.01	•
Calliandra calothyrsus	0.33	0.45	0.53	0.93	1.03	0.12	0.22	0.03	0.51	0.34
Gliricidia sepium (HYB)	0.07	0.05	0.07	0.41	0.12	0.01	•	•	0.32	•
Albizia procera	•	•	0.01	0.02	0.06	•	•	0.01	0.11	0.11
Casuarina cunninghamiana	•	0.06	0.02	0.05	0.10	•	•	•	•	•
Erythrina poeppigiana	•	0.04	0.05	0.04	0.04	•	0.06	0.02	0.01	0.01
Grevillea robusta	•	0.01	0.01	0.01	0.02	•	•	•	•	•
Erythrina indica	0.01	0.01	•	•	•	0.01	•	•	•	•
Acacia decurrens	•	•	•	•	•	•	•	•	•	•
Acacia melanoxylon	•	•	•	•	•	•	•	•	•	•
Acacia mearnsii	•	•	•	•	•	•	•	•	•	•
Mimosa scrabella	•	•	•	•	•	•	•	•	•	•
Significance (F test)	*	***	***	***	***	ns	ns	ns	***	***
$LSD_{0.05}$	0.86	0.60	0.32	0.72	0.68	2.11	1.01	0.23	0.58	0.41
CV %	56.42	59.06	35.30	38.36	45.75	92.87	94.84	122.13	54.75	43.92

†Stems < 1 cm diameter, partially green; ‡stems 1 - 5 cm diameter. Tends to be woody.
ns, *, *** = Not significant and significant at the 5 % and 0.5 % levels of probability, respectively.
"•" indicates not harvested. Not included in analysis.

TABLE A7. TOTAL AND LEAF DRY WEIGHT BIOMASS HARVESTED FROM TREE SPECIES IN FIVE YEARS AT THE CALCAREOUS SITE

	Total biomass						Leaf biomass					
Species (variety)	1992	1993	1994	1995	1996	1997†	1992	1993	1994	1995	1996	1997†
	t/ha											
Leucaena leucocephala (K636**)**	12.71	13.63	12.21	13.49	12.90	9.71	4.27	6.17	5.35	6.51	5.96	4.15
Leucaena hybrid (KX3)	12.07	13.62	10.68	12.69	12.95	11.94	4.03	6.57	4.84	6.25	5.83	5.86
Leucaena shannonii	4.32	6.94	8.60	10.64	8.91	7.46	1.15	3.05	3.37	3.58	3.01	2.86
Leucaena diversifolia (K156)	3.30	5.69	6.23	8.78	10.01	7.28	1.09	2.84	3.05	4.34	4.58	3.64
Delonix regia	1.58	4.21	6.77	9.32	9.80	4.55	0.64	3.11	4.18	5.81	5.07	1.98
Gliricidia sepium (HYB)	2.50	4.54	4.20	4.99	4.10	2.24	1.14	3.05	2.71	3.26	2.44	1.25
Senna siamea	1.47	4.84	3.70	4.41	3.97	3.59	1.08	3.56	2.79	3.18	2.75	2.42
Calliandra calothyrsus	1.71	2.66	3.34	3.39	2.10	1.90	0.68	1.71	2.06	1.87	1.21	1.00
Albizia lebbeck	1.10	2.22	2.89	3.92	2.93	2.44	0.50	1.57	2.04	2.69	1.73	1.48
Albizia guachapele	0.29	0.95	1.17	1.02	0.85	0.98	0.14	0.76	0.86	0.76	0.59	0.61
Leucaena salvadorensis	0.40	0.90	0.86	0.56	1.12	0.33	0.14	0.44	0.39	0.33	0.40	0.17
Casuarina cunninghamiana	•	0.13	0.55	0.94	1.16	0.86	•	0.10	0.40	0.71	0.80	0.62
Enterolobium cyclocarpum	0.22	0.36	0.49	0.90	0.76	0.50	0.10	0.29	0.36	0.67	0.34	0.39
Inga vera	•	0.33	0.73	1.00	0.67	0.28	•	0.22	0.56	0.71	0.43	0.21
Erythrina indica	0.41	0.32	0.25	0.20	0.22	•	0.19	0.20	0.14	0.09	0.18	•
Acacia angustissima	0.75	0.13	0.09	•	•	•	0.39	0.06	0.05	•	•	•
Paraserianthes falcataria	0.06	0.28	0.19	•	0.40	•	0.04	0.20	0.15	•	0.16	•
Tephrosia candida	0.15	0.06	•	•	•	•	0.04	0.03	•	•	•	•
Desmodium gyroides	A	A	A	A	A	A	A	A	A	A	A	A
Erythrina poeppigiana	A	A	A	A	A	A	A	A	A	A	A	A
Significance (F test)	***	***	***	***	***	***	***	***	***	***	***	***
$LSD_{0.05}$	1.62	1.51	1.52	2.79	2.26	2.03	0.60	0.71	0.70	1.36	1.02	1.06
CV %	42.35	30.98	28.87	38.59	34.86	36.70	43.13	26.74	25.32	35.04	32.33	38.82

†One harvest in February 1997.
*** = Significant at 0.5 % level of probability.
"•" indicates not harvested. Not included in analysis.
"A" indicates species did not emerge or died.

TABLE A8. BRANCH AND STEM DRY WEIGHT BIOMASS HARVESTED FROM TREE SPECIES IN FIVE YEARS AT THE CALCAREOUS SITE

	Small stem biomass †						Large stem biomass ‡					
Species (variety)	1992	1993	1994	1995	1996	1997§	1992	1993	1994	1995	1996	1997§
	t/ha											
Leucaena leucocephala (K636)	2.77	4.12	3.63	4.37	3.81	2.34	5.50	3.34	3.24	2.61	3.03	3.22
Leucaena hybrid (KX3)	2.66	3.65	2.94	3.22	2.94	1.79	5.27	3.37	2.63	3.21	3.80	4.18
Leucaena shannonii	1.43	2.70	3.18	4.13	3.03	2.33	1.73	1.20	2.05	2.71	2.67	2.27
Leucaena diversifolia (K156)	0.72	1.49	1.61	2.05	1.87	1.23	1.22	1.36	1.44	2.31	3.40	2.41
Delonix regia	0.30	0.90	1.17	1.74	1.51	0.57	0.63	0.20	1.43	1.78	3.22	2.00
Gliricidia sepium (HYB)	0.62	1.46	1.25	1.45	1.15	0.44	0.74	0.03	0.24	0.29	0.51	0.54
Senna siamea	0.36	1.19	0.86	1.09	0.92	0.70	0.04	0.09	0.07	0.14	0.30	0.48
Calliandra calothyrsus	0.63	0.85	1.10	1.23	0.82	0.79	0.40	0.10	0.15	0.16	0.07	0.11
Albizia lebbeck	0.15	0.56	0.66	0.97	1.01	0.54	0.45	0.10	0.19	0.26	0.19	0.42
Albizia guachapele	0.10	0.20	0.28	0.24	0.23	0.19	0.04	•	0.03	0.01	0.03	0.18
Leucaena salvadorensis	0.19	0.34	0.36	0.19	0.56	0.10	0.07	0.13	0.11	0.05	0.17	0.06
Casuarina cunninghamiana	•	0.03	0.15	0.23	0.35	0.22	•	•	•	0.01	0.01	0.02
Enterolobium cyclocarpum	0.12	0.07	0.11	0.23	0.37	0.11	•	•	0.03	0.01	0.06	•
Inga vera	•	0.08	0.16	0.26	0.21	0.07	•	0.04	0.01	0.03	0.03	•
Erythrina indica	0.10	0.10	0.07	0.08	0.03	•	0.12	0.02	0.05	0.03	0.01	•
Acacia angustissima	0.33	0.05	0.03	•	•	•	0.03	0.02	0.01	•	•	•
Paraserianthes falcataria	0.01	0.03	0.04	•	0.08	•	0.01	0.05	•	•	0.17	•
Tephrosia candida	0.08	0.04	•	•	•	•	•	•	•	•	•	•
Desmodium gyroides	A	A	A	A	A	A	A	A	A	A	A	A
Erythrina poeppigiana	A	A	A	A	A	A	A	A	A	A	A	A
Significance (F test)	***	***	***	***	***	***	***	***	***	***	***	***
$LSD_{0.05}$	0.39	0.43	0.38	0.56	0.54	0.47	0.85	0.55	0.79	1.19	0.89	0.88
CV%	41.59	30.43	25.63	27.54	32.20	40.54	51.21	53.95	70.79	92.11	56.63	46.38

†Stems < 1 cm diameter, partially green; ‡stems 1 - 5 cm diameter. Tends to be woody.
§ One harvest in February 1997.
*** = Significant at 0.5 % level of probability.
"•" indicates not harvested. Not included in analysis
"A" indicates species did not emerge or died.

TABLE A9. TOTAL AND LEAF DRY WEIGHT BIOMASS HARVESTED FROM TREE SPECIES IN FIVE YEARS AT THE BASALTIC SITE

	Total biomass						Leaf biomass					
Species (variety)	1992	1993	1994	1995	1996	1997 †	1992	1993	1994	1995	1996	1997†
	t/ha											
Leucaena leucocephala (K636)	5.41	7.74	12.05	7.93	11.77	9.53	1.36	2.69	4.68	3.57	4.34	3.18
Leucaena hybrid (KX3)	3.39	5.97	10.65	8.28	12.26	9.31	1.18	2.55	4.61	3.66	5.36	3.88
Leucaena diversifolia (K156)	1.56	2.30	5.37	5.19	9.50	6.15	0.47	1.05	2.60	2.59	3.58	2.52
Gliricidia sepium (HYB)	0.47	2.23	6.88	4.76	8.58	4.26	0.26	1.33	3.64	2.64	3.27	1.47
Leucaena salvadorensis	1.79	3.81	5.72	3.92	6.83	5.06	0.53	1.38	2.18	1.86	2.56	1.33
Leucaena shannonii	0.73	1.80	5.46	5.23	8.13	5.39	0.21	0.52	1.91	2.02	2.53	1.58
Senna siamea	•	0.22	2.20	2.84	6.46	2.35	•	0.17	1.62	1.94	3.83	1.34
Calliandra calothyrsus	2.23	1.62	2.92	2.20	2.29	0.85	0.77	0.84	1.58	1.09	1.02	0.48
Delonix regia	•	•	•	2.87	3.61	0.48	•	•	•	1.28	1.54	0.22
Enterolobium cyclocarpum	•	0.11	0.33	0.59	1.44	0.55	•	0.08	0.15	0.39	0.90	0.32
Flemingia macrophylla	•	0.07	0.73	0.37	0.85	•	•	0.03	0.42	0.21	0.34	•
Acacia angustissima	•	0.22	0.29	0.08	•	•	•	0.01	0.15	0.05	•	•
Cassia emarginata	•	•	•	0.44	0.17	0.31	•	•	•	0.11	0.11	0.06
Casuarina cunninghamiana	A	A	A	A	A	A	A	A	A	A	A	A
Desmodium gyroides	A	A	A	A	A	A	A	A	A	A	A	A
Grevillea robusta	A	A	A	A	A	A	A	A	A	A	A	A
Significance (F test)	ns	***	***	***	***	***	ns	***	***	***	***	***
$LSD_{0.05}$	3.69	3.09	3.23	2.27	3.88	2.46	1.03	1.07	1.38	1.09	1.69	1.00
CV %	111.68	90.30	46.76	46.16	45.02	42.32	101.74	76.97	44.60	46.12	47.94	46.40

†One harvest in February 1997.
ns, *** = Not significant and significant at the 0.5 % level of probability, respectively.
"•" indicates not harvested. Not included in analysis.
"A" indicates species did not emerge or died.

TABLE A10. BRANCH AND STEM DRY WEIGHT BIOMASS HARVESTED FROM TREE SPECIES IN FIVE YEARS AT THE BASALTIC SITE

Species (variety)	Small stem biomass† 1992	1993	1994	1995	1996	1997 §	Large stem biomass ‡ 1992	1993	1994	1995	1996	1997 §
	t/ha											
Leucaena leucocephala (K636)	1.49	2.64	2.99	2.79	3.09	2.00	2.54	2.42	4.37	1.57	4.21	4.36
Leucaena hybrid (KX3)	0.88	1.66	2.25	2.47	2.15	3.21	1.28	1.76	3.67	2.15	4.64	2.22
Leucaena diversifolia (K156)	0.44	0.78	1.23	1.41	1.71	0.67	0.61	0.47	1.48	1.18	4.19	2.96
Gliricidia sepium (HYB)	0.18	0.74	1.52	1.66	2.25	0.83	0.03	0.16	1.72	0.46	3.06	1.96
Leucaena salvadorensis	0.85	1.75	2.78	1.99	2.97	1.43	0.41	0.68	0.76	0.06	1.30	2.30
Leucaena shannonii	0.40	0.94	2.03	2.36	3.09	1.71	0.13	0.34	1.52	0.81	2.42	2.10
Senna siamea	•	0.04	0.46	0.84	1.29	0.47	•	0.01	0.13	0.06	1.33	0.54
Calliandra calothyrsus	0.98	0.72	1.06	0.82	1.15	0.32	0.47	0.06	0.27	0.29	0.11	0.05
Delonix regia	•	•	•	0.19	0.57	0.07	•	•	•	1.40	1.51	0.19
Enterolobium cyclocarpum	•	0.03	0.08	0.14	0.46	0.15	•	•	0.10	0.07	0.07	0.08
Flemingia macrophylla	•	0.04	0.27	0.15	0.45	•	•	•	0.01	•	0.03	•
Acacia angustissima	•	0.12	0.11	0.03	•	•	•	0.09	0.03	•	•	•
Cassia emarginata	•	•	•	0.16	0.06	0.21	•	•	•	0.16	•	0.03
Casuarina cunninghamiana	A	A	A	A	A	A	A	A	A	A	A	A
Desmodium gyroides	A	A	A	A	A	A	A	A	A	A	A	A
Grevillea robusta	A	A	A	A	A	A	A	A	A	A	A	A
Significance (F test)	ns	***	***	***	***	***	ns	***	***	***	***	***
$LSD_{0.05}$	1.06	1.00	0.88	0.67	0.90	0.66	1.66	1.24	1.22	0.91	1.61	0.99
CV %	95.47	80.07	45.10	40.34	39.13	45.60	143.36	127.70	65.98	84.52	58.74	45.07

†Stems < 1 cm diameter, partially green; ‡ stems 1 - 5 cm diameter. Tends to be woody.
§ One harvest in Februray 1997.
ns, *** = Not significant and significant at the 0.5 % level of probability, respectively.
"•" indicates not harvested. Not included in analysis.
"A" indicates species did not emerge or died.

TABLE A11. TREE DRY WEIGHT BIOMASS PRODUCTION IN THE FIRST HARVEST MADE IN OCTOBER 1994 AT THE SEMI-ARID SITE

Species (variety)	Total	Leaf	Stem <1cm	Stem >1cm
	t/ha			
Leucaena leucocephala (K636)	7.22	1.12	2.09	4.01
Cassia emarginata	1.63	0.17	1.14	0.31
Leucaena diversifolia (K156)	1.27	0.36	0.36	0.56
Leucaena leucocephala (Delin)	1.14	0.24	0.64	0.26
Acacia ampliceps	0.98	0.38	0.38	0.23
Gliricidia sepium (HYB)	0.71	0.19	0.36	0.16
Acacia colei	0.34	0.16	0.14	0.04
Enterolobium cyclocarpum	•	•	•	•
Albizia lebbeck	•	•	•	•
Delonix regia	•	•	•	•
Senna siamea	•	•	•	•
Piptadenia peregrina	•	•	•	•
Albizia guachapele	•	•	•	•
Albizia procera	•	•	•	•
Acacia holosericea	•	•	•	•
Acacia tumida	•	•	•	•
Casuarina cunninghamiana	•	•	•	•
Pseudoalbizia berteriana	•	•	•	•
Significance (F test)	***	*	**	***
$LSD_{0.05}$	2.50	0.55	1.01	1.34
CV %	88.75	99.48	93.35	113.68

*, **, *** = Significant at the 5%, 1% and 0.5% levels of probability, respectively.
Note: "•" indicates not harvested. Not included in analysis.

TABLE A12. TREE DRY WEIGHT BIOMASS PRODUCTION AT THE SECOND HARVEST MADE IN NOVEMBER 1995 AT THE SEMI-ARID SITE

Species (variety)	Total	Leaf	Stem <1cm	Stem >1cm
	t/ha			
Leucaena leucocephala (K636)	3.95	1.22	1.12	1.62
Acacia ampliceps	1.34	0.69	0.40	0.25
Leucaena leucocephala (Delin)	1.20	0.31	0.77	0.12
Leucaena diversifolia **(**K156)	0.93	0.30	0.26	0.37
Cassia emarginata	0.48	0.15	0.32	0.01
Acacia colei	0.29	0.19	0.10	•
Gliricidia sepium (HYB)	0.22	0.10	0.12	•
Enterolobium cyclocarpum	•	•	•	•
Albizia lebbeck	•	•	•	•
Delonix regia	•	•	•	•
Senna siamea	•	•	•	•
Piptadenia peregrina	•	•	•	•
Albizia guachapele	•	•	•	•
Albizia procera	•	•	•	•
Acacia holosericea	•	•	•	•
Acacia tumida	•	•	•	•
Casuarina cunninghamiana	•	•	•	•
Pseudoalbizia berteriana	•	•	•	•
Significance (F test)	***	***	***	***
$LSD_{0.05}$	1.42	0.52	0.47	0.74
CV %	79.72	82.49	71.11	101.02

*** = Significant at the 0.5 % level of probability.
Note: "•" indicates not harvested. Not included in analysis.