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EVALUATION OF TREE-CROP INTERACTIONS IN AN ALLEY
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AS CONTOUR HEDGEROWS

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EVALUATION OF TREE-CROP INTERACTIONS IN AN ALLEY CROPPING SYSTEM USING *Gliricidia sepium* (JACQ) WALP. AS CONTOUR HEDGEROWS

By

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ABSTRACT

EVALUATION OF TREE-CROP INTERACTIONS IN AN ALLEY CROPPING SYSTEM USING *Gliricidia sepium* (JACQ) WALP. AS CONTOUR HEDGEROWS

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A 0.22-ha alley cropping experiment was established on Mt. Makiling, University of the Philippines at Los Banos to evaluate the effects of number of *G. sepium* hedges per contour line, pruning height, and within-row spacing on hedgerows' height and diameter growth, pruning biomass, mortality, decomposition rates, root densities and distribution, and water potential. Yields of maize (*Zea mays*) and mungbean (*Vigna radiata*) in two cropping seasons were also determined.

Hedgerows from the 5-cm within-row spacing had the highest mortality rate and volume of biomass from the initial clipping (3.9 dry kg/m^2 alley or approximately 19.5 t/ha/yr) and subsequent top prunings (1.2 dry kg/m^2 alley or approximately 6 t/ha). Pruning was found to be optimum at height of 2.0 m. Number of hedges per contour line did not significantly affect biomass yield; height and diameter growth; mortality of hedgerows; and yields of intercrops. Height and diameter growth of hedgerows and mungbean yield significantly declined with increasing hedgerow density. None of the treatments significantly affected maize yields.

At least 50 percent of the hedgerow prunings (young twigs and leaves) decomposed within four to eight weeks. Application of pruning biomass in the alleys improved N, P, K, and pH after one year, and stabilized OM after an initial decline. Tissue analysis of *G. sepium* young twigs and leaves showed that the average percent N, P, K, ash, crude protein, and crude fiber were 2.69, 0.28, 2.87, 8.94, 19.75, and 23.63, respectively.

Up to 90 percent of roots counted in hedgerows were < 1-mm diameter and more than 70 percent were located in the top 30 cm of the soil. The 5- and 10- cm within-row spacings had the highest root densities (number of roots/dm^2).

The pre-dawn and day-time water potential of nine-month-old hedgerows were most negative at 5-cm within-row spacing. Despite the absence of a clear pattern, water potential in the 32-month-old hedgerows was affected by number of hedges per contour line, pruning height, within-row spacing, and their interaction.

G. sepium hedgerows benefitted the intercrops but also competed intensely for water and nutrients in the tree-crop interface.

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INTRODUCTION

1.1 Background

1.1.1 The Expanding Philippine Uplands

The plunder of the Philippines forests in the last thirty years opened and made accessible large tracts of logged-over areas to the booming population in the lowlands. From 1969-1974, the country's forest area (which includes both commercial and inadequately stocked logged-over forests) declined from 16.65 million ha to 13.68 million ha (DNR, 1976). Over the years, the forest resource further decreased to 11.51 million ha in 1976 (NEDA, 1977); to 7.40 million ha in 1980 (Revilla, 1985); and to 7.10 million ha in 1987 (DENR, 1988). The nation's forest cover, which was 49.1 percent in 1950 dropped to 22.2 percent in 1987 (Garrity et al., 1992). Out of the 22.2 percent forest cover, about 3.4 million ha are considered residual forests and between 0.8-1.0 million ha virgin and old growth forests (DAI, 1992).

Indiscriminate harvesting in the natural forests followed by shifting cultivation and permanent agriculture has resulted in the continued expansion of open, denuded, and grassland areas. Moreover, in many inadequately stocked residual forests, clear cutting, rampant cattle ranching, small-scale logging, wood salvaging, and fuelwood gathering further contributed to degradation. Thus, in 1987, the Department of Environment and Natural Resources (DENR) estimated about 11.9 million ha of open areas, which are mostly in hilly or mountainous, and generally having slopes above 18 percent (DENR, 1988; Sajise, 1979, 1980; and Librero, 1977). Of this area, about 7-8 million ha are under some form of upland cultivation and home to 17.8 million people (Cruz and Zosa-Feranil, 1988). The upland farmers eke out a substandard living in marginal, *Imperata*-dominated, inhospitable, rainfall-dependent, hydrologically-impaired, and environmentally-fragile upland areas (de La Salle and UPLB/PESAM, 1986; Sajise, 1979, 1985).

In a developing country and in an agricultural economy such as the Philippines, the foregoing statistics imply the need for sound and sustainable management of natural resources that is responsive to the expansion and intensification of agricultural production. With the present annual population growth rate of 2.4-2.6 percent, the natural resource base can only adequately support the Philippines' projected population of 78.8 million by the year 2000 (Megino, 1978). This assumes that lowland farm productivity improves by about 40 percent based on 1978 production levels, that rural industries are established in the lowlands creating "economic magnets", that conversion of prime agricultural lands for urban use is minimized, and that productive and sustainable farming systems in the fragile uplands are adopted by farmers (Gwyer, 1977; Megino, 1978; Porter, 1987).

1.1.2 The Choice

The Philippines faces a herculean job in rehabilitating 7-8 million ha of denuded and marginal uplands. Although there are other alternatives in making these areas productive, the government through DENR is largely limited to only one choice; that is, to enlist the cooperation and participation of 17.8 million farmer-occupants. In pursuing this option, DENR has to promote farmer-oriented, productive, protective, sustainable, and socially-acceptable agroforestry systems. Government technicians have to learn and extend upland farming technologies that could address the need for food and cash income while addressing the issues of soil erosion, siltation of river systems, declining farm productivity, and loss of biodiversity.

Hence, the alley cropping system with the use of contour hedgerows has been promoted for adoption in the uplands. As an agroforestry system, alley cropping along the contour or sloping agricultural land technology (SALT) requires the planting of woody perennials along the contour as hedgerows and growing agricultural crops (annuals and perennials) in between the hedgerows. The system has the potential to meet the need for food and cash income and respond to the government's concern for environmental stability and socioeconomic upliftment of upland farmers. Alley cropping fits well with the available labor and capital needs of many upland farmers.

1.1.3 Alley Cropping on Sloping Lands

Alley cropping along the contour or SALT promises productivity and sustainability in the uplands (Kang and Wilson, 1987; Laquihon, 1988; Watson, 1983; MBRLC Staff, 1988). The system allows crop production in the alleys (e.g. in between the hedgerows) and has the potential of minimizing soil erosion, increasing soil organic matter, and improving microclimatic conditions. The hedgerows are periodically clipped or pollarded to minimize their shading effect on the crop and provide fresh organic residues to the soil. In an integrated SALT system, the prunings are used as forage for ruminant animals, mainly goats and rabbits, and the dung recycled into the alleys. As an agroforestry scheme, therefore, it meets both the productive and protective criteria of an idealized system. It has the capacity to effectively restore soil fertility of degraded tropical lands and improve crop productivity in the long term.

In an alley cropping system, highly desirable species for contour hedgerows are the fast growing, nitrogen-fixing, leguminous trees. Nitrogen-fixing legume trees develop a symbiotic relationship with *Rhizobium* bacteria and fix nitrogen to meet internal N demand. Eventually, nutrients are recycled back into the soil from the trees' organic materials through periodic pollarding, litterfall, root turnover and death, and other residues. The woody perennials' roots withdraw leached nutrients from deeper soil horizons and via biomass turnover recycle these into the soil.

As an upland technology, however, alley cropping needs further evaluation, verification, and refinement. Its success as a technology in rehabilitating denuded uplands and increasing farm productivity largely depends on the growth and nutrient-cycling characteristics of leguminous tree species; on the resource sharing patterns below- and above-ground between the hedgerows and the crops; on crop type and rotations; on the type, kind, and intensity of management inputs; and on the ease of adopting the system by the upland farmers.

In the research that I conducted, several of the foregoing factors were investigated in an alley cropping system using *Gliricidia sepium* as the contour hedgerow species and maize (*Zea mays* Linn.) and mungbean (*Vigna radiata* (L.) Wilcjek) in a crop rotation scheme as the agricultural crops.

1.2 Objectives

The research, which was conducted from September 1, 1990 to April 10, 1993 in the Demonstration Area of the University of the Philippines at Los Banos (UPLB) Agroforestry Program, College, Laguna, Philippines, had the following objectives:

a. Evaluate the differences in height and stem diameter growth, mortality of hedgerow plants, biomass from the initial clipping and subsequent prunings, crop yield, and rate of decomposition of pruning biomass over time under different number of hedges per contour line, within-row spacing of hedgerow plants, and pruning height.

b. Determine and analyze differences in the root distribution of hedgerow plants from the hedgerow base towards the alley under different treatments with root auger and trench methods of sampling.

c. Determine and analyze the soil and plant water potential of the hedgerow plants under different treatments.

d. Determine and provide explanations for the optimum combinations of cutting regime, within-row spacing, and number of hedges per contour line in an alley cropping system based on significant differences in a, b, and c above.

1.3 Hypotheses

The research tested the following hypotheses:

a. The hedgerows' height and stem diameter growth before initial clipping and stem diameter after the initial clipping will decrease with more dense within-row spacings, more intense cutting regimes, and more hedges per contour line.

b. Biomass yield and mortality rate of hedgerows will increase with more dense within-row spacings, more intense cutting regimes, and higher number of hedges per contour line.

c. Crop yield will increase with less dense within-row spacings, more intense cutting regimes, and less number of hedges per contour line.

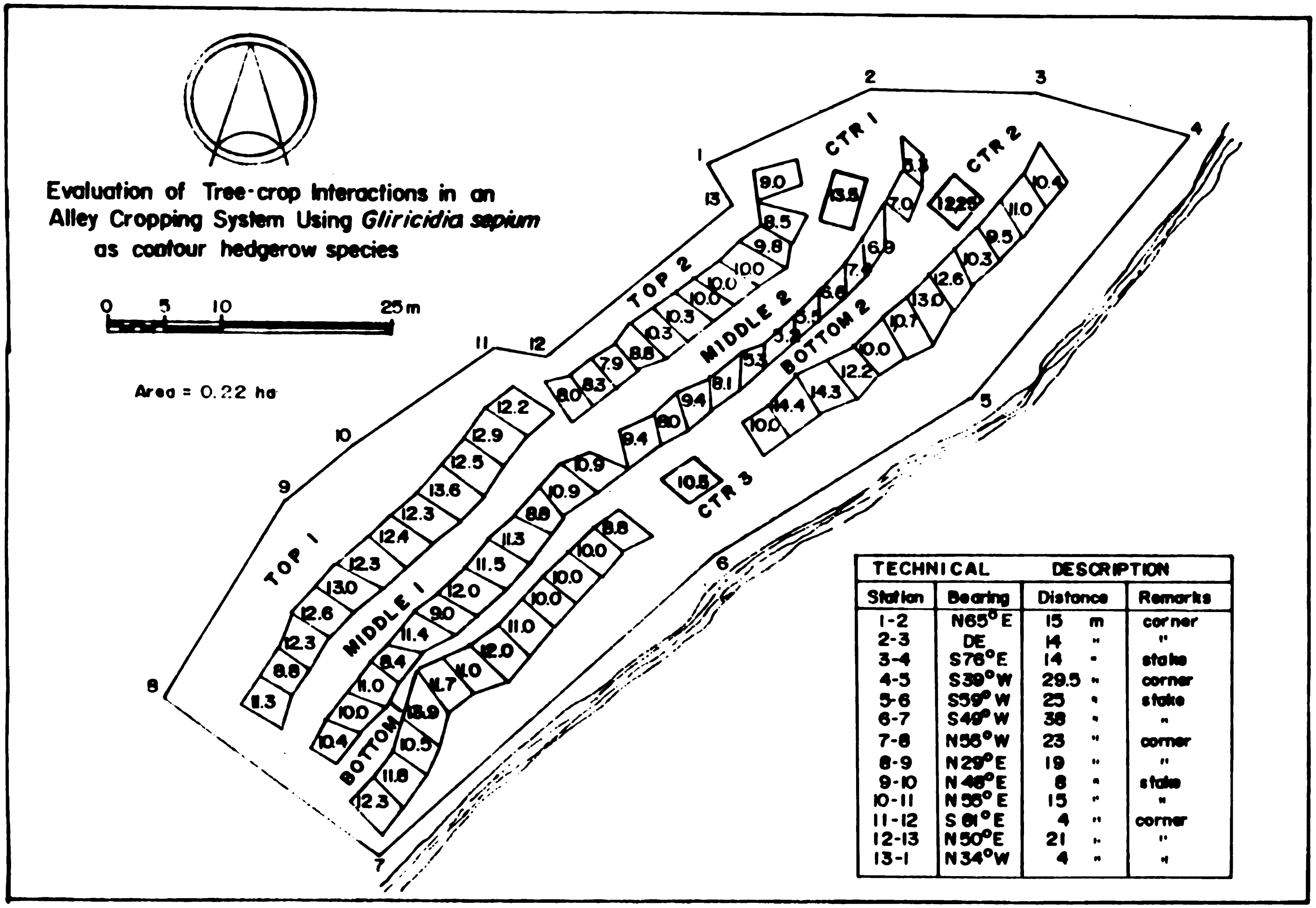
d. Root distribution from the hedgerow base towards the alleys at various depths in the ground will decrease regardless of treatments applied.

e. The soil and plant water potential becomes more negative with more dense within-row spacing of hedgerows and more intense cutting frequency.

f. The pattern of root distribution and plant water potential will explain the significant effects of pruning height, within-row spacing, and number of hedges per contour line on growth, yield, and survival.

1.4 Description of the Research Area

Figure 1.1 shows the experimental site which has a total area of 0.22 ha. It is located in the UPLB Agroforestry Demonstration Area, College, Laguna, Philippines. The site was enclosed with a used fish net to serve as a fence and boundary of the area. The slope ranges from 30 to 60 percent. The exact location of the experimental site is 14^0 hypotheses′ 07" N and 121^0 14′ 20" E and it has an elevation of 98-100 masl. This was determined by a Magellan Global Positioning System (GPS) on July 15, 1993.



TECHNICAL		DESCRIPTION	
Station	Bearing	Distance	Remarks
1-2	N65° E	15 m	corner
2-3	DE	14 "	"
3-4	S76°E	14 "	stake
4-5	S39°W	29.5 "	corner
5-6	S59° W	25 "	stake
6-7	S49° W	38 "	"
7-8	N56°W	23 "	corner
8-9	N29°E	19 "	"
9-10	N 46°E	8 "	stake
10-11	N 56° E	15 "	"
11-12	S 61° E	4 "	corner
12-13	N50°E	21 "	"
13-1	N34°W	4 "	"

Figure 1.1. The experimental site and layout of the main and sub-plots. Number inside the main plot represents the area of each sub-plot (m^2).

Table 1.1 indicates the average monthly and annual rainfall in the area from 1990 to 1992 based on data from the National Agromet Station at the University of the Philippines at Los Banos (UPLB), College, Laguna. Declining amounts of rainfall occurred from 1990 to 1992, with high precipitation occuring during the months of May to November (Figure 1.2). The declining pattern in the average annual rainfall from 1990-1992 could be attributed to the cyclical "El Nino" drought that was experienced in the Philippines during this period.

The experimental site was formerly the upland demonstration area of the UPLB Institute of Forest Conservation until it was abandoned in 1987. The vegetational species before the research plot establishment were mainly of shrubs, wild bananas, palms, patches of napier grass and *Imperata* sp., and plantings of sweet potato. A small creek runs at the bottom of the site. The soil is of volcanic origin, and ranges from clay to clay loam with an initial pH of about 5.8-6. The bottom part of the site had an initial pH of 5.9 and contained the greatest amounts of OM, P, K, and N compared with the top and middle plots. The soil profile has a plow layer of 10-15 cm with a value and chroma of 4/4, a 30 cm B horizon with a value and chroma of 5/6, and C horizon which starts at 31 cm and below with a value and chroma of 5/6. The B horizon is sandy to clay loam with a mix of small stone particles. The C horizon, which is the parent material, is stony with hardened sand and clay.

Table 1.1. Average monthly rainfall (mm) and number of rainy days/month from 1990-1992 at the National Agromet Station at the University of the Philippines at Los Banos, College, Laguna.

Month	**1990 monthly rainfall (# of rainy days/mo)**	**1991 monthly rainfall (# of rainy days/mo)**	**1992 monthly rainfall (# of rainy days/mo**
January	12.7 (6)	33.3 (10)	8.4 (9)
February	3.9 (4)	23.6 (10)	15.7 (5)
March	31.1 (7)	72.5 (6)	32.1 (3)
April	6.6 (5)	29.2 (6)	37.5 (6)
May	239.7 (19)	50.3 (6)	114.4 (11)
June	369.2 (22)	281.4 (16)	74.0 (11)
July	254.5 (23)	295.4 (19)	406.3 (24)
August	426.1 (24)	504.6 (28)	329.4 (23)
September	203.1 (19)	186.2 (19)	240.9 (20)
October	310.5 (20)	66.7 (9)	168.7 (20)
November	323.6 (19)	287.9 (19)	382.4 (17)
December	150.5 (23)	161.7 (20)	102.0 (22)
TOTAL (mm)	2331.5 (191)	1992.8 (168)	1911.8 (171)

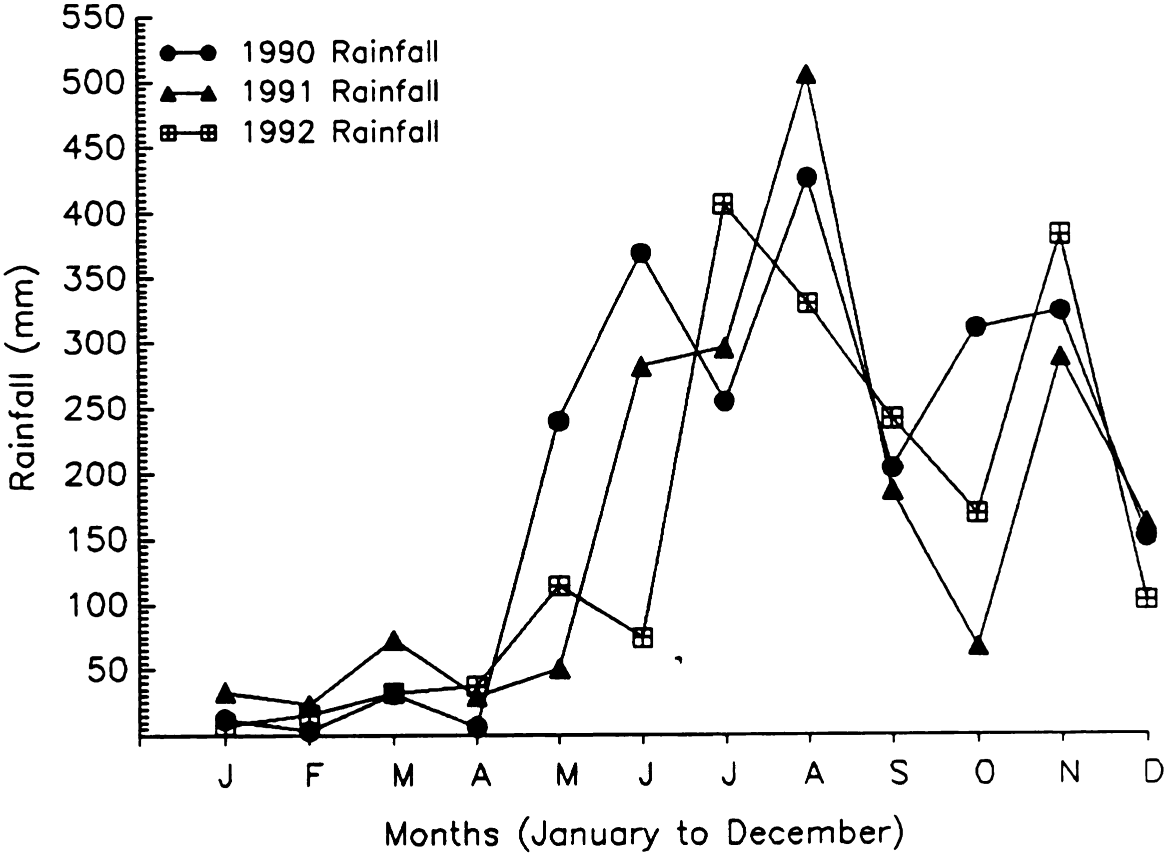


Figure 1.2. Monthly rainfall from 1990 to 1992 at the National Agromet Station, University of the Philippines at Los Banos, College, Laguna, Philippines.

1.5 Plot Establishment, Planting of Hedgerows and Crops, and Data Gathering

The research plot establishment, measurements, and data-gathering phase lasted for about 22 months. The dates/periods when the researcher established the experiment, conducted measurements of key parameters, and performed other research activities are shown in Table 1.2. A second measurement of water potential was done on April 8-10, 1993.

1.6 Scope and Limit of the Research

The research focused on the evaluation of tree-crop interactions in an alley cropping system using *G. sepium* as the contour hedgerow species, and maize and mungbean as the intercrops in sequential planting. The study gathered and analyzed diameter and height growth, mortality of hedgerows over time, pruning biomass, root distribution, soil and plant water potential, crop yields, and decomposition rates to provide answers to questions regarding the negative effects of competition between the hedgerows and the crops. The study was also expected to determine and explain the patterns of tree-crop interface in an alley cropping system. In this study, incident light radiation before and after pruning the hedgerows was not collected because of equipment problems. Although alley cropping in sloping lands minimizes soil erosion, the study did not evaluate such influences. The research assumed that the dense contour hedgerows, the prunings, and crop biomass which were placed in the alleys would minimize soil erosion and restore soil fertility in the long term (Young, 1987, 1989). Moreover, expected recommendations from this study will be limited to areas which have similar agroecological conditions and farming practices. Specifically, results from the interactions between

Table 1.2. Periods of research plot establishment, measurements of key parameters and conduct of other related activities.

Activity	Date/Period
1. Site identification and preparation; soil sampling	late Aug - mid-Sept 1990
2. Planting of hedgerows and first maize crop	mid-end Sept 1990
3. Thinning and replanting of hedgerows; tending of maize	Oct-Nov 1990
4. Harvesting of first maize crop; weighing air-dried shelled corn and stover	mid-end Dec 1990
5. Site preparation, planting of first mungbean crop, tending of plot, and soil sampling	Jan-March 1991
6. Harvest of mungbean; height, diameter, and survival count measurements	March-April 1991
7. First water potential measurement	late May 1991
8. Measurement of diameter, height, and survival count	late July-early Aug 1991
9. Initial clipping of hedgerows at 30 cm above the ground; decomposition and tissue analysis	mid-Aug 1991
10. Second maize crop planting; soil sampling	early Sept 1991
11. Tending of maize and hedgerows	Oct-Nov 1991
12. Harvest of maize and stover; first root sampling by auger	mid-Dec 1991
13. Second mungbean crop; soil sampling	mid-Jan 1992
14. Pruning hedgerows back to 30-cm high; decomposition and tissue analysis	Nov-May 1992

Table 1.2. (cont'd).

Activity	Date/Period
15. Harvest of second mungbean	late March-early April 1992
16. Measurement of hedgerow diameter; survival count	early April 1992
17. Second root sampling with auger	early June 1992
18. Root sampling by trench profiles	mid-June 1992
19. Second measurement of water potential	early April 1993

the hedgerows and crops might not be the same in highly acidic soil and in areas where competition for water is very intense at certain times of the year (e.g. areas with more than four months of dry season). Also, the research site has volcanic soil; thus, results might not also be applicable in soils of non-volcanic origin.

Chapter 2

REVIEW OF LITERATURE

2.1 Alley Cropping as a Designed Agroforestry System

In the tropics, alley cropping offers great promise as a bush fallow system in the cultivation of fragile uplands. Classified as a zonal agroforestry system (Nair, 1985), alley cropping essentially combines the growing of leguminous trees as hedgerows and planting of agricultural crops (e.g. food crops) in the alleys which are formed by the hedgerows (Kang et al.,1984; Wilson et al., 1986; and Kang and Wilson, 1987).

Alley cropping with hedgerows planted along the contours in sloping areas has the potential to address the need for simple and effective soil erosion control on open fields, mineral nutrient import to balance crop nutrient uptake, and enterprise diversification toward mixed farming systems that could include ruminant animals and perennials (Garrity, 1992). The system reduces fallow period; it could improve nutrient capital, maintain a high level of soil organic matter, and increase farm production. When hedgerows are planted along the contour, soil erosion is minimized, nutrients are kept in the alley, and water infiltration increases (Young, 1987, 1989, 1991). As an agroforestry production system, alley cropping could integrate the production of agricultural crops, trees, and animals in the same area (Lal, 1987 as cited by Lal, 1989a).

The Mindanao Baptist Rural Life Center (MBRLC) in Kinuskusan, Davao del Sur, Philippines, has partly demonstrated some benefits of alley cropping. In 1978, MBRLC started the planting of leguminous hedgerows along the contours and termed the system as "Sloping Agricultural Land Technology" or SALT, MBRLC concluded that alley cropping has the following advantages over traditional slash and burn farming: a) protection of top soil against erosion, b) restoration of soil structure and fertility, c) efficiency in food crop production, d) potential application of the system to at least 50 percent of the Philippine uplands, e) easier duplication and replicability, and f) clear focus on resource-limited and small farmers (Laquihon et al., 1991). MBRLC's demonstration plots have shown that only contour hedgerows in sloping lands can sustain and improve crop and fruit production over time. The center strongly promotes contour hedgerows to arrest soil erosion during intense rainfall and, thereby, sustain crop production. MBRLC's 10-year experience with SALT has proven that with high base-status soils of recent volcanic or marine limestone origin in areas with even distribution of annual rainfall, SALT is the appropriate technology for upland farming (Laquihon et al., 1991; Garrity, 1992).

When the hedgerows in an alley cropping system are pruned regularly to minimize their shading effect, the hedges produce green manure or mulch for the agricultural crop. This improves soil condition (i.e. organic matter, pH, temperature), and over a longer period, restores soil fertility. Alley cropping allows crop cultivation and bush fallowing to occur on the same tract of land at the same time (Kang et al., 1984). Along this line, MBRLC's initial observations showed that an average of 70 g of earthworm castings were found in each 30 cm^2 in the SALT system while only about 4 g were found in a non-SALT system. MBRLC's workers also found that a SALT farm has water infiltration rates seven times faster than the typical upland farm. In addition, with the use of moisture probes placed at 15-cm depth, it was initially observed that the average moisture retention of a SALT farm was higher than the non-SALT area (Laquihon et al., 1991).

These observations were discussed earlier by several authors. For example, Kang et al. (1985) claimed that alley cropping increased topsoil moisture retention. Kang and Wilson (1987) found that earthworm activities increased with alley cropping, thereby improving soil aeration. The presence of organic matter (biomass carbon) as mulch also resulted in higher soil microbial activity (Yamoah and Mulongoy, 1984), and increased soil pH (more basic) which facilitates the availability of most nutrients.

Although Raintree and Warner (1986) categorized alley cropping as a system having moderate to high labor intensity and high land-use intensity, MBRLC's work argued that the system would only require more labor in the first year during the establishment phase and gradually tapers down after the planting of hedgerows and perennial crops (Tacio, 1993). Further, MBRLC concluded that within five years, the gradually decreasing area for annual crops and the low intensities of labor use in land under perennial crops/hedgerows explained the lowered labor requirements of alley cropping (Laquihon et al. 1991).

As a modified bush fallow system, alley cropping exploits the potentials of leguminous trees and shrubs. The legumes' symbiotic relationships with rhizobia bacteria and mycorrhizal fungi improve their ability to survive in marginal sites. Moreover, most trees or woody shrubs are believed to develop deeper rooting systems than agricultural crops; therefore, they are able to access and recycle nutrients in the lower soil horizons which would not otherwise be available to agricultural crops (Ewel, 1986; Poulsen, 1978; Wilson, Kang, and Mulongoy, 1986).

Accordingly, when nitrogen-fixing species are used as contour hedgerows, alley cropping would require low external inputs (Laquihon, 1988; Watson, 1983; Kang et al., 1984), provided that the crop's nutrient offtake is less than what is recycled in the form of organic matter. The system's assumptions are based on the ability of the hedgerows to draw nitrogen from the atmosphere through fixation and various nutrients from deeper soil horizons, and convert these into biomass which may be managed and utilized as organic fertilizer for agricultural crop production (Sumberg and Atta-Krah, 1988; Watson, 1983; Kang et al., 1984; Kang et al., 1990).

When hedges are planted densely along the contour of sloping lands, alley cropping controls soil erosion during heavy rainfall (Kang et al., 1984; Watson, 1983; Laquihon, 1988; Laquihon et al., 1991). MBRLC's initial observations over a period of six years from its experimental site showed that in a SALT area, top soil loss was only 3.4 MT/year while the plot which typified a traditional upland farm lost 194.3 MT/year. This observation was earlier hyphothesized in 1953 when the Soil Conservation Service of the Philippines conducted the first recorded research on alley cropping with leucaena (*Leucaena leucocephala*) as contour hedgerows to control erosion on hillsides and increase maize yields (Benge, 1987). MBRLC's verification of the hypothesis came from its demonstration plots, which were set up for comparative studies of various SALT and non-SALT systems.

MBRLC's SALT recommends the planting of double rows/contour line with nitrogen fixing trees at 0.50-.75 m spacing and 4 m between the double hedgerows, to effectively minimize soil erosion and provide adequate pruning yields to the strips (which are termed alleys at the International Institute of Tropical Agriculture or IITA). Then, permanent and cash crops are alternately planted in the 4-m strips (Watson, 1983; Laquihon, 1988).

In addition to the protective and productive aspects of alley cropping, Aken'ova and Atta-Krah (1986) reported that *G. sepium* hedges, if left uncut for 8-9 months, shaded the cogon grass (*Imperata cylindrica*) and reduced the rhizome yield of the weed as the shading effect increased. Yamoah et al. (1986a) also observed that *Cassia siamea, Flemingia congesta,* and *G. sepium* hedgerows were also effective in controlling weeds during a cropping season. In the Philippines, canopies of densely-planted leucaena, *G. sepium,* and *Acacia auriculiformis* were seen to eradicate most of the pernicious cogon grass, provided that the plantings or the hedges are not burned during the dry months.

2.2 Limitations of Alley Cropping System

Brewbaker (1986) pointed out some limitations of alley farming as a land use technology in a review of an IITA-sponsored alley farming workshop in Ibadan, Nigeria. He mentioned that alley farming takes some land out of food crops. SALT, for instance, could take as high as 20-25 percent of an area out of crop production (Newell, 1989). Moreover, Brewbaker underlined that alley farming has been less successful in dry areas where moisture limitations could become severe. I have also observed that SALT has not been widely adopted in the northern part of the Philippines because of the highly seasonal rainfall pattern i.e. intense rainfall in 3-4 months followed by 6-8 dry months.

Szott (1987) as cited by Lal (1989b) concluded that higher yields in alley cropping are constrained by shading, root competition for nutrients and water, immobilization by mulch, and possible allelophatic effects of the hedgerow species. Lal (1989b) further stated that the available data on alley cropping show that the system cannot sustain production without substantial input of chemical fertilizers. His findings at IITA indicated that alley cropping could only reduce the rates of decline of soil organic matter, total N, pH, and exchangeable bases over a period of six years.

Garrity (1992) validated the above observations and claimed that an alley cropping system may need mineral nutrient importation to balance crop nutrient offtake. Basri et al. (1990) also found that *G. sepium* and *Cassia* hedgerows could not supply adequate quantities of P to meet the minimal requirements of cereal crops. They concluded that in acid soils, the P deficiency must be overcome before there is any response to nitrogen.

On highly acidic soils, Garrity (1992) pointed out the limitations of an alley cropping system. In these soils, the hedgerows' ability to grow deeper roots is inhibited by the high exchangeable aluminum in the subsoil and the limited availability of P and other mineral elements. This situation puts limits on the capability of hedgerows to pump out nutrients into the top soil in the form of litterfall or prunings. Moreover, the strong subsoil acidity also appears to promote intense root competition between the hedgerow and crop for mineral nutrients in the surface soil.

The medium to high labor requirement of alley cropping in the first three years has also limited its expansion among upland farmers, especially in areas where access to market is a problem. The labor in prunings hedgerows (three to ten times a year) competes with other income-generating tasks of the household. Thus, in many cases, alley cropping is only adopted in not more than one half ha parcel of an upland farm (Garrity, 1992; Laquihon et al., 1991). However, compared with clearing one-year fallow regrowth in savanna areas infested with *Imperata cylindrica*, alley farming took 47 percent less labor for site preparation and clearing and 18 percent less in controlling weeds (Kang, Reynolds, and Atta-Krah, 1990).

The possible sudden attacks of pests and diseases, like the psyllid (*Heteropsylla cubana*) on leucaena monoculture hedges could set back the expansion of alley cropping in the uplands. This happened with MBRLC, which started a leucaena-based SALT system in 1978. The psyllid forced many upland workers to identify alternate species for contour hedgerows. Thus, in addition to leucaena and *G. sepium,* which have been extensively used as hedgerows in most alley cropping studies, several potential nitrogen-fixing leguminous species are now being tried. They include *Flemingia congesta, F. macrophylla, Calliandra calothyrsus, Acacia vilosa, L. diversifolia, Desmodium gyroides,* and *D. rensonii* (Laquihon, 1988; Laquihon et al., 1991).

2.3 Hedgerow Ideotype

Contour hedgerows play a major role in an alley cropping system. The choice of the right species could spell the difference in the productive, protective, and rehabilitative potentials of the system. Obviously, the hedgerow should be nitrogen-fixing and a multipurpose tree species. The species should have the desired characteristics and traits as a hedgerow. Moreover, the characteristics of the ideal plant or its "specifications", as coined by Huxley (1985), should be based on the system's needs and the technical requirements of the available plant types. In alley cropping, selection of woody perennials that will be used as hedgerows should consider the overall objectives of rehabilitation and food production in the same piece of land over a period of time.

Dickmann (1985) suggested that in identifying a " model tree", the desired traits and characteristics of a species that will serve a defined purpose must first be determined. These characteristics could become the compendium of yield-related traits of an ideotype (Dickmann, Gold, and Flore, 1994). Donald (1968) termed the model plant as an "ideotype" which "is expected to perform or behave in a predictable manner within a defined environment." Applying the ideotype concept to alley cropping, a "hedgerow ideotype", therefore, must have the ideal characteristics, traits, or specifications for achieving upland rehabilitation and agricultural production on the same land over time. Huxley (1985) considers this model hedgerow species as an "associative ideotype". As an ideotype, the model hedgerow could provide a workable goal for plant breeders, help understand the species physiology, and guide the selection of potential breeding stock from wild populations (Dickmann, 1985). A hedgerow ideotype, therefore, may be used in the selection and evaluation of potential species or improve lines within a species for alley cropping. It would be the standard by which nitrogen fixing trees may be compared after selection and evaluation.

Existing knowledge and experimental data on plant morphology and physiology are required in constructing ideotypes (Dickmann, 1985). In addition, relevant biophysical and socioeconomic factors in the uplands must be incorporated or defined. Results of socioeconomic surveys and consultation with farmers will also help in defining a hedgerow ideotype (Wickramasinghe, 1992). By doing this, the resulting ideotype will not only typify a tree that can produce high quantity and good quality prunings, but will also indicate its excellent performance in degraded uplands and its high acceptability among marginal farmers. Regardless of species, therefore, a hedgerow ideotype denotes a tree with matchless growth performance, high productivity, good adaptability, and high acceptability.

A subset of traits of a hedgerow ideotype is presented below. The subset may be considered as a part of a more comprehensive attributes of a multipurpose tree ideotype (Dickmann, Gold, and Flore, 1994; Chuntanaparb and MacDicken, 1991). The subset of traits of a hedgerow ideotype could be adopted as the initial characteristics of a "working" hedgerow ideotype that may be expanded, re-defined, or condensed after more empirical data become available (Dickmann, Gold, and Flore, 1994).

(a) Grows fast even in marginal and acidic soils;

(b) Fixes atmospheric nitrogen through symbiotic relationship with either *Rhizobium* or *Frankia*;

(c) Can be directly seeded or planted with minimum site preparation;

(d) Can withstand periodic and severe prunings;

(e) Has low C:N ratio of biomass;

(f) Has high biomass yield;

(g) Develops deep root systems to efficiently exploit existing and leached nutrients in deeper soil horizons;

(h) Can withstand a 3-6 months dry period;

(i) Has resistance to pests and diseases even in monocultures;

(j) Regenerates after fire;

(k) Can effectively suppress weeds and grasses such as *Imperata cylindrica*;

(l) Has good survival even in high planting densities; and

(m) Has high farmer preference as a hedgerow species.

Acceptable ranges for each of the foregoing parameters may be established for a hedgerow ideotype. Both *G. sepium* and leucaena, being multipurpose trees, could satisfy the hedgerow ideotype. These species are the most biologically suitable and preferred by farmers in their alley cropping system (Glover and MacDicken, 1987 as cited by Chuntanaparb and MacDicken, 1991; Kang et al., 1984; Vergara, 1982). With *G. sepium*, for instance, screening of the 56 natural and 31 derived provenances (Glover, 1986) with the clarity of a defined hedgerow ideotype might result to a better species for hedgerows.

2.4 Resource Sharing in Alley Cropping

As an agroforestry technology, alley farming shares the complexity of combined production of forest and agricultural products either simultaneously or sequentially for the social, economic, and ecological benefits of the upland communities (Combe, 1982; Huxley, 1985; PCARRD, 1979; Anon, 1982). In alley cropping, growing of woody perennials and agricultural crops on the same land is deliberate. Moreover, both the woody perennials (hedgerows) and the crop significantly interact or "interface" with each other (Anon, 1982) above and below ground (Huxley, 1985). These "dynamic" interfaces influence the use and allocation of available resource pools (light, water, nutrients) and space. Further, the resulting interactions of light, water, nutrients, and space could improve or depress crop yield and overall productivity in an alley cropping system (Ong, 1991).

Accordingly, by properly managing the resource pools spatially and temporally, inter- and intra-species competition can be minimized and complementarities maximized (Buck, 1986; Gordon and Bentley, 1990; Cannell, 1991). Since different hedgerow species and agricultural crops in alley cropping interact differently with each other, Huxley (1985) offered four possible kinds of tree-crop interface effects, namely:

(a) Positive-Negative Interface - tree grows better; agricultural crop grows worse;

(b) Negative-Neutral Interface - tree grows worse; agricultural crop relatively unaffected;

(c) Positive-Positive Interface - both tree and agricultural crop do better than expected; and

(d) Negative-Negative Interface - both tree and agricultural crop are adversely affected to some degree.

In designing alley cropping systems, the third form of interface effects is the one to aim for. By manipulating the trees and tree/crop mixtures through plant height, spacing, alley width, density, timing (or phenological sequence) of planting and cultural treatments, tree-crop competitition may be minimized and complementation enhanced. Various manipulations of trees and mixtures may be performed to maximize pruning biomass and, thereby, increase crop yields. These manipulations, however, may only reach acceptable levels and not necessarily the economic optima (Cannell, 1983).

Similarly, by carefully selecting a tree species or specific phenotype which approximates the characteristics of the hedgerow ideotype (i.e. adaptability in marginal sites, deep rooting patterns), the hedgerows could multiply its benefit to the alley crops. The hedgerows deep roots could exploit existing and leached nutrients in deeper soil horizons, fix nitrogen, and eventually fertilize the crop through litterfall, root turnover, and pruning biomass (Ewel, 1986). Thus, a properly selected hedgerow species in an alley cropping system would be able to minimize negative interface effects. The hedgerows would utilize, re-allocate, and recycle other resources that are outside the reach of alley crops.

2.5 Management of Hedgerows for Biomass Production

The hedgerow's pruning yield depends largely on pruning height, frequency of cutting, in-row spacing, between-row spacing, and tree species. Other factors include the possible shading (competition) effect of agricultural crops on the hedgerow (Duguma et al., 1988); and fertilizing the hedgerow or the agricultural crop (Mwenye, 1984; Kang et al., 1985). Cannell (1991) mentioned that the differences in local climate and soil might explain the conflicting results of the effect of cutting heights on fodder and green mulch, particularly in leucaena. In general, Cannell (1991) states that "pruning of any sort will alter tree shape, total dry matter production, and distribution of growth within the tree".

For a given site and climatic condition, several variables may be manipulated to counter the negative effects of hedgerows and increase the hedgerows' biomass and crop yields. Optimum combinations of hedgerow management variables may hold the key in restoring degraded tropical uplands and improving crop production.

Pruning yield evaluation of various hedgerow species has largely concentrated on leucaena and *G. sepium*. Except for some PCARRD completed and ongoing studies (PCARRD, 1989), research activities of the International Rice Research Institute (IRRI) in Claveria, Misamis Oriental, and MBRLC's demonstration area in Davao del Sur, Philippines, IITA has generated most of the existing information on the pruning yield of hedgerows under different cutting regimes. Hence, the need exists for determining optimum pruning yields under various cultural management of hedgerows.

2.5.1 Pruning Height and Frequency of Cutting

Except for the observation of Gutteridge (1985), most hedgerow species, particularly leucaena and *G. sepium* increased their biomass with higher pruning heights. This is because of the higher amount of foliage and storage reserves (of carbohydrates and minerals) left on the trees with higher pruning heights (Cannell, 1991; Erdmann, Nair, and Kang, 1993). For instance, Duguma et al. (1988) found that with leucaena, *G. sepium*, and *Sesbania grandiflora*, biomass, drywood, and total nitrogen yield from hedgerow prunings increased with increasing pruning heights of 25, 50, and 100 cm. Mendoza et al. (1981) and Benge (1976), mentioned the same pattern with leucaena var. Peruvian. The latter observed that mean dry matter yield of leucaena doubled as the cutting heights were increased from 15 cm to 300 cm (mean dry matter yield increased from 10.68 to 23.61 MT/ha/yr). In this case, the leucaena single hedgerows were planted 3 m apart.

Das and Galvi (1981) recommended a pruning height of between 75-150 cm to obtain the optimum biomass yield of leucaena planted in blocks. Watson (1983) noted that most farmers would be able to cut the hedgerows with a bolo (a machete) at about 50-100 cm height. Although hedges cut at higher pruning heights have more food reserve available in their stems to support coppicing (Duguma et al., 1988), hedgerows higher than 100 cm were found to have increasing shading effect on the agricultural crops, especially if the alleys were less than 4 m apart (Kang et al. 1985; IITA, 1980, 1982).

Alferez (1980) recommended a cutting height of 30-40 cm for leucaena. This was also supported by Vergara (1982) and Briscoe (1989). However, from the farmers' point of view, ideal pruning heights could be meaningless because many will just cut the hedgerows at the most convenient height, which is between the knee and the waist (or between 30 to 100 cm above the ground) depending on the farmer's height. This preference, however, may change if, via demonstration sites, farmers could see and learn that cutting at other hedgerow heights may yield higher biomass.

Alferez (1980), Mercado et al. (1982), and Watson (1983) suggested that leucaena hedges should at least be allowed 6-12 months to grow before conducting the initial clipping for green manuring. This would enable the plants to establish a more extensive root system, withstand drought, and re-grow faster after subsequent cuttings.

With respect to frequency of subsequent hedgerow cuttings and its effects on pruning yield, some studies concluded that dry matter production increased as cutting intervals increased. For example, Das and Dalvi (1981) and Osman, (1981) found that a longer cutting interval after the initial clipping significantly increased dry matter production in leucaena. Duguma et al. (1988) observed the same pattern at IITA with *G. sepium, Sesbania grandiflora*, and leucaena. They used cutting interval periods of 30, 60, 90, and 180 days for leucaena and 30, 90, and 180 days for *G. sepium* and *S. grandiflora*. Twenty-five percent of the leucaena and all of the *S. grandiflora* died within 60 days when a 30-day cutting interval was used. Survival of *G. sepium* and *S. grandiflora* hedgerows under the various cutting frequencies was lower compared with leucaena. Kidd et al. (1984) also observed low survival rates of *S. grandiflora* and *G. sepium* (51 percent and 64 percent, respectively) in their alley cropping study because of severe cutting, dry weather, and weed competition.

Except for Guevarra et al. (1978) who studied pruning frequencies based on the attained heights of 55, 105, and 155 cm in dense plantings of leucaena, the majority of the works on cutting frequency used an interval period in days. A more preferred basis for studying frequency of cutting hedgerows would be to record the heights of the coppice regrowth after initial clipping is performed at specified pruning heights.

Information on the effects and implications of varying coppice growth heights in pruning are relatively scarce. At the farm level, this information is relevant because farmers are more concerned with what they see in the farms after the initial clipping rather than keeping track of cutting interval periods. In short, applied research efforts should determine optimal coppice regrowth height for repeated prunings of the hedgerows.

Varying pruning height and cutting interval also influenced biomass nitrogen content. For instance, Duguma et al. (1988) reported that the percent nitrogen concentration of prunings increased with decreasing pruning frequencies (e.g. at longer intervals of cutting) and with increasing pruning heights. The higher labor cost of more frequent prunings and the dependence of total N on total biomass yield do not justify short cutting intervals, even at optimum pruning heights. Further, at longer cutting intervals, the subsequent regrowth of the hedgerows is less disrupted.

2.5.2 Within-Row Spacing of Hedgerows

Cannell (1983) and Huxley (1985) discussed the importance and theoretical aspects of varying plant densities in alley cropping. They pointed out that as the within-row spacing becomes closer (which means increasing plant densities), the annual yield of leafy shoots increases up to a certain optimum point, after which yield gradually starts to decline. The decline is mainly attributed to increasing density stress at higher populations of hedgerow plants.

Mwenye (1984) experimented with 2 m and 4 m between-row spacings using leucaena, *Acioa barterii, Alchornea cordiflora*, and *G. sepium*. He found that the dry-matter yield of hedgerows doubled in one maize cropping season as the between- row spacing decreased (i.e. from 4 to 2 m) in both fertilized and unfertilized plots. Macklin et al. (1988) analyzed the wood yields of leucaena in alley cropping systems with between-row and within-row spacings as the key variables. Like Mwenye (1984), they found that wood yields of 7-month regrowth decreased with increasing between-row spacing; yields declined with increasing within-row spacing. The foregoing studies were only done in one cropping season of maize; therefore, the pattern of biomass yield with different within- and between- row spacings over a period of time can not be predicted. Moreover, neither studies measured stem diameter growth and survival, which are critical parameters in density-stressed plants (Cannell, 1983; Harper,1977).

2.6 Crop Yields

The major factors which influence crop yield in an alley cropping without fertilization are biomass nutrient content, cumulative decomposition, and volume of biomass; kind of tree-crop interface effects; and method of applying prunings in the alleys. Crop yields may also vary with every hedgerow species because each differs in biomass yield, nutrient content of harvested biomass, decomposition rate of biomass, and tree-crop interface effects.

Accordingly, the yield of alley-planted crops indirectly measures and evaluates the suitability of certain species for hedgerow planting. Highly suitable hedgerow species imply: (1) that they produce high volume of biomass in response to various cultural treatments, and (2) that their biomass contains low C:N organic matter. Suitability also implies that hedgerow species do not adversely compete with the crop for light, water, and soil nutrients.

Some workers evaluated and compared the suitability of certain species as hedgerows by comparing the yields of maize, cowpea, kenaf, and taro under different cutting regimes, planting densities of hedgerows, and methods of applying the prunings in the alleys. Mwenye (1984) observed that the growth and yield of maize in leucaena and *G. sepium* (nitrogen-fixing species) plots were the highest when compared to the plots of non-nitrogen fixing species (*Acioa barterii*, and *Alchornea cordifolia*). *G. sepium* and leucaena had the highest leaf decomposition rates and total N yields from prunings (36 kg/ha/yr and 76 kg/ha/yr, respectively).

Similarly, Kang et al. (1984) considered leucaena and *G. sepium* as the most appropriate woody species for alley cropping with various crops, including maize, cassava and cowpea. Previous and subsequent studies supported their observations (Kang et al. 1981, 1985; Yamoah et al., 1986a). Duguma et al. (1988) found similar results in comparing the yields of maize in alley farms using leucaena, *G. sepium*, and *Sesbania* sp. With taro as the alley crop, Kidd and Taogaga (1985) reported that yield under *G. sepium* hedgerows was significantly higher compared with the control (plots without *G. sepium* hedgerows).

The popularity of leucaena as a multipurpose tree has been a key factor in the rapid spread of alley cropping in the tropics. In the Philippines, SALT started as a leucaena-based production system until the psyllid damaged most leucaena stands in 1985. Torres (1983) even developed a model for predicting the yield of maize based on known parameters of leucaena hedgerows, such as optimum cutting regimes, biomass yield, nitrogen content, and between-row spacings. Sumberg and Atta-krah (1988), however, criticized Torres' model because some of their assumptions on the leucaena-based alley cropping system were quite unrealistic.

Besides the biomass yield and nitrogen content of the hedgerow species, the interface affects crop yield. The below- and above-ground interactions between the hedgerow and the crop could limit the growth of the crop component. Mwenye (1984) concluded that leucaena and *G. sepium* hedgerows improved maize yield because of high contribution to soil organic matter as a consequence of their nitrogen-fixing characteristics and deep root systems. These traits allowed them to fix atmospheric nitrogen and extract water and nutrients from deeper soil horizons; thus, in theory, they do not compete with agricultural crops which mostly feed on the surface soil.

Studies of Kang et al. (1985) showed that there were significant differences in incident radiation before and after cutting of different rows in the alley. The edge rows (rows which are nearer the hedges) had lower percent radiation compared to those in the middle rows. Thus, the shading of crops on the edges of hedgerows reduced crop yield (Mwenye, 1984; Szott, 1987 as cited by Lal, 1989b). In an earlier study, Kang et al. (1981) noted the low yield from maize rows which were planted near the hedgerows.

Hedgerow shading has negative effects on crop yields; it, however, reduces soil temperature and surface moisture evaporation (Wilson, Kang, and Mulongoy, 1986; Laquihon et al., 1991). Thus, with reduced soil temperature, more soil moisture is retained which facilitates the activities of earthworms and other soil microorganisms (Yamoah et al., 1986b; Kang et al., 1985). As a net result, the crop gains greater benefits from properly managed hedgerows. This was also observed in a MBRLC study (Laquihon et al., 1991).

MBRLC's experience with SALT revealed that alley cropping did not yield positive income for the farmers in the first two years of adoption.

However, after two years, income from alley crops was consistently higher than on farms without SALT (Watson and Laquihon, undated; Laquihon, 1987; Laquihon et al., 1991). The increase in income came from increasing productivity of annual cash crops and harvests from perennial crops. More importantly, the upland demonstration area continued to produce comparable maize yields over ten years. This continuous maize cropping could not be done in an sloping area without contour hedgerows (Tacio, 1993).

Crop yield in an alley farming system is also affected by the method of applying prunings in the soil. Wilson Kang, and Mulongoy (1986) reported that incorporating the biomass (green manure) into the soil was superior to surface application. Decomposition was faster with green manure and volatilization was higher with surface application (mulch). Consequently, nitrogen-use efficiency is better with the incorporation of biomass in the soil than with surface application. Green manuring, however, requires more farm labor compared with mulching or surface application. Hence, Watson (1983) and Laquihon (1988) advocated surface application of prunings along the alleys, not only for convenience sake, but also as barriers for reducing sheet erosion during high rainfall.

2.7 Root Development in Alley Cropping

Roots provide anchorage for plants, function as a storage reservoir, and serve the vital function of absorption and translocation of water and nutrients (Continuous and Fischer, 1987). The physiological processes involved in the formation of organic material (CH_2O's) by the green aerial parts of the plants and uptaking nutrients and moisture by the roots are interdependent. Root growth slows down with poor carbon dioxide assimilation. Similarly, the plant's aerial growth suffers when roots are only able to absorb small amounts of nutrients and water. Thus, root absorptive capacity is a major determinant in plant growth and development

(Schuurman and Geodewaagen, 1965). The crop's final yield according to Brown and Scott (1984) depends largely on the stable functional equilibrium between shoot and root development. Biological stress which could affect this relationship could considerably reduce total dry matter production.

In degraded tropical uplands, the roots of woody perennials enhance the process of rehabilitation and restoration of soil fertility. By functioning as "nutrient pumps" in marginal and infertile sites, tree roots absorb leached nutrients, tap additional nutrients and water in a deeper and larger volume of soil, and recycle these to the surface soil in the form of biomass (Poulsen, 1978; Ewel, 1986; Sanchez et al., 1985). Moreover, some nitrogen-fixing woody species further intensify this "nutrient pumping" function by fixing atmospheric nitrogen through their roots' symbiotic relationship with *Rhizobium* or *Frankia*. Through dying, decomposition, and turnover, roots contribute topsoil organic matter (McClaugherty et al., 1982; Vitousek and Sanford, 1986). Thus, understanding root growth and development of woody plants in a bush fallow system or in its modified form, alley cropping, could provide clearer guidelines in managing trees or hedgerows for biomass production.

Several authors identified various soil factors, light, competition, and cultural treatments which limit or enhance root growth and development (Lyr and Hoffman, 1967; Brown and Scott, 1984; Rogers and Head, 1968; Berendse, 1979). Unfortunately, the effects of these variables on the root growth and development of hedgerows are hardly known.

Therefore, this review provides a brief background on understanding roots in the context of alley cropping systems.

2.7.1 Soil Variables

Among soil variables, Lyr and Hoffmann (1967) identified soil temperature, soil moisture, soil aeration and soil fertility (mineral nutrition) as major determinants in the growth and development of tree roots. The authors' discussion pointed out clearly the influence of soil moisture and soil fertility on root growth and development. They emphasized that in dry soils, (a) roots are found at greater depths than in moist soils, (b) root/shoot ratio is higher and decreases (in favor of the above-ground organs) with increasing soil moisture content, (c) water deficiency inhibits root growth before cessation of shoot growth, and (d) low soil moisture accelerates root suberization and reduces effective absorbing surface.

Accordingly, in areas which receive variable annual rainfall, seasonal periodicity of root growth is more pronounced than in areas which get even distribution of rainfall in a given year (Rogers and Head, 1968). Intense root competition tends to reduce soil moisture over a short period of time (Huxley et al., 1989). Moreover, the high transpiration rate of some species influence soil moisture. Soil moisture also depends on rates of evaporation and water holding capacities of different soils (Continuous and Fischer, 1987).

On infertile sites, trees are inclined to initially allocate more photosynthates to roots in order to improve nutrient and water absorption. Eventually, this results in increased growth of above ground parts (Vitousek and Sanford, 1986; Lyr and Hoffman, 1967). Some pioneer species with high root/shoot ratios possess greater ability to penetrate hard soil layers which facilitates their revegetation of compacted and degraded sites. In soil layers rich in nutrients, trees do not invest much for enlarging their root systems. Most roots (including high concentration of fine roots) are found in the nutrient-rich zones in the soil profile (Lyr and Hoffman, 1967).

2.7.2 Effect of Light on Root Growth and Development

The trees' carbohydrate output from photosynthesis depends greatly on light; thus, shading tends to reduce photosynthetic efficiency in plants, especially among shade-intolerant species. This implies lesser carbohydrate to allocate for root and shoot growth. Thus, competition for light among hedgerow plants would tend to reduce root growth. In trees, Lyr and Hoffman (1967) found that increasing shade decreases growth as a whole but leads to a relative stimulation of shoot growth at the expense of root development. In effect, shading limits the allocation of photosynthates to root growth. Only surplus quantities which are not required for shoot growth are channeled to the roots.

From the foregoing discussion, it can be inferred that unmanaged hedgerows (e.g. when hedgerows are not regularly clipped or pollarded) would unfavorably affect the crop growth and development.

2.7.3 Root Competition and Cultural Management

Brown and Scott (1984) in their soybean studies, observed that in high plant populations, both intraspecific and interspecific root competition occur. They concluded that in soybeans, competition between plants limits the soil volume explored by the roots, and induces primary lateral growth. In mixed plantings, interspecific competition may be reduced by selecting species or crops with different rooting depths (Berendse, 1979). The deeper-rooting plants, especially nitrogen fixing species, can draw nitrogen from the air and absorb additional nutrients in the lower soil horizons. These sources of nutrients for the deeper-rooting species could mean lesser consumption from the common resource pool, which is shared with the shallow-rooting crop. The shallow-rooting plants have to invest more photosynthates in roots to improve their competitive abilities (Berendse, 1979). Thus, in highly competitive environment, plants will develop root systems with improved absorptive capacity, larger total root surface area, higher rooting density, good spatial distribution, faster root growth, and better root longevity (Caldwell and Richards, 1983). Over time, therefore, the roots' plastic behavior would result to a changed soil environment with their accumulation of litter and redistribution of nutrients in the profile (Bowen, 1985).

Manipulation of plant spacings can reduce roots' intraspecific competition. Atkinson et al. (1976), who worked with apple trees, found that wider spacings stimulated the growth of horizontal major roots with few vertical "sinkers" while at closer spacings, the roots were mainly vertical sinkers. In the same study, they observed that with closer spacings, 25 percent of root weight occurred below 50 cm, compared with 15 percent at the widest spacing. These findings may have important implications in managing hedgerows in an alley cropping system; but, whether or not this inference may be true in an alley cropping system is not known. These observations imply that there is the possibility of hedgerows developing deeper roots with denser spacing.

Cultural practices can reduce root/shoot ratio in trees. These include nitrogen fertilizer application, pruning, crown cutting, and defoliation (Lyr and Hoffman, 1967; Head, 1969). Nitrogen fertilizer application discourages the investment of CH_2O's in root growth (therefore, a reduction of root/shoot ratio) because of the lesser need to increase the tree's root absorptive area. The other practices tend to result in temporary imbalance in root/shoot ratio (i.e. more roots, less shoots); hence, a decrease in the allocation of photosynthates in root development compared with shoot development until the tree regains its original root/shoot ratio. Cultural practices tend to temporarily inhibit root development. This observation, however, should be evaluated in managing hedgerows. It can only be inferred that root growth may be reduced during periods of repeated hedgerow cuttings because hedgerow plants have to stabilize their root/shoot ratios.

2.7.4 Root Distribution

Analysis of root distribution of plant components in alley cropping could offer further understanding of the system (Buck, 1986; Huxley, 1985). Alley cropping as an emerging technological approach for restoring degraded tropical lands has had only a few completed root studies to strengthen and advance its claims and further clarify conflicting observations. Root studies in alley cropping systems would also explain patterns and responses of tree/crop interactions.

To date, the results of studies on root competition between hedgerows and crops are conflicting. Kang et al. (1981) and Torres (1983), contended that roots of leucaena at 0-20 cm depth and up to 100 cm distance from the hedgerows would not compete with maize roots for moisture or nutrients. However, a recent study showed that leucaena, *Cassia siamea, Prosopis chilensis*, and *Eucalyptus tereticornis* are likely to compete with maize and other crops for nutrients and water in areas which experience seasonality in rainfall (Johnson et al. 1988). Furthermore, Johnson et al. (1988) found that most of the fine roots (less than 2 mm in diameter) were concentrated near the surface soil, although some roots reached deep soil levels. In both studies, the workers sampled roots at different depths and lateral distances from the plants using the auger method. Johnson et al. (1988), however, did not sample roots of hedgerows but worked on closely planted tree species.

A study by Ong, Rao, and Mathuva (1992) found that the influence of leucaena extended laterally to about 5 m. They used buried galvanized iron as barriers between the leucaena and the maize crop. Their initial conclusion claimed that the below-ground competition between leucaena and maize was of minor importance or the root barriers (galvanized iron) were ineffective. This finding, however, conflicts with the result of Solera's (1992) study in the Philippines. He found that the significant reduction of upland rice yield in an alley cropping system using *Cassia spectabilis, G. sepium*, and *Flemingia congesta* as hedgerow species could be largely attributed to the depression of crop yields from the rows near the hedgerows. He concluded that the reduction in crop yields was caused by the below and above ground competition between the crop and the hedgerows Lateral root spread of hedgerows varied with hedgerow species. The highest hedgerow root density was found within 40 cm of soil surface. As expected in acid soils, the root density decreased with soil depth.

2.8 Summary

The foregoing review underlined the need to evaluate critical parameters of tree-crop interactions in an alley cropping system, the role of nitrogen-fixing trees as contour hedgerows, and key variables that may be manipulated to optimize the interaction effects and maximize the overall system's productivity (i.e. hedgerows and crop productivity). The review emphasized the importance of determining, then analyzing, key variables that could help explain current and emerging patterns in hedgerow biomass production, crop production, and root growth and development. Moreover, the review highlighted the need for empirical studies that could explain tree/crop competition and complementation in an alley cropping system. Obviously, further studies on tree-crop interactions will enhance understanding of the complex biological and environmental requirements of alley cropping.

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Chapter 3

GROWTH AND YIELD OF ABOVE-GROUND HEDGEROWS AND INTERCROPS

Abstract

A 0.22-ha alley cropping experiment was established on Mt. Makiling, University of the Philippines at Los Banos to evaluate height and diameter growth, pruning biomass, mortality, and decomposition rate of *Gliricidia sepium* hedgerows at different number of hedges per contour line, pruning height, and within-row spacing. The yields of alley crops (*Zea mays* and *Vigna radiata*) that were planted in rotation in two cropping seasons, were also determined.

Within-row spacing significantly affected the one-year height and diameter growth and biomass of the *G. sepium* hedgerows. The greatest height and diameter growth was obtained from 40-cm within-row spacing and the lowest from 5-cm within-row spacing. The highest biomass from the initial clipping came from 5-cm within-row spacing. The number of hedges per contour line did not significantly affect height and diameter growth and one-year pruning biomass. The average one-year biomass from the initial clipping was 3.4 dry kg/m^2 alley, at least 30 percent of which was young twigs and leaves. This is approximately equivalent to 1.7 kg/m^2 if applied in two adjacent alleys.

Biomass from the subsequent prunings was highest from the 5-cm within-row spacing and 2.0-m pruning height. Mortality of the hedgerows was not significantly affected by the treatments within one year after establishment. However, after initial clipping and subsequent prunings, the hedgerows in 5-cm within-row spacing suffered about 14 percent mortality. The average pruning biomass from the first and second pruning

was 0.7 dry kg/m^2 alley, at least 60 percent was young twigs and leaves. This is approximately equivalent to 0.35 kg/m^2 if applied in two adjacent alleys.

About fifty percent of the young twigs and leaves decomposed within four to eight weeks. The average N, P, K, ash, crude protein, and crude fiber in percent of the tissues were 2.69, 0.28, 2.87, 8.94, 19.75, and 23.63, respectively.

Mungbean yield in the first crop was significantly lowered in the 5-cm within-row spacing. In the first and second cropping seasons, maize yield was not significantly influenced by any of the treatments. None of the treatments significantly affected mungbean yield in the second crop.

3.1 Introduction

The main attraction of alley cropping is its potential to meet the intercrop's needs: nutrients are restored through periodic applications of organic matter; microclimatic conditions are improved; fallow period eliminated in ecologically-fragile uplands; and top soil protected from erosion during periods of intense rainfall. This potential, however, largely depends on the hedgerow's inherent capacity to produce biomass and respond to various management practices. For instance, the hedgerow's coppicing characteristics and yield pruning biomass over time are important considerations in managing alley cropping systems. The amount of biomass that is applied in the alleys directly relates to soil fertility and sustainability of crop production over the long term. High yields of pruning biomass mean lower farm production costs because the farmer purchases less commercial fertilizer.

Most farmers, in the short term, will consider the alley crop's yield and costs (establishment and maintenance) as the major parameters in assessing the potential of alley cropping. Thus, a higher volume of pruning biomass would mean less production input in alley cropping -- less fertilizer purchased at a comparable production level per unit area. In the long term, however, farmers prefer to produce sustainably at low cost. Farmers are starting to realize that they need to increase production at decreasing farm inputs, but not at the expense of continually mining the soil of its resources.

Accordingly, in this evaluation of *Gliricidia sepium* as a hedgerow species, yields of maize and mungbean (mungo) intercrops were included. In addition, data on height and diameter growth, pruning biomass yield, rates of decomposition of periodic prunings, and percent mortality of hedgerow plants over time, were gathered and analyzed. Thus, the study responded to the short- and long-term requirements of a sustainable alley cropping system.

The study varied number of hedges per contour line, pruning height, and within-row spacing of *G. sepium*. It hypothesized that the hedgerows' height and stem diameter growth before initial clipping, and stem diameter after initial clipping will decrease with more dense within-row spacings, more intense cutting regimes, and more hedges per contour line. Moreover, the research postulated that biomass yield and mortality of hedgerow plants will increase with more dense within-row spacings, more intense cutting regimes, and higher number of hedges per contour line. I also hypothesized that yields of maize and mungbean will increase with less dense within-row spacings, more intense cutting regimes, and few number of hedges per contour line.

3.2 Materials and Methods

3.2.1 Experimental Design

Figure 1.1 shows the layout of the experimental field planting. The experimental design is split-plot with three replications. First, the replicates and treatments for the main plots were drawn randomly following the principles of complete randomized design (CRD); then treatments for the sub-plots within a main plot were randomly assigned. Three control plots were set-up, one in each replication. In the control plots, intercrops were planted without the benefit of prunings from the hedgerows.

Treatments in the main plots were the following:

A1 = Single hedgerow of *G. sepium* planted along the contour line; and

A2 = Double hedgerow of *G. sepium* planted along the contour line with 0.5-m distance between the hedgerows.

Treatments in the sub-plots were the factorial combinations of the following pruning heights (B) and within-row spacings (C):

B1 = Pruning back to 30 cm at hedgerow height of one-m

B2 = Pruning back to 30 cm at hedgerow height of 1.5-m

B3 = Pruning back to 30 cm at hedgerow height of 2.0-m

C1 = 5-cm within-row spacing of hedgerow plants

C2 = 10-cm within-row spacing of hedgerow plants

C3 = 20-cm within-row spacing of hedgerow plants

C4 = 40-cm within-row spacing of hedgerow plants.

Treatments in the main and sub-plots, respective areas of the sub-plots, including the control plots, are shown in Appendix Table 3.1. The area and location of each sub-plot are indicated in Figure 1.1. The sub-plot treatments that were assigned randomly to each main plot were the following:

B1C1 = Pruning of hedges with 5-cm within-row spacing at one-m height

B1C2 = Pruning of hedges with 10-cm within-row spacing at one-m height

B1C3 = Pruning of hedges with 20-cm within-row spacing at one-m height

B1C4 = Pruning of hedges with 40-cm within-row spacing at one-m height

B2C1 = Pruning of hedges with 5-cm within-row spacing at 1.5-m height

B2C2 = Pruning of hedges with 10-cm within-row spacing at 1.5-m height

B2C3 = Pruning of hedges with 20-cm within-row spacing at 1.5-m height

B2C4 = Pruning of hedges with 40-cm within-row spacing at 1.5-m height

B3C1 = Pruning of hedges with 5-cm within-row spacing at 2.0-m height

B3C2 = Pruning of hedges with 10-cm within-row spacing at 2.0-m height

B3C3 = Pruning of hedges with 20-cm within-row spacing at 2.0-m height

B3C4 = Pruning of hedges with 40-cm within-row spacing at 2.0-m height.

The intercrops planted in the alleys were *Zea mays* and *Vigna radiata* (L.) Wilcjek. The maize variety was IPB Var 2 and the mungbean variety was the 60 to 70-day CES 55. The seeds were procured at the Institute of Plant Breeding (IPB), UPLB College of Agriculture, College, Laguna, Philippines. In year one, maize was first planted followed by mungbean. Similarly, during the second year maize was again planted followed by mungbean. Crops during the second rotation benefitted from the application of the initial and subsequent prunings of the hedgerows. The same varieties of intercrops were used during the first- and second-year planting seasons.

3.2.2 Site Preparation and Establishment of Experimental Units

Before the experimental plots were laid out, the site was cleared of weeds, grasses, vines, wild bananas, shrubs, and a few pioneer tree species. Large trees nearby the site were also pruned to minimize shading of the experimental area. In two corners of the site, one-m deep trenches were dug so that the root systems of nearby trees would not affect the hedgerows and the intercrops. The ground was prepared with the use of hoes, rakes, and shovels. The site preparation was more or less typical of upland farming in the Philippines.

After the ground was cleared and prepared, the experimental plots were established. First, the contour lines of the upper hedgerows were laid out with the use of an A-frame. The lines were corrected following the procedure outlined by Watson and Laquihon (undated) in marking contour lines. Thus, all the lines of the upper hedgerows for a given main plot are on the same contour. The lower hedgerows were determined by measuring a fixed 4-m surface distance from the lines of the upper hedgerows. All the measured alleys or strips have a 4-m distance between the upper and lower hedgerows. After the hedgerow lines were marked with bamboo sticks, furrows with an average depth of 5-10 cm were dug following the contour hedgerow lines.

After the furrows were dug, seeds of *G. sepium* were dibbled following the assigned treatments for the main plots and sub-plots. The seeds were soaked in water, drained, and wrapped with a wet jute sack overnight before the day of planting. Dibbling of the *G. sepium* seeds was done in the second week of September 1990.

During the establishment phase, 2-m alleys (surface distance) between measured plots were laid out. In addition, unmeasured single hedgerows with 2-m alleys were also established at the top and bottom of the measured top and bottom main plots. Hedges between the main plots have borders of 1.5 m while borders of sub-plots within the main plots are 0.5 m. Because of the terrain and size of the experimental area, the hedgerows for all the main plots except TOP 2 (Replication 1 for Main Plot A1) was set up with a length of 3.5 m. The TOP 2 main plot has sub-plots with the length of 2.5 m.

After the establishment of the experimental site and dibbling of *G. sepium*, the area was fenced with a used fish net. The fencing protected the experiment from stray animals and passers-by. A perimeter survey of the experimental area was also conducted to determine the site's total area and the area of each sub-plot.

3.2.3 Planting of Intercrops

The first maize crop was planted a week after the *G. sepium* seeds were dibbled. The maize was planted in furrows inside the alleys at a density of 35,000-40,000 hills per hectare following the recommended guidelines by Tabinga and Gagni (1985). Each alley had five rows of maize and within-row distance of 40-50 cm (Figure 3.1).

After the first maize crop was harvested in December 1990, the plots were prepared for the planting of mungbean in January, 1991. The stovers, which were left at each sub-plot after weighing, were placed along the base of the contour hedgerows. Five rows of mungbean were planted inside the alleys at row spacings of 50-75 cm following the guidelines by Cagampang and Lantican (undated). Two to three seeds per hill were dibbled in the furrows at a distance of about 30-40 cm. The mungbean was harvested in late March 1991.

The second maize crop was planted after the initial hedgerow clippings in September 1991, after the prunings were placed in the alleys. This crop was harvested in December 1991. After the maize harvest, the site was prepared for the second mungbean crop which was planted in January 1992 and harvested in late March 1992. In both the first and second croppings of maize and mungbean, the same preparation and planting procedures were followed.

3.2.4 Tending of Plots

Two weeks after the first maize crop was planted, the plots were weeded. Hilling up was also done for the maize plants. Weeding was periodically performed in the whole experimental area. About a month from the day of planting, the *G. sepium* hedges were thinned to their specified within-row distances; the good thinnings were used in replanting sub-plots with poor germination.

Another replanting of subplots with poor survival was also done in early November 1990. Bareroot seedlings from the border hedgerows were used for replanting.

Both the first and second cropping of maize were sprayed with Azodrin (an insecticide for borers) using a concentration of 4-5 ml per 16 l of water. The first maize crop, however, was heavily damaged by rodents; hence, the application of rat poison was resorted to several times. The typhoon "Ruping" on November 13, 1990 hit Luzon and Visayas islands in the Philippines and damaged about 25 percent of the maize crop in the study area. In both the first and second crops of maize and mungo, commercial fertilizer was not applied.

Figure 3.1. First and second crop of maize and a perspective of the experimental site.

The mungbean crops in the first and second plantings were watered twice a week during the last two weeks of February and first two weeks of March. Four weeks after the planting, hilling up was also performed for the mungbean plants. The mungbeans were sprayed with insecticide to control worm damage on the young leaves of the plants. During the first cropping, rat poisons were also used to minimize rodent damage on young beans.

3.2.5 Sampling, Measurements, and Analysis

Height and Diameter Growth. Over a 12-month period, the height and diameter of hedgerow plants were measured every six months. Another measurement of the diameter of hedgerows was performed after 18 months to determine the pruning effect on biomass. The first measurement was done in early March 1991 and the second in early September 1991. The third measurement of the diameter was done in April 1992. Before the first measurement, 10-16 hedgerow plants were selected from each subplot following the procedures of systematic sampling. The stems of these plants were painted red at about 10 cm from the ground. To be consistent, only the painted plants were measured for the height and diameter growth. Height in m was determined with the use of meter tape and the diameter in cm was obtained with a vernier caliper at approximately 3 cm above the ground. After the measurements, the data from each main plot and sub-plots were summarized and tabulated. The means of 10-16 plants per sub-plot were used in the statistical analysis.

Hedgerow Survival. Six months after planting the hedgerows, a total count of surviving hedgerow plants per sub-plot was made. This was done again after 12 (before the initial clipping) and 18 months (after the initial clipping and subsequent prunings). The total number of hedgerow plants for all the main and sub-plots was determined and divided with the area of each sub-plot. Thus, the resulting hedgerow survival is in number of hedgerow plants per m^2. The number of hedgerow per m^2 from the 6-, 12-, and 18- month counts was calculated. The total surviving hedgerow plants per sub-plot after six months was used as the basis in computing the percent mortality of hedgerows after 12 months, and 12 months the basis after 18 months. Thus, the percent mortality shows the difference in the survival of hedgerows per sub-plot between 12 and 6 months and 18 and 12 months. The percent differences in the hedgerow survival between 12 and 6 months and 18 and 12 months were calculated for each treatment. These calculations were used in the statistical analysis.

Pruning Biomass-Initial Clipping. For the initial clipping of *G. sepium* hedgerows, plants were cut at the height of 30 cm above the ground (Figure 3.2). This was done for all the contour hedgerow plots including the borders. All the prunings (stems, young twigs, and leaves) were weighed using a 50-kg weighing scale (hanging type). The stems, twigs, and leaves were wrapped in a fish net before weighing. Representative samples were taken to determine the ratio of all the stems and young twigs and leaves. The dry weight of the biomass was calculated based on the average moisture content of the samples that were subjected to moisture content and tissue analysis. Dry weight per sub-plot was calculated and expressed per m^2 alley.

Pruning Biomass- Subsequent Prunings. The procedures used in determining the pruning biomass in the initial clippings were also employed for the subsequent prunings. The hedgerows were cut back to 30 cm above ground as soon as the plants reached the specified treatment heights for prunings. Bamboo sticks, which were calibrated to 1-, 1.5-, and 2- meter high, were placed in each sub-plot so that it would be easier to determine whether or not most of the plants have attained the required pruning height. Dry weights of the prunings were computed using the dry weight percent of the

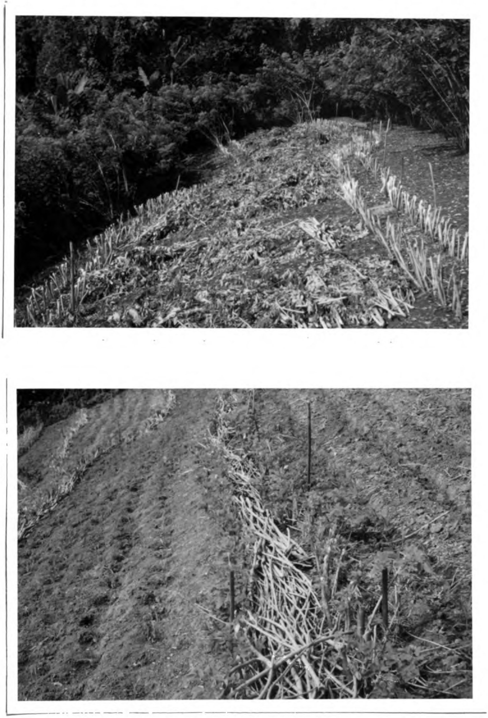

Figure 3.2. Initial clipping of hedgerows at 30 cm above the ground and placement of stems in between the hedges. Note the average 4-m height of hedgerows after one year.

samples that were subjected to moisture content and tissue analysis and expressed kg/m^2 alley.

Decomposition and Tissue Analysis. For the initial clippings, samples for tissue analysis and decomposition were obtained from two randomly selected sub-plots per main plot and per replicate. Thus, 12 samples were taken for tissue analysis and moisture content determination and decomposition. A triple beam balance was used in weighing samples for tissue analysis and decomposition.

For the subsequent prunings, only one sample was taken from each main plot (six samples) for decomposition. From the six samples, three were randomly selected for the tissue analysis. This was done to reduce the cost of analysis.

All the sub-samples for tissue analysis were sent to the UPLB Institute of Animal Science, Animal Nutrition Division for the determination of percent crude protein (CP), percent ash, percent crude fiber (CF), and moisture content (MC). A part of the sample from the UPLB Institute of Animal Science after grinding was sent to the UPLB Soil Laboratory for the N, P, and K analysis. Standard chemical laboratory procedures were used in the analysis. The UPLB Soil Laboratory uses Microkjeldahl method for N, molybdovanadate method for P, and flame photometer method for K.

For the decomposition study, all sub-samples were initially weighed, placed in decomposition containers, and weighed every week for a period ranging from six to 13 weeks until the weights of the materials have stabilized. The decomposition containers' dimensions were 30.48 cm by 40.64 cm with a thickness (depth) of 7.62 cm. The containers were made of chicken wire with 16 mesh per 6.45 cm^2, each hole having a size of 0.64 cm by 0.64 cm. The containers with the samples were placed on the ground during the whole duration of the weight loss determination. The accumulated weight loss of samples over the duration of measurements was used in plotting the decomposition of the prunings over time.

Yields of Intercrops. For the first and second maize crops, grain and stover yields per sub-plot were determined. The shelled maize was air-dried to about 14-15 percent moisture content (the average equilibrium moisture content of the air in the experimental area) before weighing. This was done by drying the grains under the sun for two to three consecutive days.

For the stover yield determination, all the maize plants within each sub-plot were cut to about 3 cm above the ground, wrapped in a fish net, and weighed with the 50-kg hanging-type scale. The maize ears were included in the weighing of the stover.

For estimating the dry weight of the stover, two samples per main plot (a total of twelve samples) were obtained for moisture content determination. The samples were placed in a draft oven at the UPLB Institute of Engineering for 3 hours at 120 °C. The dry matter of the stover in kg/m^2 was computed.

For the mungbean grain yield, mature beans were harvested from each sub-plot as soon as they become brownish to blackish in color. All the beans from a sub-plot were placed in a designated bag (each bag was coded for a given sub-plot). Subsequent pickings of mature beans were placed in the same bag. This was done because the beans did not mature at the same time. All the net bags were regularly dried under the sun until all the beans were harvested from the plots. After threshing, the grains were sun-dried for about two to three days until the weights stabilized. The intercrops' grain yields were all translated into g/m^2 for each sub-plot for comparison and analysis.

The intercrop yields from the three control plots were also determined in both the first and second planting seasons. These plots did not receive any pruning biomass throughout the experiment. The yields of maize and mungbean from the control plots were used in comparing yields with those plots which received prunings.

3.2.6 Statistical Analysis

All the yield data were converted and standardized into unit/m^2 for each sub-plot. The other parameters were expressed in their respective units such as height in m, diameter in cm, and mortality of hedgerows in percent. The data were entered into the Lotus 1-2-3 spreadsheet, converted into ASCII files, and analyzed with the use of MSTATC and/or SYSTAT software. All the figures arising from the analysis were generated with the PLOTIT software. Analysis of variance (ANOVA) and multiples range tests were performed for the yield data, height and diameter growth, percent mortality of hedgerows over time, initial clippings, and subsequent prunings. The results of the decomposition studies were plotted for comparison and analysis. Patterns and trends of CP, ash, CF, N, P, K were observed from plotted raw data and means. Results of tissue analysis from the first and second prunings and at various pruning heights were subjected to T-test. The coefficient of variations (CVs) in all the analyses of variance are shown in Appendix Table 3.2

3.3 Results

3.3.1 Hedgerows

3.3.1.1 Height and Diameter

12-Month Height and Diameter of Hedgerows

In both the six- and 12-month periods, the height and diameter growth of *G. sepium* were significantly affected by within-row spacing ($p < 0.01$) (Tables 3.1 and 3.2). The number of hedges per contour line did not significantly affect height over the 12-month period. However, at 12 months, the number of hedges per contour line significantly influenced diameter growth ($p < 0.05$). Obviously, the effect of within-row spacing on height and diameter growth of *G. sepium* hedgerows was more apparent than the number of hedges per contour line during the early growth of hedgerows. Within a year, the interaction between the number of hedges per contour line and within-row spacing did not significantly affect the height and diameter of the hedgerow plants.

In both the 6- and 12-month periods, the height and diameter means of hedgerows in the 40-cm within-row spacing were significantly higher than those in the 5-, 10-, and 20-cm within-row spacings (Figures 3.3 and 3.4). There is no significant difference in the height and diameter means of those in the 10- and 20-cm within-row spacing. The hedgerows which were planted at 40-cm within-in row spacing had the greatest diameter and height growth over the six- and 12-month periods; the least were those in the 5-cm within-row spacing. Diameter and height growth was much faster among the hedgerows in the 40- and 20-cm category compared with those in 10- and 5-cm within-row spacings. The hedgerows planted with 40 cm

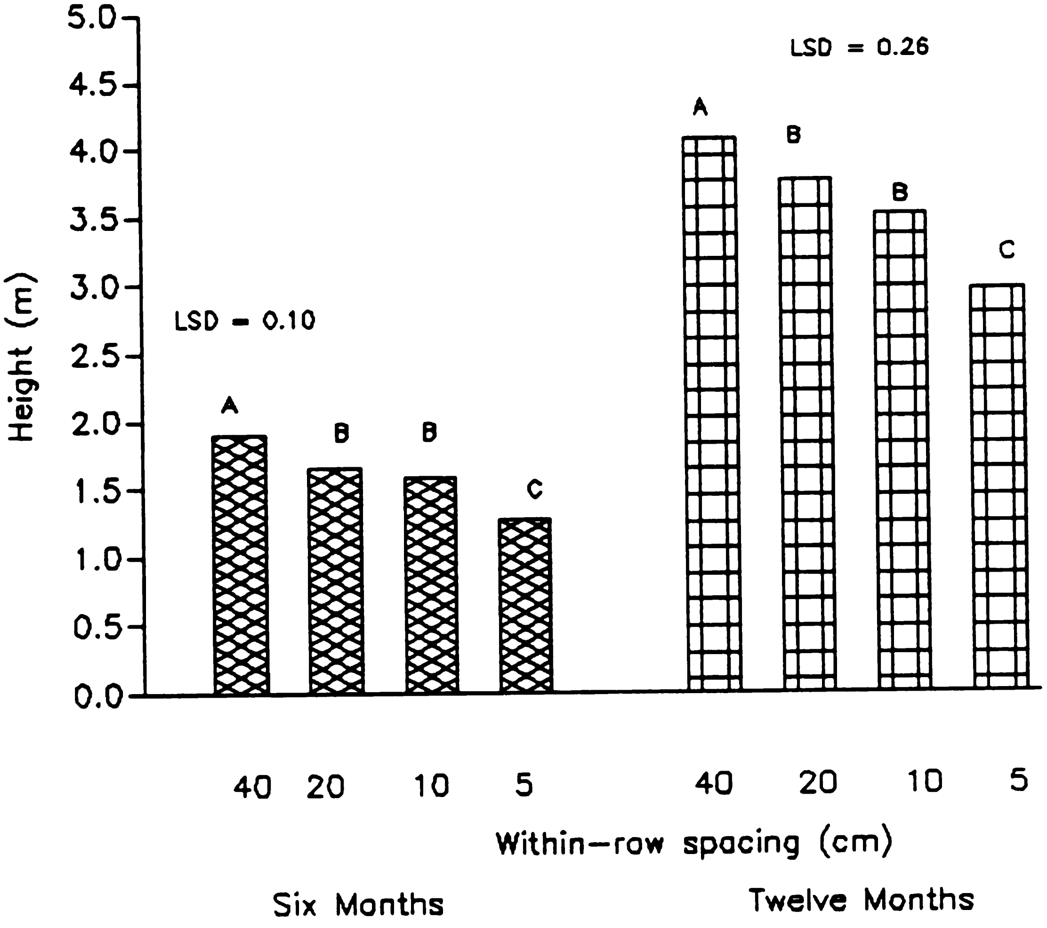

Figure 3.3. Means of height of hedgerows at different within-row spacing for the six- and 12-month periods. Bars topped with the same letter are not significantly different (LSD, $p < 0.05$).

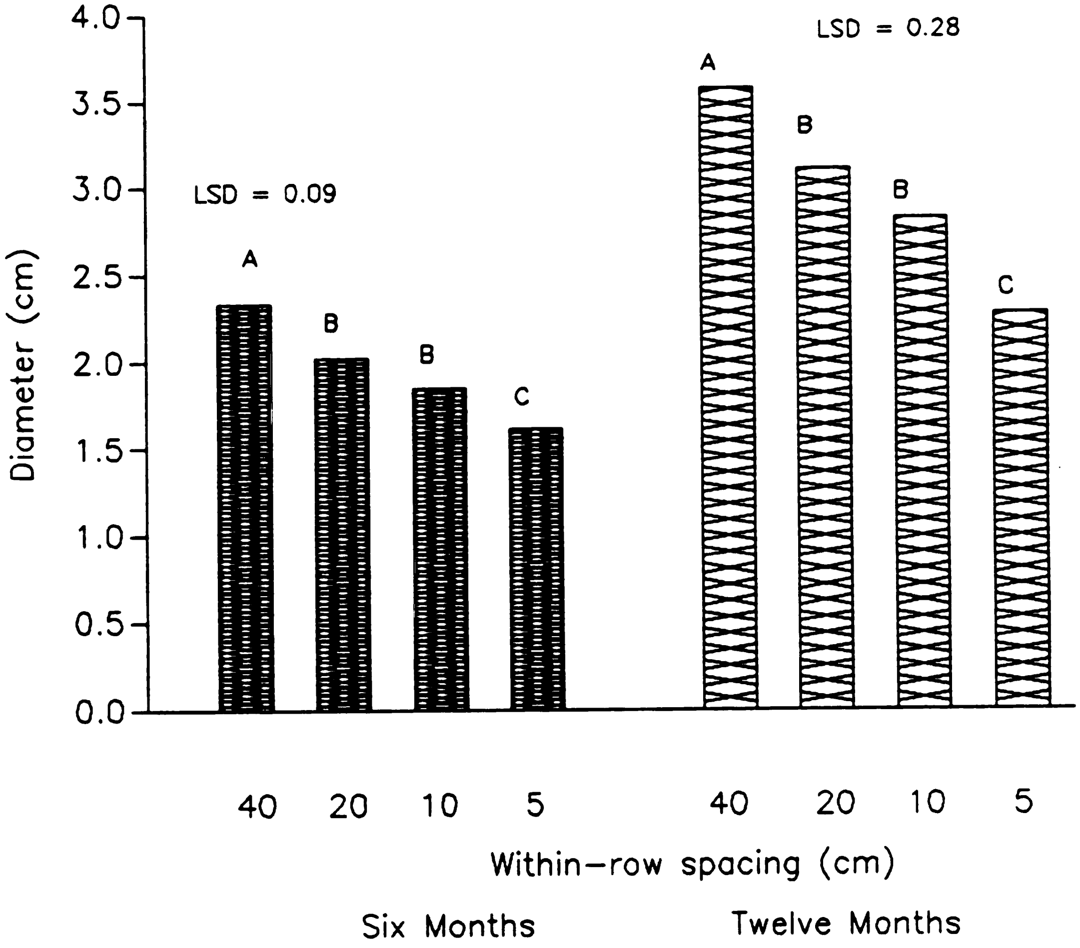

Figure 3.4. Means of diameter of hedgerows at different within-row spacing for the six- and 12-month periods. Bars topped with the same letter are not significantly different (LSD, $p < 0.05$).

within-row spacing grew in diameter and height by more than 20-30 percent faster compared with those in the denser within-row spacing.

18-Month Diameter of Hedgerows

The combinations of pruning height and within-row spacing significantly affected the diameter growth of hedgerows after 18 months of establishment, initial clipping, and subsequent prunings ($p < 0.01$) (Table 3.3). Similarly, the number of hedges per contour line also influenced diameter growth ($p < 0.05$). However, the interaction between the treatments did not significantly affect the growth of hedgerows. All the treatment means from 5-, 10-, and 20-cm within-in row spacings at all pruning heights were significantly less than those from the 40-cm within-row spacing for all pruning heights. The 20-cm within-row spacing x pruning height combinations had the greatest diameter means compared to those in the 5- and 10-cm within-in row spacing x pruning height

Table 3.1. F-values of analysis of variance[1] for the six- and 12-month height of hedgerows.

Source of Variation	**Six-Month**	**12-Month**
No of hedge per line	0.01	3.78
Within-row spacing	68.38***	31.82***
Interaction	1.83	0.73

[1] *** Significant at one percent probability

Table 3.2. F-values of analysis of variance[1] for the six- and 12-month diameter of hedgerows.

Source of Variation	Six-Month	12-Month
No of hedge per line	0.87	12.05**
Within-row spacing	110.03***	36.79***
Interaction	0.86	0.88

[1] *** Significant at one percent probability;
** Significant at five percent probability

Table 3.3. Analysis of variance[1] for the 18-month diameter of hedgerows.

Source of Variation	F-Value
Number of hedges/contour line	10.94**
Pruning Height x Within-row spacing	30.58***
Interaction	1.75

[1] *** Significant at one percent probability;
** Significant at five percent probability

combinations. This observation was also found between the 5-cm within-row spacing x pruning height combination and those of the 10-cm within-row spacing x pruning height treatment means. Those in 10-cm within-row spacing had higher diameter means (Figure 3.5). Within each of the 5-, 10-, and 20-cm within-in row spacings, there were significant differences in the diameter means of the hedgerows which were pruned at 1.0, 1.5, and 2.0 m. This is not true, however, with the 40-cm within-row spacing. Surprisingly, in the 5- and 10-cm within-in row spacings, the means were higher with hedgerows which were pruned at the attained heights of 1.5 m compared with those cut at 2.0 and 1.0 m. In the 20-cm within-row spacing, hedgerows which were cut at 2.0 m had higher diameter means, followed by those cut at 1.0 m and 1.5 m attained heights. There was no significant difference between the means of hedgerows cut at 1.0 m and 1.5 m. The range test on the diameter of hedgerows after 18 months highlighted the effect of pruning in sub-plots with closer within-row spacing. It seemed that pruning does not affect diameter growth of hedgerows at wider within-row spacing.

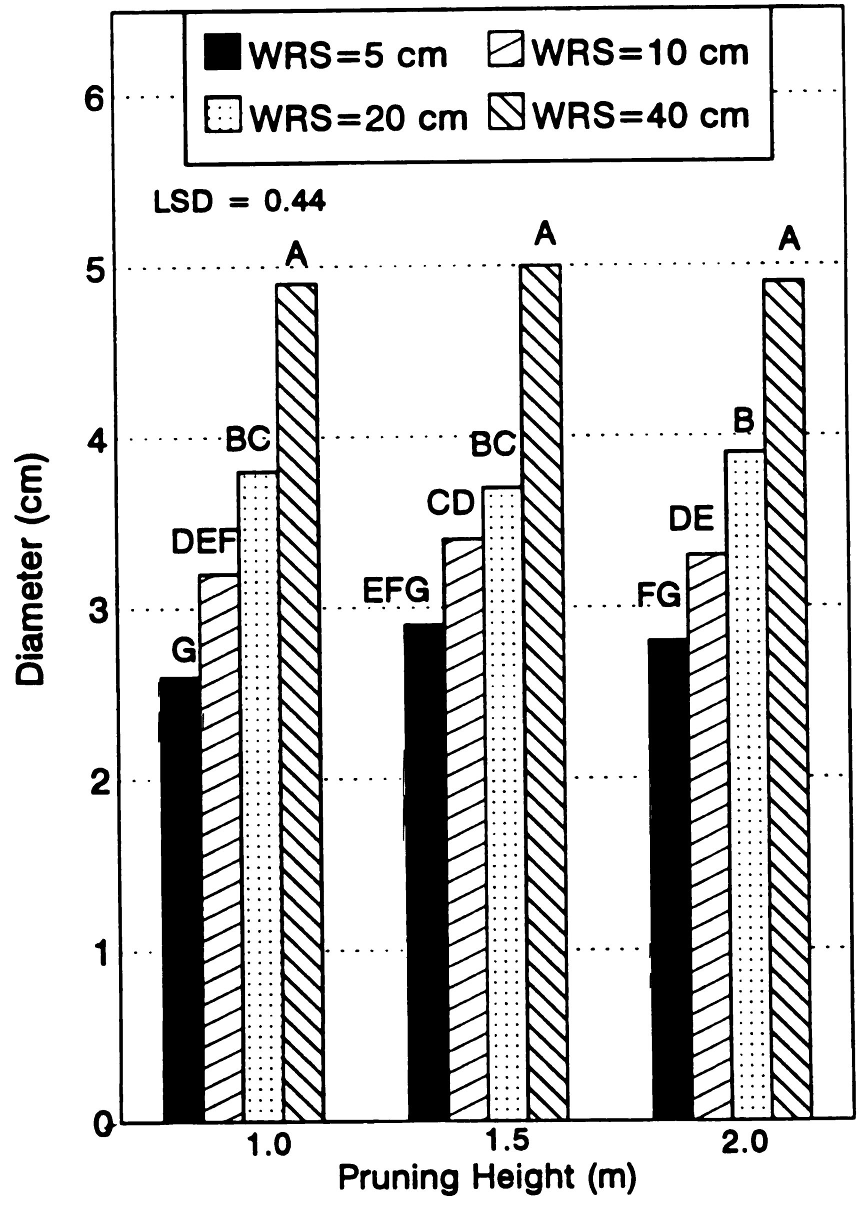

Figure 3.5. Means of diameter of 18-month old hedgerows at different within-row spacing and pruning heights. Bars topped with the same letter are not significantly different (LSD, $p < 0.05$).

3.3.1.2 Percent Mortality of Hedgerow Plants

Between 12 and 6 months after planting, the effects of number of hedge per line and within-row spacing on the percent mortality of hedgerow plants per m^2 were not significant (Table 3.4). The number of surviving hedgerow plants was not greatly reduced by high density planting before the initial clipping. Between 18 to 12 months, however, after the initial clipping and subsequent prunings, the combination of pruning height and within-row spacing significantly reduced the number of hedgerow plants ($p < 0.01$). The number of hedges per contour line did not significantly affect mortality of hedgerow plants.

Only the means of the percent mortality of hedgerow plants for the 12-18-month period were subjected to Fisher's Protected LSD test because none of the treatments in the 6-12-month period was significant with the F-test. The means of the 10-, 20-, and 40-cm within-row spacing at all pruning heights were significantly less than those in the 5-cm within-row spacing at all pruning heights (Figure 3.6). With 5-cm within-row spacing, however, the hedgerows that were cut at 1.5 m had less percent mortality compared with those that were pruned at 1.0 m. Those hedgerows at 20-cm

Table 3.4. F-values of analysis of variance[1] for percent mortality of hedgerows between the 6th and 12th months and 12th-18th months after planting.

Source	6-12 Month	12-18 Month
Number of hedges/contour line	6.72	9.88
Within-row spacing	1.09	3.33***
Interaction	2.41	1.62

[1] *** Significant at one percent probability

within-row spacing and pruning heights of 2.0 m and 1.5 m had the least percent mortality of hedgerows over an 18-month period. These hedgerows had the highest survival compared with those from other within-row spacing. The hedgerows with the highest mortality were those in the 5-cm within-row spacing and pruning heights of 1.0 and 2.0 m.

3.3.1.3 Biomass from Initial Clipping

The number of hedges per contour line did not significantly affect the biomass from initial clipping; however, the F-test on the effect of within-row spacing treatments on dry biomass was highly significant ($p < 0.01$). The *G. sepium* single hedgerows produced as much biomass as the double hedgerows after one year (Table 3.5).

All the treatment means were significantly different from each other. The highest mean came from 5-cm within-row spacing (3.9 dry kg/m^2 alley), followed by those from 10-cm within-row spacing, 20-cm within-row spacing, and 40-cm within-row spacing (Figure 3.7). As expected, the hedgerows from the 40-cm within-row spacing had the lowest dry biomass.

Ratio of Leaves/Young Twigs and Stems. In the initial clipping, one-year old *G. sepium* hedgerows produced biomass which was mainly composed of stems; only 32.1 percent was considered as young twigs and leaves (Table 3.6). In the subsequent prunings, at least 60 percent was categorized as young twigs and leaves. The average percent of young twigs and leaves tended to increase with increasing pruning heights.

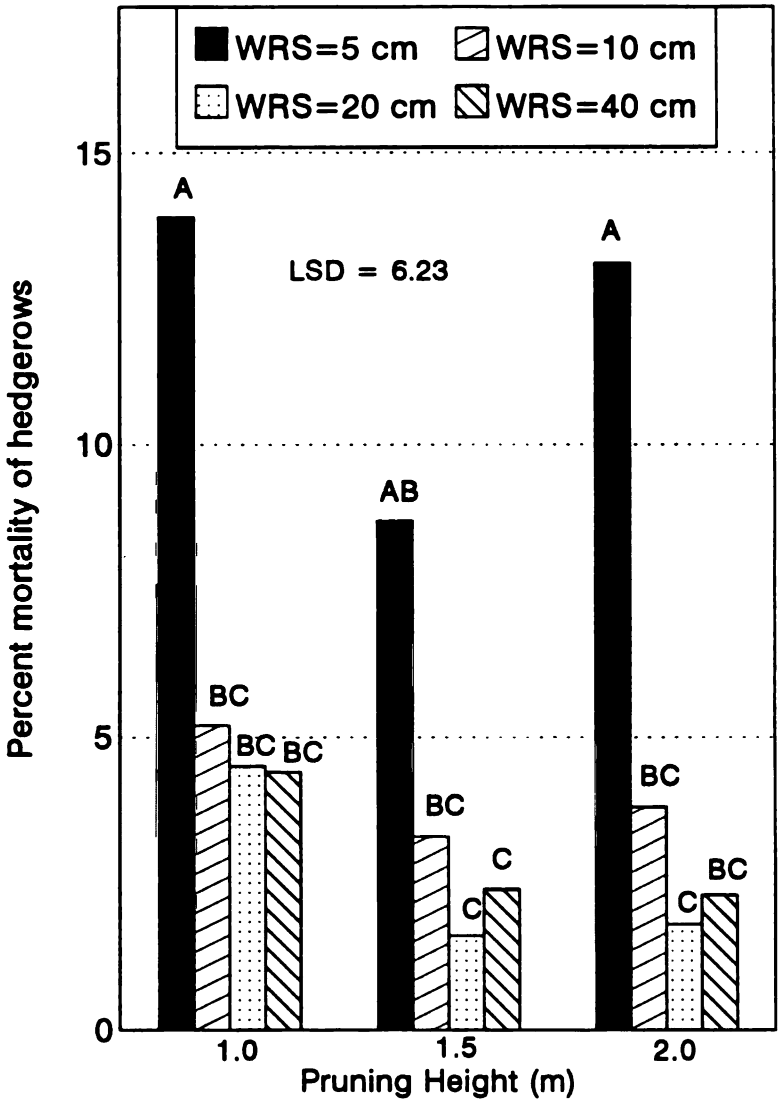

Figure 3.6. Means of percent mortality of hedgerows after 18 month at different combinations of pruning height and within-row spacing. Bars topped with the same letter are not significantly different (LSD, $p < 0.05$).

Table 3.5. Analysis of variance[1] of dry biomass from initial clipping of hedgerows.

Source	**F-Value**
No of hedge/contour line	0.50
Within-row spacing	6.77***
Interaction	0.31

[1] *** Significant at one percent probability

Table 3.6. Percent of total pruning biomass of hedgerows in young twigs and leaves.

	Source of Hedgerow Biomass	**% of young twigs and leaves**[1]
1.	Initial clipping of hedgerows (after one year of establishment)	32.1
2.	Pruning of hedgerows at 1.0-m height	60.8
3.	Pruning of hedgerows at 1.5-m height	61.9
4.	Pruning of hedgerows at 2.0-m height	66.9

[1] **Based on one representative sample per main plot or six samples per pruning activity.**

3.3.1.4 Biomass from Subsequent Prunings

The F-tests for the effect of the combinations of pruning height and within-row spacing on the dry pruning biomass were significant ($p < 0.01$) (Table 3.7). The number of hedges per contour line did not significantly affect the dry pruning biomass. The interaction effect also was not significant. There is sufficient evidence to conclude that the dry pruning biomass from the single and double hedgerows are not significantly different from each other. In both prunings, the pruning biomass means of hedgerows which were cut back to 30 cm at heights of 2.0 m in 5-, 10, and 20-cm within-row spacing were significantly higher compared with the other combinations of pruning height and within-row spacing. The hedgerows which produced the least dry biomass were those pruned at 1.0-m height regardless of within-row spacing (Figures 3.8 and 3.9).

In the first pruning, the means of dry biomass from hedgerows which were cut at 2.0 m high having 10-, 20-, and 40-cm within-row spacing were not significantly different. This was also true with the differences in the means of those hedgerows pruned at attained heights of 1.0 and 1.5 m having 5-cm and 10-cm within-row spacing. Apparently, differences in the means of dry pruning biomass are more attributed to the frequency of pruning and more dense hedgerow planting. The hedgerows with closer within-row spacing which were pruned at 2.0-m high produced the highest volume of biomass.

In the second pruning, the differences in the means of dry pruning biomass were not significant in the hedgerows which were cut at 1.0-m high. However, this pattern was not clearly observable in those hedgerows cut 1.5- and 2.0-m high. There was significant difference between the means of hedgerows cut at 1.5-m high with 20- and 40-cm within-row spacing. This was also true with the hedgerows cut 2.0-m high with

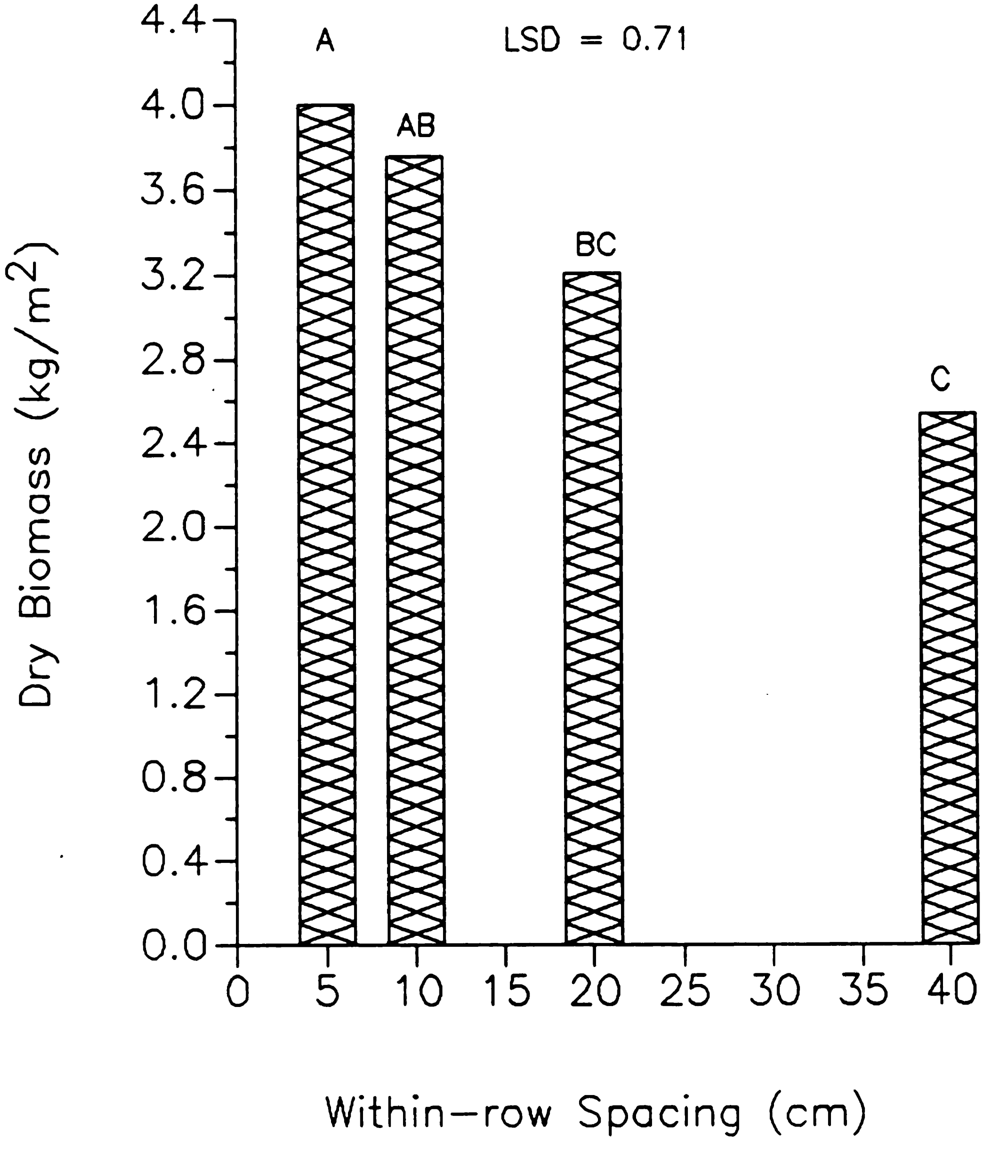

Figure 3.7. Means of dry biomass from initial clipping at different within-row spacing. Bars topped with the same letter are not significantly different (LSD, $p < 0.05$).

Table 3.7. F-values of analysis of variance[1] of dry biomass from the first and second prunings.

Source	1st Pruning	2nd Pruning
Number of hedges per line	1.91	2.19
Pruning Height x Within-row spacing	13.81***	12.95***
Interaction	1.05	0.90

[1] *** Significant at one percent probability

within-row spacing of 5- and 10-cm. In both cases, the former had lower means of dry pruning biomass (Figures 3.8 and 3.9). Clearly, the interaction of pruning height and within-row spacing influenced dry pruning biomass above the 1.0-m high pruning height.

Pruning Interval. Table 3.8 shows the pruning interval in days reckoned from the date of initial clipping and subsequent pruning date. It took more days for the hedgerows pruned higher to grow and reach their treatment heights. Moreover, during the dry season when the second pruning was conducted, the number of days for the hedgerows to reach treatment pruning height almost doubled compared with the first pruning, except for the hedgerow that were cut at 2.0-m high.

Table 3.8. Number of interval days in the first and second pruning periods at different pruning heights in m.

Pruning height in m	Interval days for the 1st pruning reckoned from date of initial clipping	Interval days for the 2nd pruning reckoned from date of first pruning
1.0	51	108
1.5	71	145
2.0	116	115

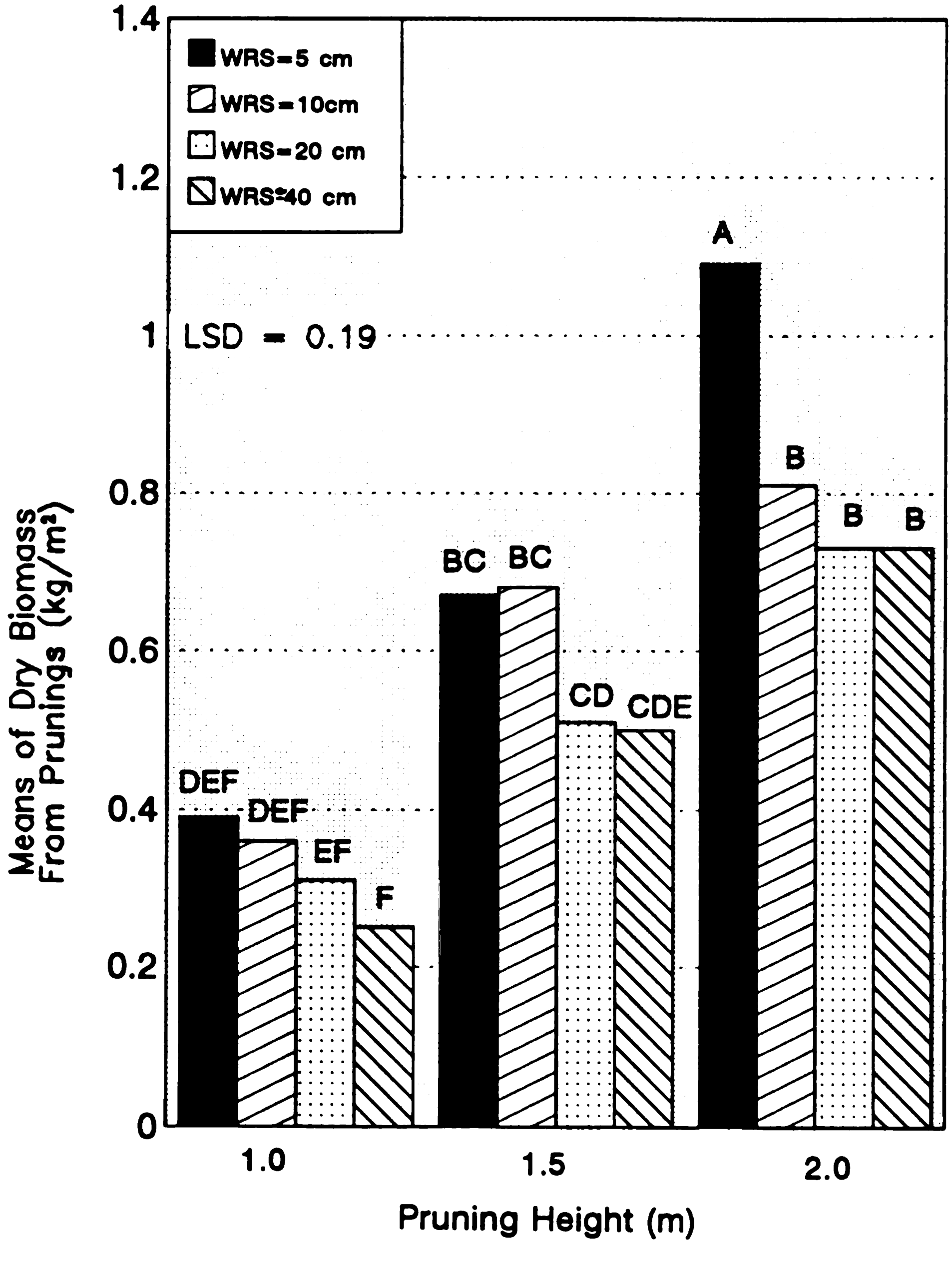

Figure 3.8. Means of dry biomass from the first prunings. Bars topped with the same letter are not significantly different (LSD, $p < 0.05$).

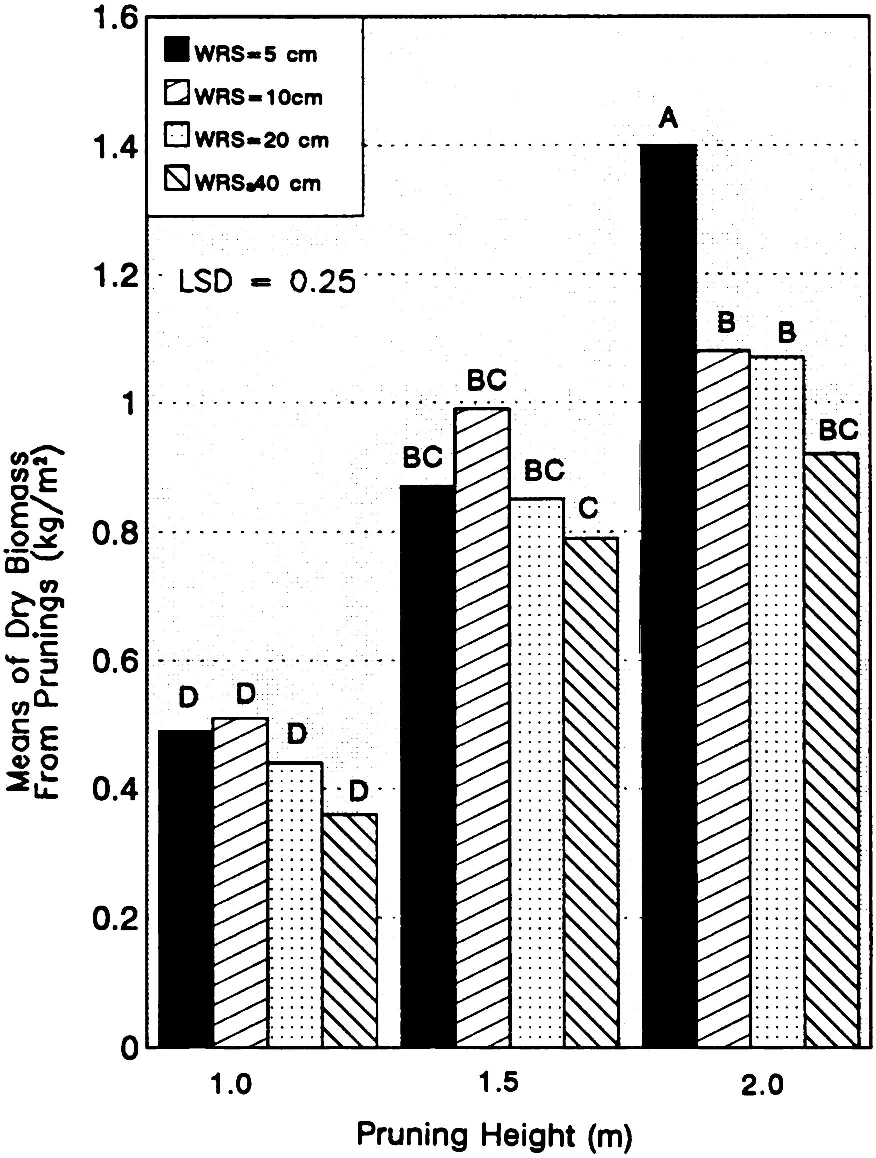

Figure 3.9. Means of dry biomass from the second prunings. Bars topped with the same letter are not significantly different (LSD, $p < 0.05$).

3.3.1.5 Decomposition and Tissue Analysis

Decomposition. In the initial clipping, only 38 percent of the total weight of samples decomposed over a period of six weeks, despite a fairly moderate amount of precipitation during these months (Figure 3.10 and Table 3.9). In the subsequent prunings, however, the accumulated weight loss of most pruning samples over six to eight weeks reached 48-60 percent (Figures 3.11 and 3.12). During high precipitation, when the prunings from the 1.5- and 2.0-m hedgerows were decomposing, the percent accumulated weight loss of samples after one week ranged from 40-46 percent for all the pruning heights. This percent accumulated weight loss is two to three times higher than the weight loss of the samples from the first pruning of hedgerows.

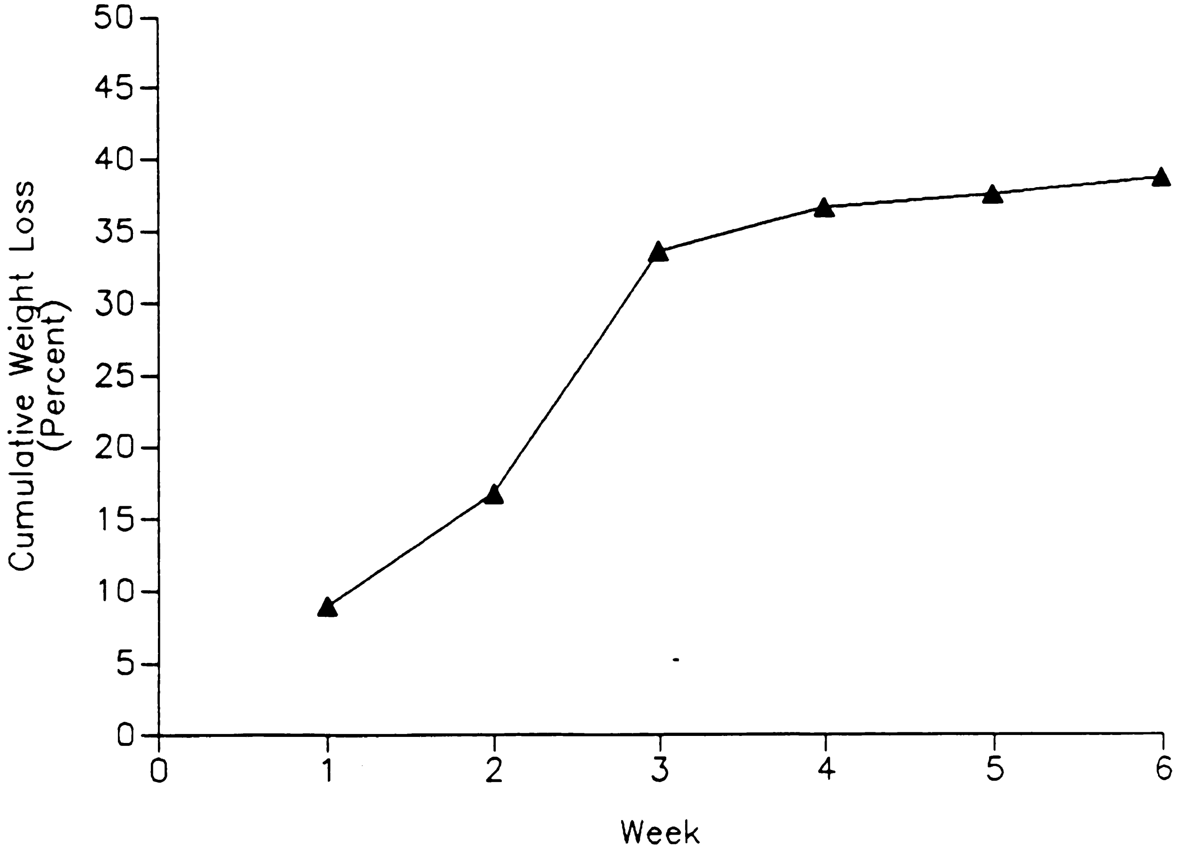

Figure 3.10. Decomposition of biomass from initial clipping over time.

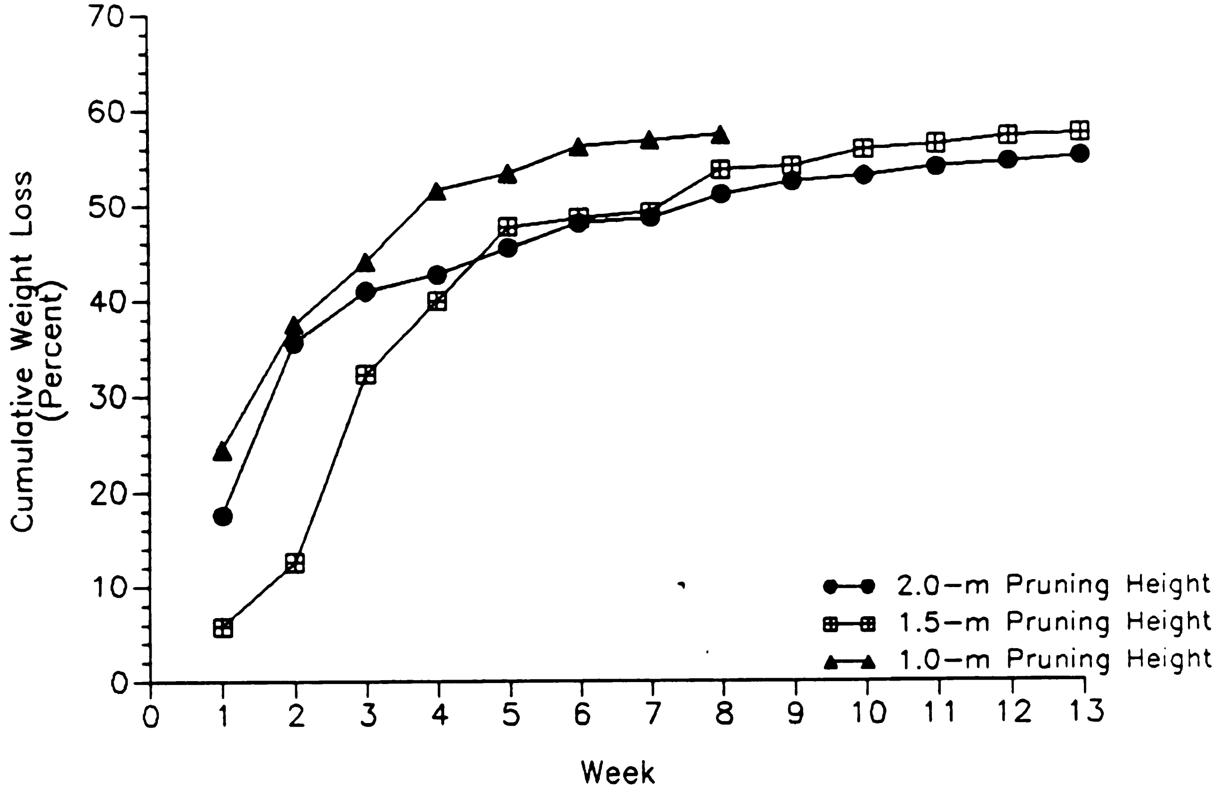

Figure 3.11. Decomposition of the first pruning biomass over time.

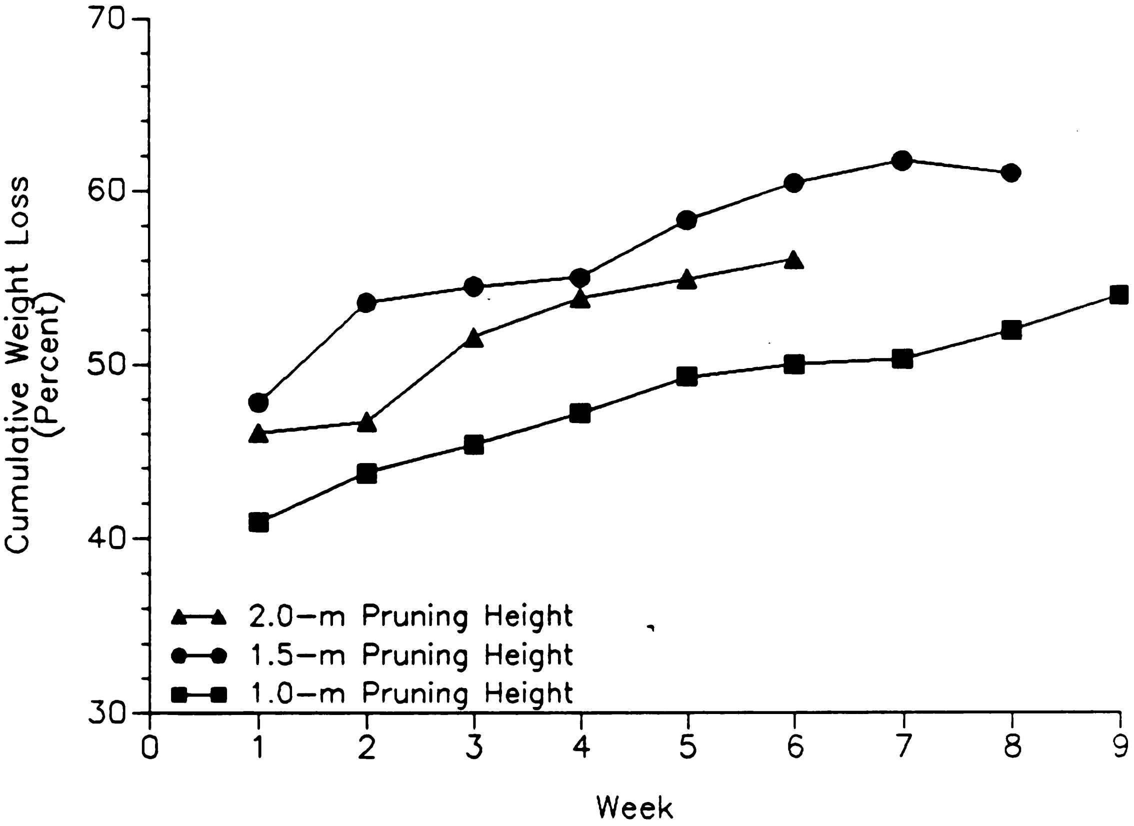

Figure 3.12. Decomposition of the second pruning biomass over time.

Table 3.9. Decomposition period of various prunings and the corresponding amount of precipitation during each period.

Source of biomass	**Start of decomposition period**	**End of decomposition period**	**Amount of precipitation in mm**	**No of weeks to attain 50% decomposition**
Initial clipping	9/13/91	10/26/91	252.9	6[1]
First pruning at 1.0-m high	11/3/91	12/30/91	449.6	4
First pruning at 1.5-m high	11/23/91	2/29/92	185.8	7
First pruning at 2.0-m high	1/7/92	4/16/92	93.7	8
2nd pruning at 1.0-m high	2/29/92	5/1/92	69.6	7
2nd pruning at 1.5-m high	4/16/92	6/11/92	225.9	8
2nd pruning at 2.0-m high	5/1/92	6/12/92	188.4	4

[1] At week 6, the accumulated decomposition of biomass was only 38.6 percent.

Tissue Analysis. The tissue analysis (Table 3.10) was obtained to estimate nutrient contribution of the biomass. The data gathering was not designed for statistical analysis with respect to the various treatments. The result, however, indicated that the average percent ash gradually declined with increasing pruning height (e.g. decrease in pruning intensity) in the first pruning; however, this pattern changed during the second pruning. Percent ash moderately increased with greater pruning heights in the second pruning. In the first and second prunings, CP exhibited a declining trend with increasing pruning height. This trend was more observable, however, in the second pruning. Percent CF, percent P, and percent K steadily declined during the first pruning; however, in the second pruning, percent CF and percent K gradually increased with increasing pruning height. Percent P declined during the second pruning. Percent N increased with pruning height during the first pruning, but declined in the second pruning period. The general trend of N, CP, K, and P tended to decline from the initial clipping up to the second pruning.

The tissue components from the first and second prunings and at various pruning heights were subjected to T-test to determine if there were significant differences in their means ($p < 0.05$) (Table 3.11). Only CF declined significantly from the first to the second pruning. The T-tests on the tissue components at various pruning heights were not significant ($p < 0.05$).

Table 3.10. Results of the tissue analysis[1] of samples from the hedgerow prunings.

Prunings[2]	**% Ash**	**% CP**	**% CF**	**% N**	**% P**	**% K**
Initial clippings	9.49	21.14	23.52	2.32	0.29	3.08
1st pruning at 1.0-m	10.89	16.41	35.31	2.06	0.34	3.65
2nd pruning at 1.0-m	7.65	20.83	18.66	2.81	0.27	1.91
1st pruning at 1.5-m	9.64	19.31	32.14	2.73	0.27	3.20
2nd pruning at 1.5-m	7.97	20.92	15.22	2.87	0.24	2.91
1st pruning at 2.0-m	7.39	17.73	20.16	3.34	0.27	2.47
2nd pruning at 2.0-m	9.61	21.93	20.44	2.70	0.25	2.91
AVERAGE	8.94	19.75	23.63	2.69	.28	2.87

[1] CP = crude protein; CF = crude fiber

[2] Data on the initial clippings are the means of 12 samples, 4 randomly selected samples from each replicate; those of the subsequent prunings come from the average of three samples, one from each replicate.

Table 3.11. T-test[1] for various tissue components from the first and second prunings.

Tissue Component in %	**Means of 1st pruning**	**Means of 2nd pruning**	**t-test value**
Ash	9.31	8.41	1.22
Crude protein	17.82	21.23	-2.08
Crude fiber	29.20	18.11	3.72***
N	2.71	2.89	-0.32
P	0.29	0.25	1.68
K	3.11	2.58	1.61

[1] *** Significant at one percent probability

3.3.2 Intercrops

3.3.2.1 Maize Grain and Stover

First Maize Crop

The effects of the number of hedges per contour line and within-row spacing on the yields (grain and dry stover) of maize were not significant in the first crop (Table 3.12). The average grain yield of the first maize crop was 144.6 g/m^2 of grain. This could be roughly translated into about 1.4 tons per hectare.

The control plots had an average yield of shelled maize of 173.6 g/m^2, slightly higher than the 144.6 g/m^2 of the treated plots. The average dry weight of stover from the control plots was 596 g/m^2, higher than the 426 g/m^2 from the treated plots.

Table 3.12. F-values of analysis of variance of the air-dried weight of shelled maize and oven dry stover from the first crop.

Source of Variation	Corn Stover[1]	Shelled Corn[1]
Number of hedges/line	0.13	0.28
Within-row spacing	0.61	0.26
Interaction	0.12	0.68

[1] All F-values are non-significant at $p < 0.10$.

Second Maize Crop

The F-tests ($p < 0.10$) for the effects of the number of hedges per contour line and the combination of pruning height and within-row spacing on the yields (air-dried grain and dry stover) of the second maize crop were not significant (Table 3.13). The average yield of shelled maize in the second crop was 141.2 g/m^2 or about 1.4 tons/ha, slightly lower than the average yield from the first maize crop.

The control plots had average shelled maize yield of 135.6 g/m^2, lower than the yield of the first maize crop from the same plots. The average dry weight of stover was 691 g/m^2, slightly higher compared with the first maize crop and with the treated plots (687 g/m^2).

Table 3.13. F-values of analysis of variance of the air-dried weight of shelled maize and oven dry stover from the second crop.

Source of Variation	**Corn Stover**[1]	**Shelled Corn**[1]
Number of hedges per line	0.19	0.22
Pruning height x within-row spacing	1.39	1.53
Interaction	0.59	0.76

[1] All F-tests are non-significant at $p < 0.10$.

3.3.2.2 Mungbean

In the first crop, the effect within-row spacing on mungbean yield were significant ($p < 0.10$) (Table 3.14). However, the effects of the number of hedges per contour line and the interaction effects were not significant. In the second harvest, the number of hedges per contour line, combination of pruning height and within-row spacing, and interaction did not significantly affect the air-dried yield of mungbean ($p < 0.10$) (Table 3.15). In this case, the number of hedges per contour line and the combinations of pruning height and within-row spacing were not found to influence the production of air-dried mungbean.

In the first mungbean crop, the highest yield came from the 20-cm within-row spacing, followed by those from the 40-cm within-row spacing. The least yield came from those 5-cm within-row spacing (Table 3.16). There was significant difference in the means of 20-cm within-row spacing and those in the 5- and 10-cm within-row spacings. However, there was no significant difference in the means of 10-cm and 5-cm within-row spacings.

Table 3.14. Analysis of variance[1] for the air-dried mungbean yield from the first crop.

Source of Variation	**F-Value**
Number of hedges per contour line	0.67
Within-row spacing	2.84*
Interaction	0.43

[1] * Significant at 10 percent probability

Table 3.15. Analysis of variance for the air-dried mungbean yield from the second crop.

Source	**F-Value**[1]
Number of hedges per contour line	0.03
Pruning Height x Within-row spacing	1.69
Interaction	0.45

[1] All values are non-significant at $p < 0.10$.

The average mungbean yield from the treated and control plots from the first cropping were 52.4 g/m^2 and 53.7 g/m^2, respectively. These yields translate to about 0.52 t and 0.54 t per ha, respectively. In the second mungbean crop, the average yield from the treated and control plots declined to 40.1 g/m^2 and 43.3 g/m^2, respectively.

Table 3.16. Means of mungbean yield (g/m^2) from the first crop.

Treatments	Means Ranked Order[1]
Within-row spacing of 20 cm	57.5 A
Within-row spacing of 40 cm	52.2 AB
Within-row spacing of 10 cm	50.9 B
Within-row spacing of 5 cm	49.1 B

[1] Values followed by the same alphabetical letter are not significantly different.

3.4 Discussion

Contour hedgerows are the unique feature of alley cropping in uplands. The hedgerows serve as a vegetative barrier against soil erosion and as a "factory" of organic matter for the intercrops. These intertwining service functions of hedgerows are the cornerstones of alley cropping. Without contour hedgerows, alley cropping in the uplands will not be sustainable. Contour hedgerows conserve top soil and restore soil fertility. Accordingly, the hedgerows' height and diameter growth, pruning biomass, mortality of hedgerows, and quality and decomposition rate of prunings are important variables in achieving the purposes of alley cropping. The present study on *G. sepium* hedgerows revealed that the above parameters can be directed to obtain optimum net gains while minimizing the unfavorable impacts of competition on the intercrop. Several controllable variables were highlighted which could be managed to improve alley cropping in the short- and long-term. The results also provided insights regarding the performance of *G. sepium* as a hedgerow species.

The results of the height and diameter measurements, percent mortality of hedgerows, and, to a certain extent, the dry pruning biomass suggest that

G. sepium hedgerow plants compete for light and space in their early growth and development. This competition affects diameter and height growth, percent mortality over a period of time, and production of pruning biomass. It was observed that diameter and height growth of hedgerows increased with increasing within-row spacing (less dense planting of hedgerows). Within the 12 to 18-month observation period, positive linear relationships still existed between height and diameter growth and within-row spacing of *G. sepium* hedgerows. The competition for light and space was more intense among hedgerow plants which were planted at 5-cm within-row spacing, as evidenced by their highest mortality over the 18-month period and low height and diameter growth. As the densities of hedgerows increased, more weak and shaded plants died. Obviously, plants in the sparsely-planted hedgerows (20- and 40-cm within-row spacing) did not have to compete for light and space early in their development stage.

The above observation confirms Harper's (1977) statement that during the early growth of plants, yield is positively determined by density; but, this relationship changes as the plants reach the limits of the resource-supplying power of the environment. At this stage, yield becomes independent of planting densities. Then, plants begin to compete for limited and finite supply of resources (Ford, 1975). Within the 12 to 18-month period of measurement in the present study, however, the hedgerows did not appear to have come to the limits set by the available resources in the environment; dense hedgerows yielded the highest dry initial pruning biomass. Hedgerows in more dense within-row spacing were forced to maximize space and resource availability in their early growth; thus, the hedgerows yielded higher biomass despite their lowest attained height and diameter growth. Hedgerows in more dense within-row spacing could immediately contribute the most organic matter for the intercrops. Therefore, higher biomass yield is a net gain from dense planting of hedgerows even though the plants are subjected to early stress and intraspecies competition. In addition, since hedgerows from more dense within-row spacing were short, they had the least threat of shading the crops compared with the taller, wide-spaced hedgerow plants. Also, at more dense planting, contour hedgerows are more effective in controlling soil erosion and slowing down the speed of water running down from the higher slopes (MBRLC Editorial Staff, 1988; Laquihon et al., 1991).

Studies on leucaena hedgerow species, such as those of Lu and Hu (1981); Guevarra et al. (1978); and Ella et al. (1989), concluded that biomass (prunings, leaves, or wood) increased with planting density. Desai et al. (1988), however, found that there was no difference in biomass production due to plant densities of leucaena over a three year period. Lu and Hu (1981) also observed that leucaena plantings of more than 5,000 trees/ha had high mortality due to competition for light and nutrition. In *G. sepium*, Sumberg (1986) observed that yield increased with increasing density. He found that gliricidia produced the highest mulch when established at approximately 10 plants/m of hedgerow (i.e. 10-cm within-row spacing).

Studies with other plants indicate that those in high densities are able to maximize yield per unit area during their early stage of growth and development (Harper, 1977). This reasoning might also apply to hedgerows. Perhaps during the early stage of hedgerow development, the supply of resources for growth has not yet fallen below the combined demands of the individual plants (Donald, 1963); hence, higher pruning yields from dense planting of hedgerows. This may also explain why the number of hedges per contour line and the interaction effect did not produce significant difference in the height and diameter growth of hedgerows, percent mortality of hedgerows over time, and pruning from the initial clipping during the 12-month period. Conceivably, the significant effect of the number of hedges per line on the 18-month diameter of hedgerows may be due to the fact that the supply limit of available resources was nearing its critical point. Accordingly, between 6 and 18 months of hedgerow growth, an opportunity exists to harvest pruning biomass when shoot growth is still increasing but before it gets to an optimum point after which the yield declines (Cannell, 1983; and Huxley, 1985).

In the short term, therefore, the benefits from densely planted *G. sepium* hedgerows in terms of biomass yield (organic matter) and erosion control (keeping fertile top soils in the alley) may yet outweigh the unfavorable impacts of intraspecies competition on the productivity of intercrops. It is suspected that during the early growth of hedgerows, when available resources are not yet limiting, intraspecies competition among hedgerows may not yet pose a threat to intercrops. Possibly, the hedgerows have not yet developed extensive lateral roots towards the alley and deprive the intercrops of moisture and nutrients.

In the long term, the hedgerows will be regulated by the "law of constant final yield" (Kira et al., 1953 as cited by Harper, 1977). The density issue becomes invalid; the hedgerows will be limited by the resource-supplying power of the environment. Densely planted hedgerows would be forced to "self-thin" in order to grow and survive (Harper, 1977). In densely established hedgerows, plants with large stem diameters would tend to obtain a greater proportion of available soil resources at the expense of the smaller hedgerow plants until an equilibrium of co-existense is achieved. When this happens, a temporal optimum density for hedgerows would have been attained.

3.4.1 Key Variables in Managing the Hedgerows

The present study highlighted key variables that could be manipulated to optimize benefits from the hedgerows for the alley crop. These variables are plant density (number of hedges per contour line, within-row spacing) and pruning height. These variables can be managed to get an optimum pruning biomass, effect a certain level of hedgerow plants mortality, possibly influence the nutrient composition of prunings, check root growth to minimize the tree-crop interface, and minimize the hedgerows' shading effect.

Initial pruning biomass is maximized from densely planted hedgerows, especially if they are initially cut to 30-40 cm above ground and maintained at that height (Briscoe, 1989; Watson, 1983; Garrity, 1991, pers. comm.). In the present study, the average N, P, and K contribution of *G. sepium* biomass to the soil from the initial clipping (3.4 kg dry biomass/m^2 alley or 17 t dry matter/ha) was estimated to be 144 kg, 14 kg, and 154 kg per ha, respectively. The average N, P, and K contribution from each subsequent pruning (0.7 kg dry biomass/m^2 alley or 3.5 t dry matter/ha) was estimated to be 56 kg, 5 kg, and 60 kg per ha, respectively[1]. Considering the higher average density of 13,333 trees/ha in the study and the volcanic soil in the site, these estimates are within the range of those reported by Atta-Krah and Sumberg (1987) and Budelman (1986) as cited by Kang and Mulongoy (1987). Atta-Krah and Sumberg (1987), for instance, reported that pruning yields ranged from 2.85-3.06 t dry matter/ha with N contribution of 79-104 kg/ha. Budelman (1986) as cited by Kang and Mulongoy (1987) estimated an average of 15.2 t dry matter/ha from *G. sepium* at 10,000 trees/ha. Thus, planting hedgerows at high densities (5- and 10-cm within-row spacing) can be a strategy to

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[1] These estimates were calculated based on the following formula: kg of element/ha = kg dry biomass/m^2 alley divided by 2 x percent of young twigs and leaves (30 and 60 % for the initial clipping and subsequent prunings, respectively) x amount in percent of the element from the tissue analysis x 10,000 m^2 per ha. The dry biomass (kg/m^2 alley) is assumed to be applied in two adjacent alleys.

maximize initial and subsequent pruning biomass and ultimately improve soil fertility.

Combining within-row spacing (density) and pruning height forms another scheme to optimize pruning biomass for the benefit of the intercrops. The optimum pruning height in terms of yielding the highest biomass was 2.0 m for all the different within-row spacings. In the short term, however, the highest pruning biomass could be obtained from hedgerows with 5-cm within-row spacing. As the pruning heights were reduced (e.g. pruning frequencies increased), the biomass yields of *G. sepium* decreased. This is consistent with notion that there are great amounts of storage reserves (of carbohydrates and minerals) left on the plants when they were pruned high (Cannel, 1991; Erdmann et al., 1993). Thus, hedgerows should be cut back to 30 cm above ground when they reached the height of 2.0 m in order to maximize biomass yield. At the height of 2.0 m, however, the hedgerows may potentially shade the intercrops in the alleys.

Previous work which supports the results of this study include those of Duguma, et al. (1988), Das and Dalvi (1981), Osman (1981); Guevarra et al. (1978); and Atta-Krah and Sumberg (1987). They maintained that with nitrogen-fixing species such as leucaena, *G. sepium*, and *Sesbania grandiflora*, pruning biomass increased with pruning heights. Hedgerows attaining heights of more than 100 cm, however, should be pruned back to 30-40 cm above ground to minimize their shading the intercrops (Kang et al., 1985; Ong, 1989; and Briscoe, 1989). Das and Galvi (1981) even recommended pruning leucaena between 75-150 cm to obtain optimum biomass yield.

Given the need to minimize the hedgerow's shading effect on the intercrop while maximizing pruning biomass, the question of optimum pruning height for *G. sepium* would then be a concern. Results of the first and second pruning of hedgerows suggest that pruning at heights of 1.0 and 1.5 m will reduce biomass by about 30 to 75 percent per cutting based on the means of pruning at the height of 2.0 m. Will this reduction in biomass outweigh the benefit to the intercrop from reduced hedgerow shading?

The yields of maize from the first and second cropping and mungbean in the second crop were not significantly affected by the various treatments. The maize crop yields were not affected by within-row spacing, pruning height, and number of hedges per contour line. However, within-row spacing affected the yield of the first mungbean crop. Other studies concluded that crops planted near the hedgerows had lower yield than those in the center of alley. This was observed in upland rice (Solera, 1992) with various nitrogen-fixing hedgerow species including *G. sepium*, and maize (Ong et al., 1992; Huxley et al., 1989; Salazar et al., 1993) with leucaena hedgerows. The lower yields of crops near the hedgerows were attributed to hedgerow shading and competition for moisture and nutrients by the roots of hedges and crops. Kang and Mulongoy (1987), in their studies of *G. sepium* loppings stressed that maximum benefit from green manure comes from the timely release and mineralization of its nutrients with regards to the requirements of the alley crops. The volume of pruning is important; but, the release of nutrients must be timed when the food crop needs them. Otherwise, most of the N will be lost through volatilization and leaching.

Therefore, it is possible to prematurely apply a high volume of prunings in the alleys with minimal effect on the food crop. On the other hand, it is also conceivable that small amounts of prunings at regular intervals may provide more nutrient benefits for the alley crop. In this case, the lower pruning heights (shorter pruning intervals) would be more applicable. There would even be less hedgerow shading of the intercrops.

Accordingly, a relevant question with respect to pruning would be the level of nutrient concentration of biomass at every pruning activity and the corresponding rate of decomposition. In the study of Duguma et al. (1988), they reported that N concentration of prunings increased with decreasing pruning frequencies (e.g. higher pruning heights). In the present study, however, the result of the tissue analysis of *G. sepium* prunings indicated that N increased, though not statistically-tested, with higher pruning heights. However, the lignin:N ratios between repeated prunings and at higher pruning heights may have decreased because of the significant decrease in the means of crude fiber (CF) content between the first and second prunings and among the 1.0-, 1.5-, and 2.0-m pruning heights (Salazar and Palm, 1987). Thus, it was possible that the lower crude fiber content (or lower lignin concentration) in the second pruning facilitated the decomposition process. The materials that were left in the container after 8-13 weeks were mostly young twigs. Change in the CF content would probably have a minimal influence on decomposition rates because *G. sepium* leaves already have a low C:N ratio of 10:7 (Weeraratna, 1979) and lignin:N ratio of 2.1 (Salazar and Palm, 1987). The C:N ratio is below the upper limit of 30; thus, there is enough N to meet microbial needs (Foth and Ellis, 1988). A determination of the lignin:N ratio of the *G. sepium* biomass at different pruning heights would have given a better indication of decomposition rates because lignin is the key in the breakdown of biomass (Palm and Sanchez, 1991; Melillo et al., 1982; Salazar and Palm, 1987). This becomes more important when young twigs and not only leaves are applied in the alleys, such as in this study.

The result of the present study on decomposition suggests that the 50 percent loss of initial weight of the *G. sepium* prunings at the fourth to eighth week was more of an effect of moisture condition prevailing in the experimental site rather than the "decomposability" of the biomass from different pruning heights. The slight differences in the decomposition pattern of the various prunings could be attributed to the initial drying up of green material before disintegration occurred, especially during the dry months when precipitation was quite low. Studies on *G. sepium* at International Institute of Tropical Agriculture (IITA) corroborate with the results of the study. For instance, Wilson et al. (1986) found that the number of weeks until 50 percent loss from *G. sepium* leaves ranged from 1.6 to 3.6, depending on the prevailing local rainfall pattern. Budelman (1987) used 20.3 days in his regression model as the time to lose half of the *G. sepium* mulch material. Yamoah, et al. (1986) observed that it only took 20 days for the *G. sepium* leaves to release 50 percent of their initial P content during the decomposition process. Differences in the decomposition pattern may also be attributed to the kind of biomass that was used in decomposition. Buldelman (1987), for instance, used *G. sepium* biomass with a ratio of leaves as a percent over total fresh weight with ranged from 8.1 to 12.4 percent. In another study, leaves of *G. sepium* was about 22 percent of the total biomass (Ghuman and Lal, 1990). In this study, young twigs and leaves ranged from 30-60 percent of the biomass; hence the decomposition period was longer.

3.4.2 Gliricidia sepium as a Hedgerow Species

In this study, *G. sepium* proved to be one of the more ideal hedgerow species. The species responded positively to various kinds of density plantings and repeated prunings. It produced the highest initial pruning biomass even at stressful high-density plantings. Although, the *G. sepium* hedgerows suffered mortality in high density plantings and after intensive prunings, the species proved that it could still coppice vigorously from repeated prunings. There were some indications that the prunings, when placed in the alleys at the right time could mineralize enough nutrients (particularly N and P) for the alley crop (Kang et al., 1984; Kang and

Mulongoy, 1987). There were no significant reductions in N and P of biomass over repeated prunings and at different pruning heights.

The N and P concentration (range of 1.13-4.85 percent and 0.05-0.32 percent, respectively) of *G. sepium* are comparable with leucaena (range of 0.51-5.08 percent and 0.03-0.32 percent, respectively) (Lasco, 1991). It is not attacked by a major pest or disease, such as the jumping plant lice in leucaena (Anon, 1988). *G. sepium* belongs to a family of nitrogen-fixing plants, nodulates profusely, has symbiotic relationship with rhizobia and mycorrhiza, and is a prolific seeder (Manguiat et al., 1990; Kang and Mulongoy, 1987; Glover, 1986; ILCA, 1984). *G. sepium*, however, can only fix N at the rate of 13 kg/ha/yr compared with more than 100 kg/ha/yr for leucaena (Manguiat et al., 1990; Young, 1989). Hedgerows of *G. sepium* can be established from direct seeding with high germination and survival (such as in this study) and also from cuttings (Solera, 1992). Laquihon (1988) and Laquihon et al. (1991) have consistently ranked *G. sepium* as one of the few promising hedgerow species for the uplands of the Philippines. It can tolerate a 4 to 6-month dry period and has the capacity to survive in marginal sites (Hensleigh and Hollaway, 1988).

3.4.3 Yields of Maize and Mungo

None of the treatments affected the yields of maize (grain and stover) in either the first and second cropping season. The maize yields were within the average range of 1-2 t/ha in the Philippine upland areas (Tabinga and Gagni, 1985; Laquihon et al., 1991). In the first cropping, the hedgerows were not expected to compete with maize for incident light since both were planted at almost the same period. The first maize crop, however, was hit by a typhoon and rodents. In the second season, the maize benefitted from the initial prunings, which were roughly equivalent to a maximum of 34 g N and 3.5 g P per m^2 alley (from 5-cm within-row spacing) and minimum of

22 g N and 2.2 g P per m^2 alley, more than the requirements of maize in one growing season (Tabinga and Gagni, 1985). The timing of the maize crop in the present study, however, did not coincide with the nutrient availability from prunings; hence, most of them might have been volatilized, leached, or carried away by erosion (Mulongoy and van der Meersch, 1988; Tabinga and Gagni, 1985). Also, the first of the subsequent prunings at the 1.0- and 1.5-m heights were applied in the alleys towards the end of the maize growing period, after tassling and fruiting. In the field, the second crop of maize did not suffer competition for light because all the hedgerows were cut at 30 cm above ground two weeks before planting.

Mungbean is a nitrogen-fixing crop and as a crop it would compete with the hedgerows mainly for moisture, incident light, and P. In the first crop, the hedgerows probably competed for water and nutrients with the mungbeans planted near the hedge. In addition, there might have also been a shading effect. Thus, the least mungbean yield was obtained from the 5-cm within-row spacing. In the second mungo crop, moisture stress probably caused the erratic yields from plot to plot because of the effect of uneven watering during the later part of the "El Nino" drought. In both the first and second mungbean crops, their average yields were below the 0.57 t/ha average yield of mungbean in Southern Tagalog, Philippines (Cagampang and Lantican, undated).

Some studies, however, showed that higher yields with maize were obtained with *G. sepium* hedgerows as the source of green manure (Kang et al., 1984; Kang, 1987; Kang and Wilson, 1987). Other workers, however, reported a depression of crop yields with *G. sepium* hedgerows, especially in the vicinity of the hedges (Lal, 1989; Solera, 1992). These crops include yams, cassava, upland rice, and cowpea. They attributed the lower yields to shading of the hedgerows, declining fertility of the soil, and competition for soil resources.

3.5 Conclusions and Recommendations

3.5.1 Conclusions

Based on the results of this study on *G. sepium* as hedgerows for maize and mungbean alley crops, the following conclusions are made:

1. Optimum pruning biomass was obtained from hedgerows with 5-cm within-row spacing and pruning height of 2.0-m. Initial pruning and subsequent pruning biomass increased with decreasing (more dense) within-row spacing for a period of 22 months. Pruning yields also increased with pruning height in the two pruning periods.

2. Height and diameter growth increased with increasing within-row spacing (decreasing planting density) for the 6- and 12-month measurements. After initial and subsequent prunings, mean stem diameter was still highest in the least dense planting of hedgerows.

3. Percent mortality of hedgerow plants was observed to be the highest after 18 months among hedgerows which were planted at 5-cm within-row spacing and pruned at 1.0-m. Mortality rates among hedgerows at all within-row spacing and number of hedges per contour line were not found to be significant within one year.

4. The number of hedges per contour line did not significantly affect initial and subsequent pruning yields and crop yields. Hedgerow diameter growth after 18 months, however, was significantly affected

by the number of hedges per contour line. Stem diameter was lowest in the double hedgerows.

5. Pruning did not significantly change the ash, CP, N, P, and K concentration of biomass in the first and second prunings. However, CF significantly declined between the first and second prunings. Except for CF and K, the other elements did not significantly change as the pruning heights increased.

6. This study observed that *G. sepium* hedgerows at different planting densities and pruning heights did not significantly affect the yields of maize (grain and stover). The yield of the first mungbean crop was significantly lowest in the 5-cm within-row spacings. However, in the second planting season, the number of hedges per contour line, pruning height x within-in row spacing, and interaction did not influence the yield of mungbean. In the long-term, however, crop yields are expected to increase, stabilize, and be sustained with contour hedgerows as organic matter accumulate in the alleys and soil erosion is minimized (Laquihon, et al., 1991; Lal, 1989; Tacio, 1993; Kang et al., 1990).

3.5.2 Recommendations

Based on the above conclusions, this study recommends the following management practices to optimize net gain from the hedgerows and provide more benefits to the alley crops:

1. Plant *G. sepium* in single hedgerows at 5- to 10-cm within-row spacing and prune the plants after one year to reduce shading of the crop. For maize, pruning heights of 1.5-2.0 m may not cause depression of yields provided that the hedgerows were cut back to 30

cm during the planting. Other crops, however, like mungbean may need lower pruning heights to minimize the hedgerow's shading effect. Single hedgerows may be planted along the contour since there was not much significant increase in biomass from double hedgerows. Besides, with single hedgerows, only 10-12 percent of a hectare is used up for hedgerow establishment.

2. Time the pruning of *G. sepium* hedgerows and application of biomass in the alleys so the crops will most likely use the nutrients from the green manure. With maize, application of prunings should be a week before planting and within four weeks after germination (Tabinga and Gagni, 1985). With mungbean, application of prunings should be done one week before and within 20 days after planting (Cagampang and Lantican, undated). *G. sepium* prunings will mineralize about 50 percent of their nutrient content within four to eight weeks, depending on the moisture condition of the area.

3. Long-term trade-offs between higher and more frequent pruning biomass and shading effects of hedgerows on major alley crops should be investigated so that more definite recommendations on pruning heights and planting density can be made to the upland farmers.

4. To obtain long-trends of *G. sepium* hedgerow pruning yields, mortality of hedgerow plants, and yields of maize and mungbean, the study needs to be continued for another two to three years. In the continuation of the study, the effects on crop yields of incident light before and after pruning and timing of application of prunings should also be evaluated.

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Chapter 4

ROOT GROWTH AND SOIL FERTILITY

Abstract

The root pattern and distribution of *Gliricida sepium* hedgerows at different number of hedges per contour line and combinations of pruning height and within-row spacing were evaluated in a 0.22-ha experimental site on Mt. Makiling, University of the Philippines at Los Banos, College, Laguna, Philippines. Periodic soil samples were analyzed to determine changes in soil pH, organic matter, N, P, and K over time. Maize (*Zea mays*) and mungbean (*Vigna radiata*) were planted in rotation as alley crops during two cropping seasons. Root sampling with an auger and the trench profile technique were employed to determine root densities from the hedgerow base up to 50 cm towards the alley and at a fixed distance of 50 cm from the hedgerow base.

Up to 90 percent of all roots were < 1-mm diameter and more than 70 percent were located in the top 30 cm of the soil. The highest mean root densities (number of roots/dm^2) came from the single and double hedgerows at 5 and 10 cm within-row spacings. The root densities of the double hedgerows at 5 and 10 cm within-row spacings linearly decreased with soil depth and distance from the hedgerow base towards the alley. Root densities (mg/dm^3) from auger sampling were not significantly affected by number of hedges per contour line, within-row spacing, and pruning height. The means of root densities in two sampling periods with auger, however, decreased with distance from the hedgerow base towards the alley. Based on the rooting pattern, root densities, and distribution of *G. sepium* hedgerows, the alley crop would be partly deprived of nutrients and moisture as a result of intra- and interspecies competition.

Although the result of soil analysis was not subjected to statistical analysis, the average percent N, P, K, and pH declined after site clearing and the first maize crop. These elements, however, gradually increased after the hedgerows were established and after the incorporation of initial hedgerow clippings and subsequent prunings. Organic matter declined, then started to stabilize, after biomass application in the alley.

4.1 Introduction

Early advocates of alley cropping tended to stress the importance and potential of the above-ground biomass production of hedges, yields of alley crops, control of soil erosion, improvement of soil properties, integration with livestock production, and above-ground hedgerow/crop manipulation (Kang, Wilson, and Lawson, 1984; Kang and Wilson, 1987; Wilson, Kang, and Mulongoy, 1986; Sumberg and Atta-krah, 1988; Watson and Laquihon, undated; Watson, 1983; Laquihon, 1988; Laquihon et al., 1991; and MBRLC Editorial Staff, 1988). In recent years, however, there has been an increasing realization that for alley cropping to be confidently promoted by technicians and accepted by farmers as a technology, there is a need to further understand below-ground conditions and determine how various growth processes function (Buck, 1986; Lal, 1989; Young, 1991). Specific questions on root competition, complementation, distribution, growth, and turnover require answers based on empirical data.

There have been efforts to answer various hyphotheses on plant-soil processes in agroforestry; thus, some questions on erosion control, organic matter, soil physical properties, nitrogen fixation, nutrient cycling, soil toxicities, and soil water can now be answered based on direct or indirect evidence (Young, 1991). On the other hand, empirical studies that could answer specific questions on root growth, development, and competition have not been done or are lacking. There is little direct evidence on how tree roots in an agroforestry system grow, exploit soil resources, compete, and complement agricultural crops (Buck, 1986; Young, 1991; Solera, 1992). Conclusions and recommendations, which were drawn from a few studies on root system, such as those of Johnson et al. (1988), Torres (1983), Kang et al. (1981), Dhyani, Narain, and Singh (1990), Gillespie (1989), and Ong, Rao, and Mathuva (1992), appear to conflict with each other. Hence, a consensus to start focusing research on the below-ground environment of alley cropping is emerging among scientists, researchers, and extension workers. There is now a greater awareness of the role of roots in various agroforestry systems.

Is the focus on the below-ground environment of alley cropping and other agroforestry systems justified? Will further understanding of the rhizosphere help in designing and evaluating recommended cultural management practices for alley cropping? Will the focus give light on selecting hedgerow and crop ideotypes?

Dickmann and Pregitzer (1992), in their review of the structure and dynamics of woody plant root systems, argued that understanding the morphology, ecology, and physiology of the aerial parts of the tree should go hand in hand with comprehension and knowledge of the root system. This reasoning, when applied to research in alley cropping, is highly commendable because the technology targets resource-limited upland farmers in the tropics. Upland farmers could not afford to invest their time, labor, and money in establishing hedgerows only to realize in later times that this vegetative structure will not be sustainable. Only a better understanding of the root system may nullify or confirm farmers' general apprehension that trees in association with crops will compete strongly with crops for nutrients and moisture (Dhyani, Narain, and Singh, 1990).

Further understanding of hedgerow roots may direct future studies on the "root silviculture" (Dickmann and Pregitzer, 1992) of alley cropping systems. A root silviculture that will minimize carbon investment on the root system so that more could be allocated to pruning biomass accumulation may be desirable. A clearer comprehension of roots will help in modifying or innovating above-ground cultural management practices so that hedges will reduce their subsidy for root production and increase investments on shoot growth (Caldwell, 1987). An enriched knowledge on root systems could guide the screening and evaluation of potential hedgerow species that would meet the requirements of "hedgerow ideotypes" and pinpoint areas of complementarities and commensalism between hedgerows and crops (Gillespie, 1989; Dickmann, 1992; Young, 1991; van Noorwijk et al, 1988).

This study attempted to understand the behavior and growth pattern of the roots of *Gliricidia sepium*; it is a response to the urgent need to examine roots of hedgerows in an alley cropping system. The research hypothesis is that root distribution from the hedgerow base towards the alleys at various depths decreases regardless of treatments applied. It is postulated that root densities and root distribution could provide an explanation of how the hedgerows react to various treatment combinations of pruning height, within-row spacing, and number of hedges per contour line.

The study was based on the notion that the growth of hedgerow roots would affect the production of pruning biomass, crop yields, recycling of leached nutrients from the subsoil, and improvement of soil fertility. Intraspecific competition among hedgerow plants, as may be inferred from their pattern of root distribution, may constrain biomass production and indirectly favor or dampen the growth of alley crops. The research study proceeded with the understanding that roots are the major organs for nutrient absorption and movement of substances that are essential for plant growth.

Lastly, the study hopes to contribute to the scarce, but increasing efforts on hedgerow root system. It provided an experience in examining the below-ground environment. Traditional methods were used, despite the fact that by themselves, they are considered inadequate, destructive, labor-intensive, and exacting (Boehm, 1979; Schuurman and Goedewaagen, 1965). The study did not have the luxury of using new and sophisticated methods of observing roots such as the minirhizotrons which require *in-situ* installation (Hendrick, 1992; Upchurch and Ritchie, 1983). It adopted Smucker's (1984) suggestion that the direct method of extracting root and soil samples, although laborious, could still provide excellent information if the roots are quantitatively separated from the soil.

Thus, in the study, two methods were used in sampling roots. These are the sampling of roots by auger and the trench profile wall method. The latter was performed towards the end of the experiment and was employed to confirm and check the result of the root sampling by auger.

4.2. Materials and Methods

4.2.1. Root Sampling with the Use of Auger

4.2.1.1 Design of the Auger and Sampling Procedures

Figure 4.1 shows the design of the auger that was locally fabricated and used in sampling roots at 30-cm soil depth and at different distances from the hedgerows towards the alley. The design was adopted from the auger described by Schuurman and Goedewaagen (1965) and cited by Boehm (1979). The auger was made of stainless steel with inside diameter of 5.87 cm and length of 50 cm. Thus, at a sampling depth of 30 cm, the auger could bore soil with a total volume of 0.81 dm^3.

A week before sampling, the hedgerows and the alleys were weeded. The weeding was done to minimize the inclusion of roots of other species or weeds during the sampling. Sampling was performed at 0-, 25-, and 50-cm distances from the hedgerow base towards the alley. All borings in the lower and upper portions of the hedgerows were located in the mid-section of each sub-plot. For each sub-plot, a total of six borings were done, three from each of the lower and upper hedgerows. Five boreholes is more than the five borings which are recommended by many researchers (Boehm, 1979). For the double hedges per contour line, sampling started at base of the hedgerow facing the alley. A two-person team was organized, taught, and supervised to do root sampling with the auger. The first person held the auger, while the second person hammered the auger into the ground with a mallet made of a heavy piece of wood. The auger was first driven into the ground at 15 cm, pulled out, and the soil with the roots inside the core was taken out. In the same hole, the auger was again driven down to 30 cm, pulled out, and the soil with the roots inside the core was extracted. Pre-sampling was conducted to determine the ease of driving the corer into the ground, extracting the soil from the core, ascertaining and familiarizing personnel with the color of the *G. sepium* roots, and washing the soil to separate the roots. Pre-sampling gave a rough estimate and benchmark for distribution of roots at various soil depths, i.e. 0-15 cm and 16-30 cm. After the pre-sampling, it was found that there were not that many roots in the soils at the depth of 16-30 cm. Thus, soils from the cores driven in the same spot at different soil depths (0-15 cm and 16-30 cm) were combined, and placed in coded plastic bags for washing. The samples were put in a jute sack for transport into the washing area.

Two root samplings with auger were conducted. The first sampling was completed on January 10, 1992 after the second corn harvest and initial clipping of hedgerows. It was the end of the rainy season. Almost six months after, at the onset of the rainy season, on June 9, 1992, the second root sampling was started. This was after the harvest of the second mungbean crop and completion of the two subsequent prunings. The sequence of activities in both samplings were as follows: Root sampling within a selected main plot (12 sub-plots, 60 boreholes) during the first

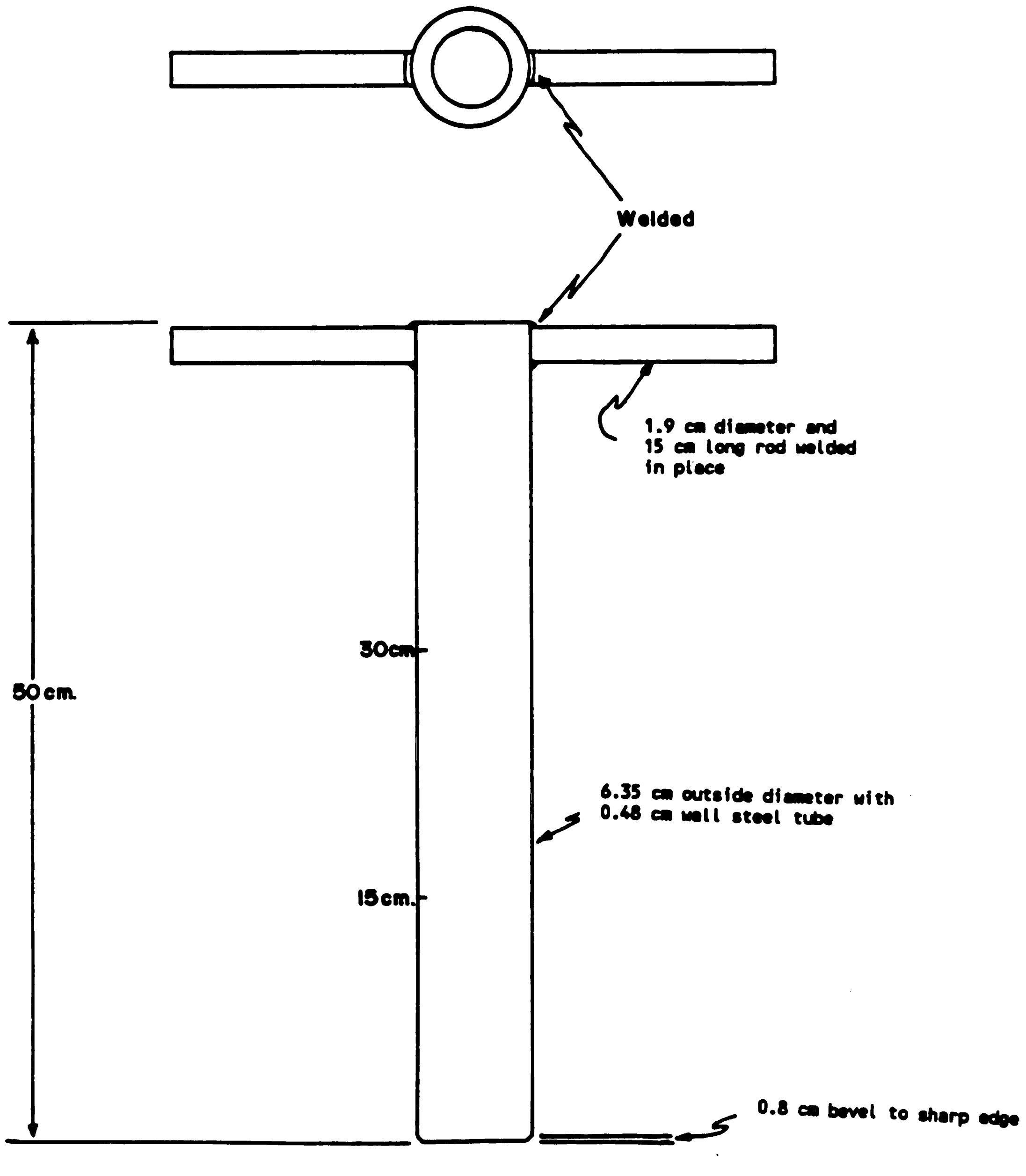

Figure 4.1. Design of the auger for sampling roots at different distances from the hedgerow base and to a soil depth of 30 cm.

day, followed by washing of roots in the second day, and weighing of roots in the third day. Thus, in each sampling period, the six main plots were completed in two weeks with an average of three main plots per week.

4.2.1.2 Processing the Root Samples

In the wash area, each sample was placed on top of a fine-meshed aluminum screen and washed slowly with water from a faucet to separate the roots from the soil. Live roots were picked with a hair puller during the washing period. Visually, the roots of *G. sepium* were easy to determine. The color of the fine roots is light to almost dirty white while the larger diameter roots were light brownish in color. Efforts were exerted to isolate dead roots and roots of other species.

After the roots were separated, they were allowed to drain dry of water, placed inside coded plastic bags, and weighed to the nearest mg at the University of the Philippines at Los Banos (UPLB) College of Engineering the following day. Three representative samples were randomly taken from each main plot (from each batch of root samples) for oven dry determination at 100 ^{0}C. The average moisture contents of the samples for each main plot (from each batch) were computed and used in determining the dry weights of root samples taken from the same main plot.

The root dry weights were computed and translated into mg/dm^3. The formula used for determining the volume of soil extracted by the auger (V) in dm^3 was the following:

$$V = (.25)\ (3.14)\ (\text{inside diameter of the auger in dm})^2\ (\text{depth of sampling in dm}).$$

With the auger's inside diameter of 0.587 dm and depth of sampling of 3 dm, the volume of soil taken by the corer was 0.81 dm^3. Root density (dry mg/dm^3) from sampling with auger was calculated by dividing the dry weight of roots per sample over the volume of the soil from the corer (0.81 dm^3).

4.2.2. Root Sampling with the Profile Wall Method

4.2.2.1 Design of the Trench Profile Sampling

Figure 4.2 shows the rectangular counting frame that was used in the trenching technique. The frame was made of a chicken wire with an original mesh size of 2.5 cm. The rectangular frame had a width (depth) of 60.9 cm) and a length of 96.5 cm, with two sizes of grids within it. The design is an adaptation from what is described by Schuurman and Goedewaagen (1965) and Bohm (1979). From the ground surface down to a depth of 30.5 cm, the square grids used had a dimension of 5.0 cm x 5.0 cm). Then, from 30.5 cm down to 60.9 cm depth, larger grids with dimension of 5.0 cm x 10 cm were used because there were fewer roots found inside the grids. Thus, from the ground surface down to a depth of 60.9 cm, roots were counted in a total of nine grids per column.

For the root profiling work, L-shaped trenches were dug. The relative locations of these trenches are listed in Table 4.1. Four trenches were dug on the lower portion of the alley and four on the upper portion. This precaution was taken to account for the possible influence of slope on the growth direction of roots because of a perceived soil fertility gradient from the upper and lower portions of the alleys. Along the contour hedgerows, each trench had an average length of 100 cm; but, the trench perpendicular to the contour hedgerows had a length of 50-60 cm. Both trenches formed an L-shape and had an average depth of 75-100 cm. A total of eight trenches were dug, four trenches per main plot, each representing a within-row spacing of 5-, 10-, 20-, and 40-cm.

Table 4.1. Relative locations of trenches in the alleys.

Treatment[1]	**Location of the trench in the alley**
Double hedgerow -WRS of 5 cm	Lower portion
Double hedgerow -WRS of 10 cm	Upper portion
Double hedgerow -WRS of 20 cm	Upper portion
Double hedgerow -WRS of 40 cm	Lower portion
Single hedgerow -WRS of 5 cm	Upper portion
Single hedgerow -WRS of 10 cm	Lower portion
Single hedgerow -WRS of 20 cm	Lower portion
Single hedgerow -WRS of 40 cm	Upper portion

[1] WRS = Within-row spacing

For the trench profiling at a fixed distance of 50 cm from the hedgerow base, roots were counted in a total of 19 columns (total length of 96.5 cm) or a total of 171 grids per trench. In this case, the wall of the trench which paralleled the hedgerow was used in counting and profiling the roots. For the root profiling from the hedgerow base up to 50-cm distance towards the alley, roots were counted in a total of 90 grids per trench. The wall of the trench perpendicular to the hedgerow was used in the counting of roots.

Figure 4.2. The rectangular counting frame that was used in counting roots within a profile. The frame had a depth of 60.9 cm and a length of 96.5 cm.

4.2.2.2 Preparing the Profile Wall

After the L-shaped trenches were dug with bar and shovel, each working face of a profile was roughly prepared with spade. Smoothing the profile wall was done with a bolo which had a round and sharpened tip. After smoothing, the roots were exposed by lightly spraying the wall with water and slowly scraping the profile with a fork before counting the roots. The same procedure was followed for all the trenches that were dug.

4.2.2.3 Counting the Roots

The rectangular frame was placed against the profile in counting the roots per grid. Five root diameter classes were used: < 1 mm, 1-2 mm, 2-5 mm, 5-10 mm, and > 10 mm. To obtain visual familiarity of the various diameter classes, especially during the initial root counts, bamboo sticks were prepared and calibrated for each class. Only the roots protruding within a grid were counted to minimize double counting of hanging roots. For each root diameter class, the root counts per grid were all converted into number of roots per dm^2. This was the root density figures that were used in the statistical analysis.

4.2.3 Soil Sampling

Both the procedures of PCARRD (1985) and Shickluna (1983) were used as guides in taking composite soil samples from the experimental site. Three composite soil samples were collected from the whole area, one from each replicate, e.g. one from top, middle, and bottom sections of the experimental site. Each sample was a composite of soils from 10 holes in the alleys. A spade was used in digging 30-cm deep holes in the ground. From each hole, approximately 4-cm slice of soil from one side was taken and placed inside a plastic pail. The holes were approximately eight m distance from each other and sampling followed a zigzag pattern (lower and upper portions of the alley).

Each composite soil sample was thoroughly mixed and pulverized by hand before air drying. After air drying, four one-kg sub-samples were obtained from each composite sample for analysis and determination of pH, percent organic matter (OM), percent total N, P in ppm, and K in me/100g soil. The sub-samples were placed in a properly labelled plastic bags and sent to the UPLB Soils Laboratory, which uses a modified Kjeldahl method for N, molybdovanadate method for P, and flame photometer method for K.

Soil compositing was done four times during the duration of the experiment. The first sampling was conducted before planting the hedges and just after the site preparation (early September 1990). This sampling established more or less the baseline soil condition of the site before the start of the research. The second was performed in early January 1991, after the harvest of the first corn crop and before the planting of the first mungbean crop. The third sampling was done in early September 1991, immediately after the initial clipping of hedgerows and before planting the second corn crop. The last sampling was accomplished in early January 1992, after the harvest of second corn crop and before the planting of the second mungbean crop. Over the four sampling periods, similar procedures were adopted in taking individual soil samples from each of 10 holes and compositing the soils for further sub-sampling and soil analysis.

4.2.4 Statistical Analysis

All the data from the root sampling with the auger and trench profiling were entered into the Lotus 1-2-3 spreadsheet, converted into ASCII files, and analyzed using MSTATC and/or SYSTAT software. Data from the sampling of roots with the auger were subjected to analysis of variance (ANOVA).

To determine the relationship between root density (mg/dm^3) and distances from the hedgerow base, the means of root density at different distances from the hedgerow were subjected to simple regression and correlation analysis. Regression and correlation were also used for the root counts/dm^2 at different distances from the hedgerow base towards the alley and at various soil depths for the data that were gathered in the trench profiling technique. The results of the soil sampling were tabulated and analyzed to determine the pattern and changes of each element over time.

4.3. Results

4.3.1 Root Densities from Sampling with the Auger

In both the first and second root samplings with the auger, none of the treatments was significant with F-test ($p < 0.05$) (Tables 4.2 and 4.3). Average root densities from lower and upper hedgerow sampling positions and from all distances from the hedgerow base were not significantly affected by the number of hedges per contour line, combinations of within-row spacing and pruning heights, and interactions. The treatments did not affect root densities and their distribution from the hedgerow base up to 50 cm towards the alleys at a sampling depth of 30 cm.

The means of root densities exhibited a decreasing trend from the base of the hedgerow towards the 50-cm distance for the lower and upper sampling positions (Table 4.4). The grand means of the second sampling were slightly lower compared with those from the first root sampling; however, the trend is more or less similar (Table 4.5).

Table 4.2. Analysis of variance for the average dry root densities (mg/dm^3) from the lower and upper sampling positions from the first sampling with the auger.

Sampling Position and Distance from the Hedgerow Base	**Source of Variation**[1]	**F-Value**[2]
1. Averaged at 0-cm distance from the base	No of hedges/line	0.002
	PH x WRS	0.761
	Interaction	0.634
2. Averaged at 25-cm distance from the base	No of hedges/line	0.400
	PH x WRS	0.908
	Interaction	0.644
3. Averaged at 50-cm distance from the base	No of hedges/line	1.297
	PH x WRS	0.557
	Interaction	1.090

[1] PH = Pruning height; WRS = Within-row spacing

[2] None of the treatments was significant at 10 percent probability.

Table 4.3. Analysis of variance for the average dry root densities (mg/dm^3) from the lower and upper sampling positions from the second root sampling with the auger.

Sampling Position and Distance from the Hedgerow Base	**Source of Variation**[1]	**F-Value**[2]
1. Averaged at 0-cm distance from the base	No. of hedges/line	0.187
	PH x WRS	0.517
	Interaction	0.758
2. Averaged at 25-cm distance from the base	No. of hedges/line	0.045
	PH x WRS	0.912
	Interaction	1.225
3. Averaged at 50-cm distance from the base	No. of hedges/line	0.234
	PH x WRS	0.651
	Interaction	1.039

[1] PH = Pruning height; WRS = Within-row spacing

[2] None of the treatments was significant at 10 percent probability.

Table 4.4. Grand means (mg/dm^3) and coefficient of variations of dry root densities from the first sampling with the auger.

Sampling Position and Distance from the Hedgerow Base	**Grand Means**	**Coefficient of Variation in %**
1. Lower hedgerow at a 0-cm distance from the base	0.71	182.5
2. Lower hedgerow at a 25-cm distance from the base	0.52	255.8
3. Lower hedgerow at a 50-cm distance from the base	0.46	296.9
4. Upper hedgerow at a 0-cm distance from the base	0.63	231.7
5. Upper hedgerow at a 25-cm distance from the base	0.58	281.6
6. Upper hedgerow at a 50-cm distance from the base	0.28	308.5

Table 4.5. Grand means (mg/dm^3) and coefficient of variations of dry root densities from the second sampling with the auger.

Sampling Position and Distance from the Hedgerow Base	Grand Means	Coefficient of Variation in %
1. Lower hedgerow at a 0-cm distance from the base	0.58	223.4
2. Lower hedgerow at a 25-cm distance from the base	0.41	395.8
3. Lower hedgerow at a 50-cm distance from the base	0.15	420.6
4. Upper hedgerow at a 0-cm distance from the base	0.35	250.4
5. Upper hedgerow at a 25-cm distance from the base	0.53	339.3
6. Upper hedgerow at a 50-cm distance from the base	0.17	465.2

Figure 4.3. shows the relationship between the grand means of root densities (across treatments, replications, and sampling positions) and distances from the hedgerow base towards the alley. The grand means of root densities from the first and second root samplings were used in running the regression and correlation analysis. The result of the t-test ($p < 0.01$), indicates that root density decreases from the hedgerow base up to 50 cm towards the alley within the 30-cm soil depth ($r = - 0.73$).

Regression and correlation analysis was also used in determining the possible relationship between root density and within-row spacing. However, the r values for the first and second samplings were - 0.02 and - 0.13, respectively. Clearly, root densities did not show linear relationship with within-row spacings of hedgerows.

The CVs for all the sampling positions and distances from the hedgerow base were extremely high (Tables 4.4 and 4.5). The average CV for the first root sampling with auger was 259.5 percent, slightly lower than the CV from the second sampling, which was 349.1 percent.

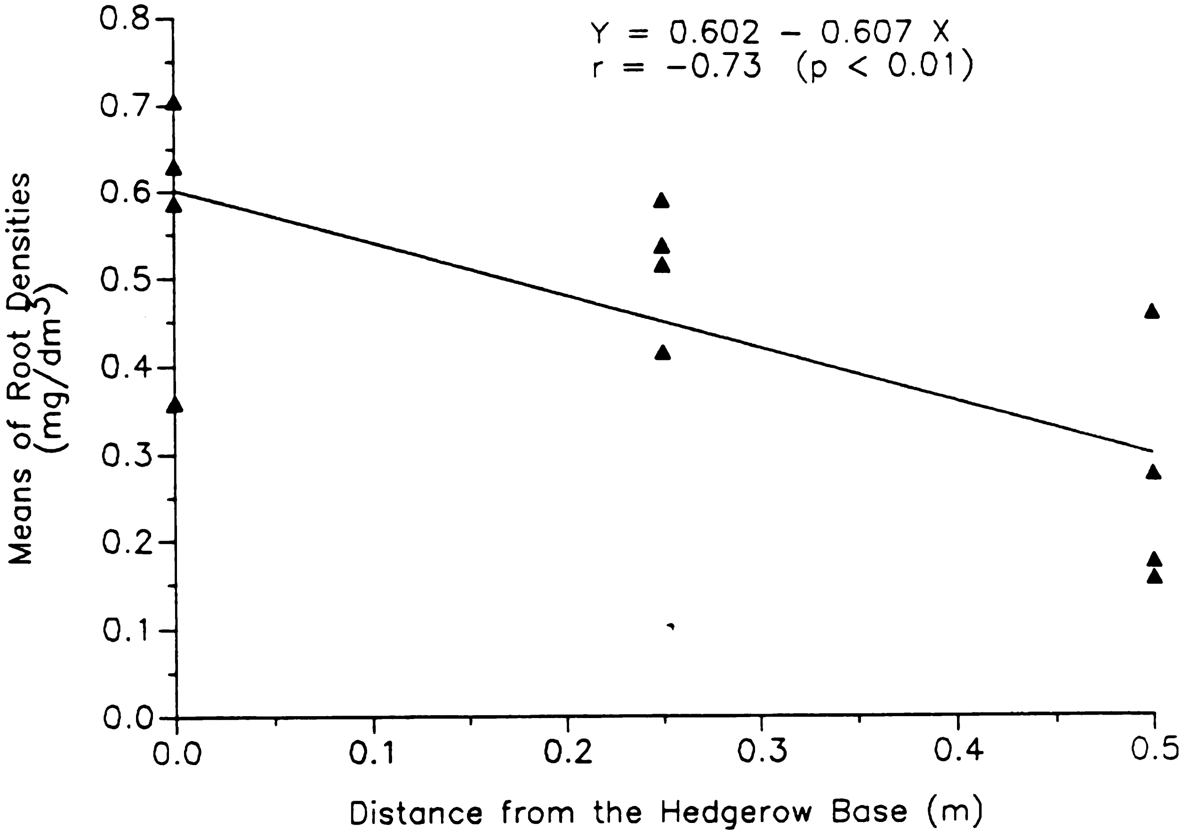

Figure 4.3. Relationship between the means of root densities (across treatments, replications, two sampling periods, and sampling positions) and distances from the hedgerow base towards the alley at 0-30 cm soil depth. The *Gliricidia sepium* hedgerows were between 16-month to 22-month-old when the samplings with auger were conducted.

4.3.2 Root Densities From the Trench Profile Method

4.3.2.1 Root Densities at a Fixed Distance of 50-cm from the Hedgerow Base

At all soil depths at a fixed distance of 50 cm from the hedgerow base, the dominant root diameter class was < 1.0 mm, with an average of 89.9 percent (Table 4.6). The total aggregate percentage of the other root diameter classes was only 10.1 percent, with 1-2 mm class capturing 7.1 percent of the total number. Roots 2-5 mm diameter tended to occur at depths lower than 25 cm. Only a few roots fell under the 5 to 10 mm and > 10.0 mm diameter classes. Overall, at the depths of 15 cm and 30 cm, where most crops grow their roots, the corresponding cumulative percentages of hedgerow roots from all diameter were 48 percent and 83 percent, respectively (Figure 4.4). The rest of the roots occurred between the soil depth of 30-60 cm.

Table 4.6. Percent distribution of root diameter classes at different soil depths and at a fixed distance of 50 cm from the hedgerow base.

Soil Depth in cm	**Percent of Root Diameter Classes**					**% of Roots based on total count**
	< 1 mm	**1-2 mm**	**2-5 mm**	**5-10 mm**	**> 10 mm**	
5	90.6	8.3	0.9	0.2	0.0	16.2
10	89.8	8.3	1.9	0.0	0.0	15.2
15	92.8	5.0	1.9	0.3	0.0	16.7
20	90.4	6.2	2.7	0.5	0.2	14.6
25	86.7	7.9	4.2	0.9	0.3	11.9
30	88.8	7.1	3.7	0.0	0.4	8.7
40	91.6	5.7	2.4	0.3	0.0	6.7
50	89.2	6.8	3.7	0.3	0.0	5.4
60	89.3	8.2	1.2	0.9	0.4	4.6
Average	89.9	7.1	2.5	0.4	0.1	100.0

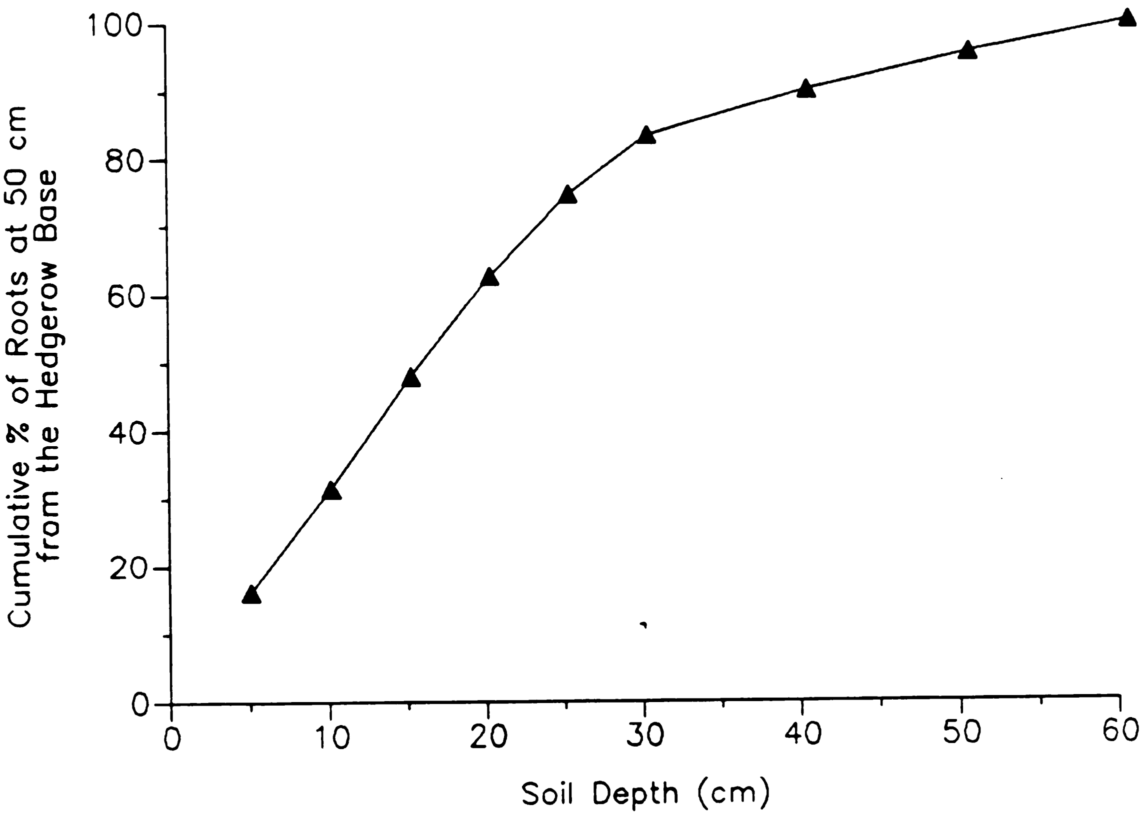

Figure 4.4. Cumulative percent of all roots at various soil depths.

In the regression and correlation analyses between density of roots belonging to the < 1.0-mm diameter class (number of roots/dm^2) and soil depths (Table 4.7), both the trenches from the single and double hedgerows yielded significant t-test results for the 5- and 10-cm within-row spacing $p < 0.05$ and $p < 0.01$, respectively. In the single hedgerows, the coefficient of correlations (r values) were -0.73 and -0.76 for the 5-cm and 10-cm within-row spacings, respectively. In the double hedgerow, the r values were much higher (-0.96 and -0.82 for the 5-cm and 10-cm within-row spacing, respectively). The t-tests for the average number of roots with < 1.0-mm diameter/dm^2 in the single and double hedgerows gave significant results ($p < 0.01$). The significant results of the t-tests

Table 4.7. Results of regression and correlation analyses[1] between the density of roots with < 1.0-mm diameter and soil depths at a fixed distance of 50-cm from the hedgerow base.

Dependent Variable	**Mean**	**r**	**t-test value[2]**
Double hedgerow-WRS of 5 cm	14.45	-0.96	8.70***
Double hedgerow- WRS of 10 cm	10.67	-0.82	3.83***
Double hedgerow- WRS of 20 cm	3.54	-0.44	1.28
Double hedgerow- WRS of 40 cm	0.77	0.22	0.59
Double hedgerow-Average across WRS	5.67	-0.94	7.58***
Single hedgerow- WRS of 5 cm	6.12	-0.73	2.83**
Single hedgerow- WRS of 10 cm	10.18	-0.76	3.08**
Single hedgerow- WRS of 20 cm	10.21	-0.65	2.28
Single hedgerow- WRS of 40 cm	7.33	-0.64	2.22
Single hedgerow-Average across WRS	8.46	-0.85	4.25***

[1] WRS = Within-row spacing; r = Coefficient of correlation

[2] *** Significant at one percent probability;
** Significant at five percent probability

for the dependent variables suggest that at a fixed distance of 50-cm from the hedgerow base, soil depths may be a relevant and accurate predictor of density of roots belonging to the < 1.0-mm diameter class.

The regression and correlation analysis between density of roots belonging to 1-2-mm diameter class and soil depths (Table 4.8) yielded significant results for the double hedgerow and within-row spacings of 5 cm ($p < 0.01$) and 10 cm ($p < 0.05$) with r values of -0.82 and -0.62, respectively. In the single hedgerow, only the trench with within-row spacing of 20 cm yielded a significant t-test ($p < 0.01$), with a $r = -0.83$.

The results of the regression and correlation analyses between root density of roots from all diameter classes/dm^2 and soil depths (Table 4.9) yielded significant t-tests on the double hedgerow with 5-cm and 10-cm within-row spacings ($p < 0.01$) and on the single hedgerow with 5-cm, 10-cm, and 20-cm within-row spacings ($p < 0.05$). In the double hedgerow, the r values were -0.96 and -0.82 for the 5-cm and 10-cm within-row spacing, respectively. The r values of the 5-cm, 10-cm, and 20-cm within-row spacings in the single hedgerow were -0.77, -0.67, and -0.69, respectively. The t-tests on the average of total roots in the double and single hedgerows yielded significant results ($p < 0.01$).

The linear relationship between root density and soil depth at a distance of 50 cm from the hedgerow base was strongest in the 5- and 10-cm within-row spacings, especially for roots belonging to < 1.0 diameter class. Root density declined with increasing soil depth. Means of root densities were higher in more dense within-row spacing than in wider within-row spacing (20- and 40-cm) as shown in Figures 4.5 and 4.6. Comparing Tables 4.6, 4.7 and 4.9, it can be deduced that there were fewer roots belonging to larger diameter classes in the 5- and 10-cm within-row spacing than in the 20- and 40-cm spacings.

Table 4.8. Results of regression and correlation analyses[1] between density of roots with 1-2 mm diameter and soil depths at a fixed distance of 50 cm from the hedgerow base.

Dependent Variable	**Mean**	**r**	**t-test value**[2]
Double hedgerow-WRS of 5 cm	0.57	-0.82	3.76***
Double hedgerow- WRS of 10 cm	1.19	-0.62	2.07**
Double hedgerow- WRS of 20 cm	0.17	-0.32	0.88
Double hedgerow- WRS of 40 cm	0.15	0.08	0.21
Double hedgerow-Average across WRS	0.52	-0.77	3.14**
Single hedgerow- WRS of 5 cm	0.05	-0.17	0.45
Single hedgerow- WRS of 10 cm	0.61	-0.29	0.79
Single hedgerow- WRS of 20 cm	0.89	-0.83	3.86***
Single hedgerow- WRS of 40 cm	0.77	-0.42	1.24
Single hedgerow-Average across WRS	0.58	-0.61	2.05

[1] WRS = Within-row spacing; r = Coefficient of correlation

[2] *** Significant at one percent probability;
** Significant at five percent probability

Table 4.9. Results of regression and correlation analyses[1] between the total number of roots in all diameter classes and soil depths at a fixed distance of 50 cm from the hedgerow base.

Dependent Variable	**Mean**	**r**	**t-test value**[2]
Double hedgerow-WRS of 5 cm	8.46	-0.96	9.33***
Double hedgerow- WRS of 10 cm	12.28	-0.82	3.72***
Double hedgerow- WRS of 20 cm	3.82	-0.43	1.24
Double hedgerow- WRS of 40 cm	1.24	0.07	0.19
Double hedgerow-Average across WRS	6.45	-0.94	7.41***
Single hedgerow- WRS of 5 cm	6.36	-0.77	3.23**
Single hedgerow- WRS of 10 cm	11.16	-0.67	2.35**
Single hedgerow- WRS of 20 cm	11.22	-0.69	2.48**
Single hedgerow- WRS of 40 cm	8.158	-0.63	2.13
Single hedgerow-Average across WRS	9.23	-0.85	4.18***

[1] WRS= Within-row spacing; r = Coefficient of correlation

[2] *** Significant at one percent probability;
** Significant at five percent probability

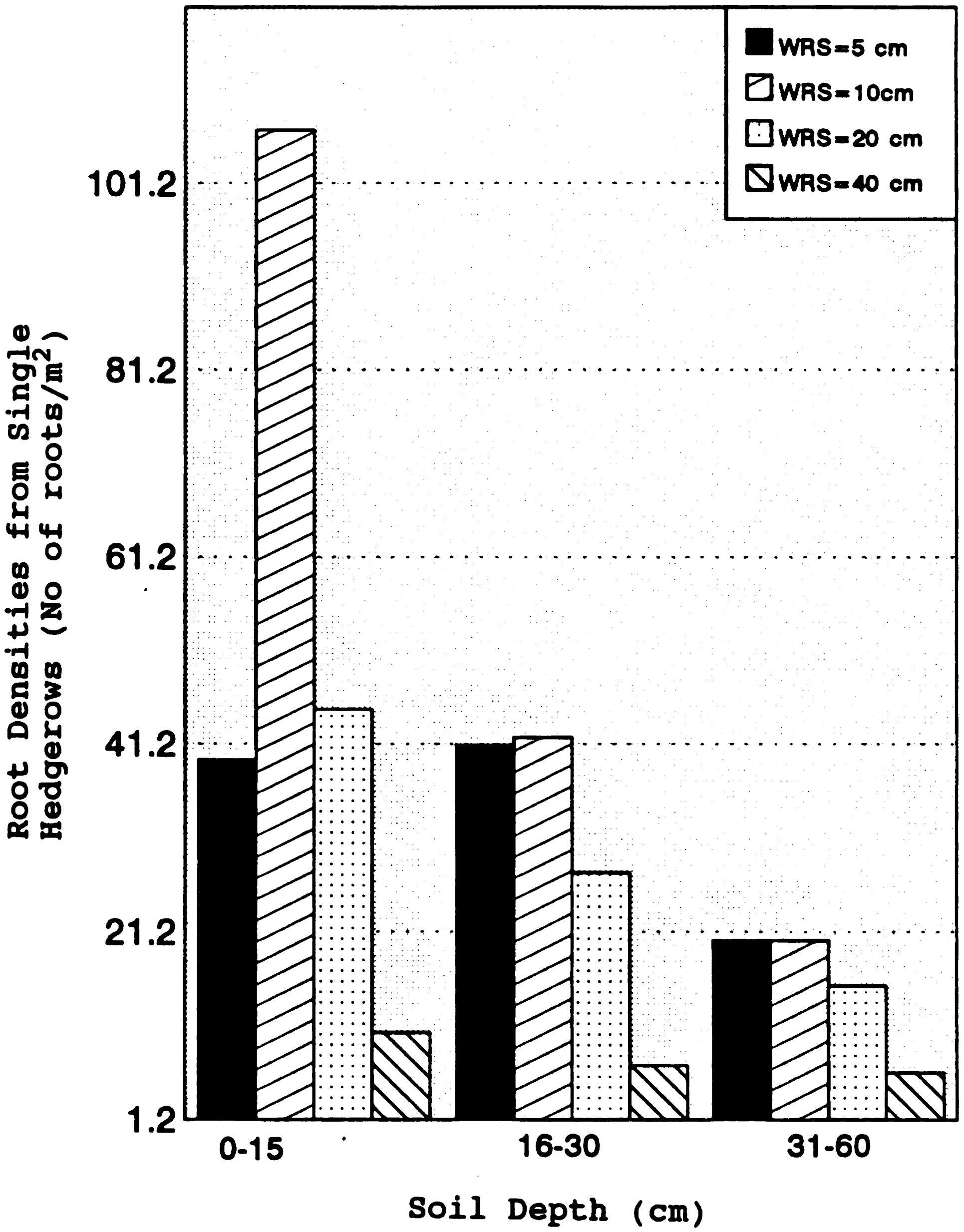

Figure 4.5. Means of root densities in single hedgerows at different within-row spacing.

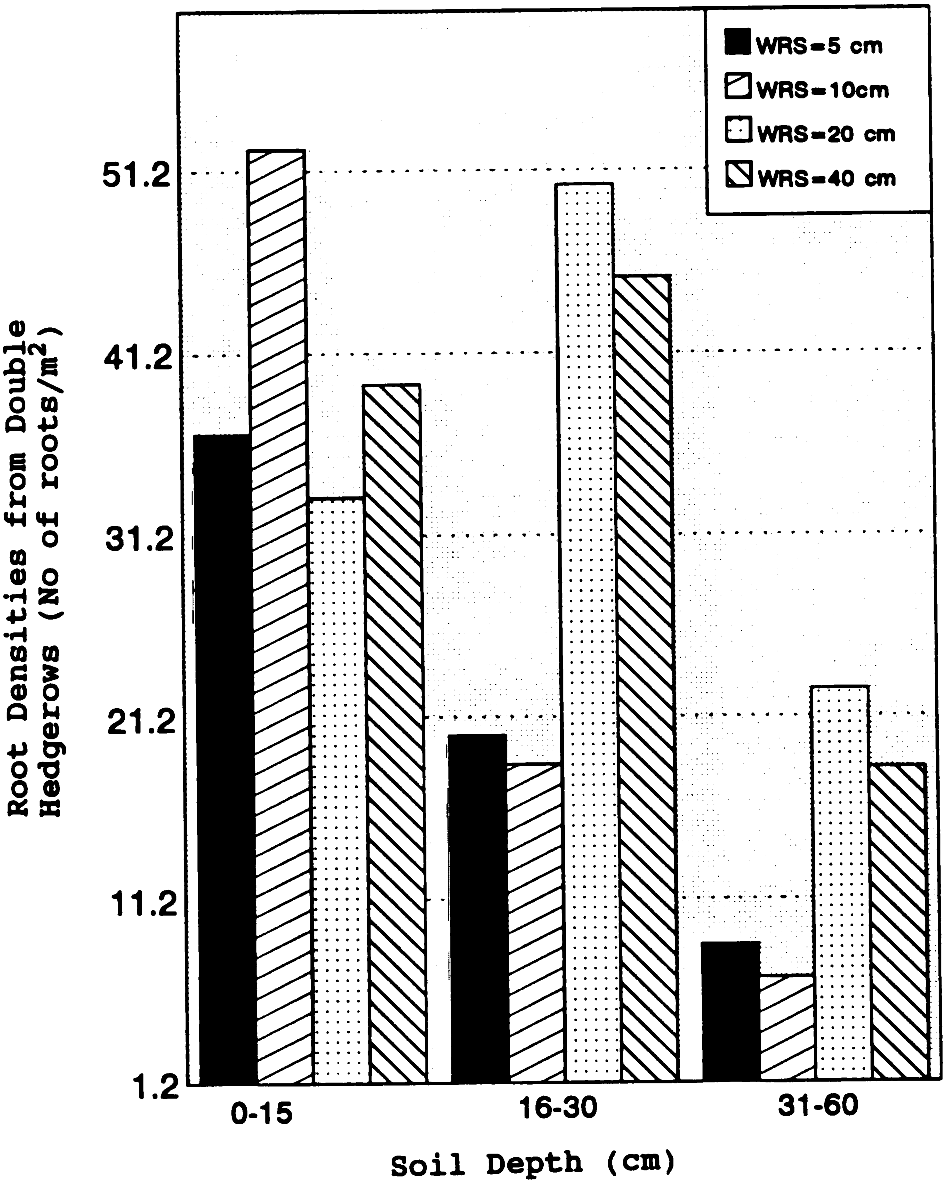

Figure 4.6. Means of root densities in double hedgerows at different within-row spacing.

4.3.2.2 Root Densities from the Hedgerow Base Towards the Alley

More than 40 percent of all root counts were found within the depth of 0-15 cm (Table 4.10). At least seventy percent of roots counted were located within the depth range of 0- 30 cm starting from the hedgerow base up to 50 cm towards the alley. Regression and correlation analyses between the percent distribution of all roots for all the three soil depths with the distance from the hedgerow base up to 50 cm towards the alley did not give significant t-tests ($p < 0.05$). The r values were 0.13, -0.61, and 0.38 for the percent distribution of roots at soil depths of 0-15, 16-30, and 31-60 cm, respectively. Based on the r values and the t-tests, there is sufficient evidence to conclude that the percent distribution of all roots from the hedgerow base up to 50 cm towards the alley was not directly related in all the three soil depths because the percent distribution of roots at all depths towards the alley appeared to be uniform (Table 4.10).

Roots belonging to the < 1.0-mm diameter class dominated in the 0-15, 16-30, and 31-60 cm soil depths (Table 4.11). These fine roots comprised 88 percent of the total roots while, the rest belonged to the other diameter classes. A closer analysis of the roots belonging to < 1.0-mm diameter class revealed that the relationship between root density and the distance from the hedgerow base towards the alley was more consistent in the double hedgerows than in the single hedgerows (Tables 4.12 and 4.13). In the double hedgerow, there were strong relationships between root density and distance from the hedgerow base for the within-row spacings of 5 cm ($r = -0.71$; $p < 0.05$) and 40 cm ($r = -0.67$; $p < 0.05$) at soil depth of 0-15 cm. In fact, for the within-row spacing of 5 cm, root densities at depths of 16-30 cm and 31-60 cm were highly correlated with the distance from the hedgerow base towards the alley (r values of -0.90 and -0.83,

Table 4.10. Percent distribution of roots from all diameter classes at different soil depths and from the hedgerow base up to 50-cm towards the alley.

Distance from the hedgerow base towards the alley in cm	Percent distribution at soil depth of 0-15 cm	Percent distribution at soil depth of 16-30 cm	Percent distribution at soil depth of 31-60 cm
0-5	47	31	22
6-10	45	31	24
11-15	42	33	25
16-20	39	34	27
21-25	39	26	36
26-30	33	33	34
31-35	43	23	34
36-40	46	25	29
41-45	46	30	24
46-50	47	24	29
Average	43	29	28

Table 4.11. Percent distribution of root diameter classes at three soil depths from eight trench profiles.

Root diameter class	**Percent distribution at soil depth of 0-15 cm**	**Percent distribution at soil depth of 16-30 cm**	**Percent distribution at soil depth of 31-60 cm**	**Average percent distribution based on total root counts at all depths**
< 1.0 mm	89	89	87	88.2
1-2 mm	5	7	8	6.6
2-5 mm	4	3	4	3.6
5-10 mm	1	0	1	0.6
> 10 mm	1	1	1	1.0

respectively, and $p < 0.01$). Except for the within-row spacing of 40 cm and soil depth of 31-60 cm, root densities in the other within-row spacings at different soil depths did not yield significant t-test results. In the single hedgerow (Table 4.13), the t-test for the coefficient of correlation between root densities at different within-row spacings and distance from the hedgerow base towards the alley appeared to be unpredictable. There were no significant t-test results from the within-row spacings of 5 cm and 10 cm at depths of 0-15 and 16-30 cm. High correlations were only obtained from the within-row spacings of 20 cm and 40 cm at soil depths of 0-15 and 16-30 cm (r values of -0.76, -0.89, -0.88, and -0.77, respectively at $p < 0.01$). Surprisingly, even at the within-row spacing of 40 cm and soil depth of 31-60, root density was found to be correlated with distance from the hedgerow base ($r = -0.64$ and $p < 0.05$).

Table 4.12. Results of regression and correlation analyses[1] between density of roots < 1.0-mm diameter and distance from the hedgerow base towards the alley in a double hedgerow and at three soil depths.

Dependent Variable	**Mean**	**r**	**t-test value[2]**
WRS of 5 cm - Soil depth of 0-15 cm	12.7	-0.71	2.83**
WRS of 5 cm - Soil depth of 16-30 cm	13.7	-0.90	5.73***
WRS of 5 cm - Soil depth of 31-60 cm	6.3	-0.83	4.23***
WRS of 10 cm - Soil depth of 0-15 cm	30.7	0.44	1.39
WRS of 10 cm - Soil depth of 16-30 cm	12.2	0.11	0.31
WRS of 10 cm - Soil depth of 31-60 cm	8.7	-0.38	1.15
WRS of 20 cm - Soil depth of 0-15 cm	14.2	-0.59	2.06
WRS of 20 cm - Soil depth of 16-30 cm	8.5	-0.67	2.58**
WRS of 20 cm - Soil depth of 31-60 cm	4.5	-0.27	0.79
WRS of 40 cm - Soil depth of 0-15 cm	2.9	-0.66	2.51**
WRS of 40 cm - Soil depth of 16-30 cm	1.7	-0.79	0.23
WRS of 40 cm- Soil depth of 31-60 cm	1.7	-0.72	2.96**

[1] WRS = Within-row spacing; r = Coefficient of correlation

[2] *** Significant at one percent probability;
** Significant at five percent probability

Table 4.13. Results of regression and correlation analyses[1] between density of roots < 1.0-mm diameter and distance from the hedgerow base towards the alley in a single hedgerow and at three soil depths.

Dependent Variable	**Mean**	**r**	**t-test value[2]**
WRS of 5 cm - Soil depth of 0-15 cm	11.1	-0.09	0.26
WRS of 5 cm - Soil depth of 16-30 cm	4.5	-0.29	0.84
WRS of 5 cm - Soil depth of 31-60 cm	2.5	-0.53	1.78
WRS of 10 cm - Soil depth of 0-15 cm	14.5	-0.32	0.955
WRS of 10 cm - Soil depth of 16-30 cm	5.7	0.11	0.31
WRS of 10 cm - Soil depth of 31-60 cm	1.9	0.71	2.83**
WRS of 20 cm - Soil depth of 0-15 cm	9.8	-0.76	3.33***
WRS of 20 cm - Soil depth of 16-30 cm	15.1	-0.89	5.54***
WRS of 20 cm - Soil depth of 31-60 cm	6.7	0.45	1.41
WRS of 40 cm - Soil depth of 0-15 cm	11.5	-0.88	5.25***
WRS of 40 cm - Soil depth of 16-30 cm	13.4	-0.77	3.39***
WRS of 40 cm- Soil depth of 31-60 cm	10.1	-0.64	2.38**

[1] WRS = Within-row spacing; r = Coefficient of correlation

[2] *** Significant at one percent probability;
** Significant at five percent probability

Since 88 percent of the total roots counted in the eight trenches belonged to < 1.0-mm diameter class, results of the simple regression and correlation analyses of the root densities of all diameter classes in both the single and double hedgerow (Tables 4.14 and 4.15) did not vary with those obtained in regressing densities of roots belonging to the < 1.0-mm diameter class. From the results, however, it can be summarized that root densities of all diameter classes were negatively correlated with the distance from the hedgerow base towards the alley in single hedgerows having within-row spacings of 20 cm and 40 cm. This was found to the soil depth of 30 cm. In the double hedgerows, negative correlational relationships existed between root densities and distance from the hedgerow base at within-row spacings of 5-, 20-, and 40-cm and a soil depth of 0-15 cm. Deeper in the soil, however, only a root density in the within-row spacing of 5 cm linearly declined from the hedgerow base towards the alley.

Distance from the hedgerow base towards the alley appeared to be a reliable predictor of density of roots belonging to < 1.0-mm diameter class to a depth of 30 cm. The linearly declining root density with respect to soil depth, however, is strongest in the double hedgerows than in the single hedgerows of *G. sepium*.

Table 4.14. Results of regression and correlation analyses[1] between density of roots in all diameter classes and distance from the hedgerow base towards the alley in a double hedgerow and at three soil depths.

Dependent Variable	**Mean**	**r**	**t-test value[2]**
WRS of 5 cm - Soil depth of 0-15 cm	39.5	-0.66	2.48**
WRS of 5 cm - Soil depth of 16-30 cm	41.1	-0.90	5.731***
WRS of 5 cm - Soil depth of 31-60 cm	20.3	-0.83	4.23***
WRS of 10 cm - Soil depth of 0-15 cm	106.9	0.52	1.74
WRS of 10 cm - Soil depth of 16-30 cm	41.9	0.08	0.22
WRS of 10 cm - Soil depth of 31-60 cm	20.3	-0.50	1.64
WRS of 20 cm - Soil depth of 0-15 cm	44.9	-0.59	2.04**
WRS of 20 cm - Soil depth of 16-30 cm	27.5	-0.65	2.42**
WRS of 20 cm - Soil depth of 31-60 cm	15.5	-0.29	0.86
WRS of 40 cm - Soil depth of 0-15 cm	10.5	-0.70	2.75**
WRS of 40 cm - Soil depth of 16-30 cm	6.9	-0.29	0.86
WRS of 40 cm- Soil depth of 31-60 cm	6.2	-0.73	3.05**

[1] WRS = Within-row spacing; r = Coefficient of correlation

[2] *** Significant at one percent probability;
** Significant at five percent probability

Table 4.15. Results of regression and correlation analyses[1] between density of roots in all diameter classes and distance from the hedgerow base towards the alley in a single hedgerow and at three soil depths.

Dependent Variable	**Mean**	**r**	**t-test value[2]**
WRS of 5 cm - Soil depth of 0-15 cm	36.8	-0.19	0.54
WRS of 5 cm - Soil depth of 16-30 cm	20.2	-0.35	1.04
WRS of 5 cm - Soil depth of 31-60 cm	8.7	-0.32	0.96
WRS of 10 cm - Soil depth of 0-15 cm	52.3	-0.42	1.32
WRS of 10 cm - Soil depth of 16-30 cm	18.6	0.16	0.45
WRS of 10 cm - Soil depth of 31-60 cm	6.9	0.62	2.22*
WRS of 20 cm - Soil depth of 0-15 cm	33.3	-0.83	4.14***
WRS of 20 cm - Soil depth of 16-30 cm	50.4	-0.89	5.68***
WRS of 20 cm - Soil depth of 31-60 cm	22.7	0.50	1.65
WRS of 40 cm - Soil depth of 0-15 cm	39.5	-0.91	6.32***
WRS of 40 cm - Soil depth of 16-30 cm	45.3	-0.63	2.31**
WRS of 40 cm- Soil depth of 31-60 cm	18.4	-0.60	2.10

[1] WRS = Within-row spacing; r = Coefficient of correlation

[2] *** Significant at one percent probability;
** Significant at five percent probability

4.3.3 Soil Sampling Over Time

Although the results of soil analysis were not statistically analyzed, the average values over four sampling periods from September 1990 to January 1992 (Table 4.16) showed that pH declined after the first corn harvest which was captured during the second soil sampling period. However, after the harvest of the first mungo crop, four months of fallow with benefits from hedgerow litterfall, initial clipping, and subsequent prunings increased pH up to 6.2. OM steadily decreased at an average of 11-12 percent in the second and third soil sampling (from 3.6 to 2.8 percent). OM appeared to stabilize during the fourth sampling. Both P and K slightly decreased after the first corn crop, but these elements gradually increased after the four months fallow, initial clipping, and subsequent prunings. As expected, N declined from the first to the third sampling periods. It only picked up in the fourth sampling after the incorporation of the initial clippings and subsequent prunings into the soil.

Table 4.16. Average results of soil analysis[1] over four sampling periods from September 1990 to January 1992.

Sampling Date	**pH**	**OM in %**	**P in ppm**	**K in me/100g**	**N in %**
Early September, 1990- before first corn crop, after site preparation	5.89	3.56	3.79	2.73	0.17
Early January, 1991 - after first corn harvest, before first mungo crop	5.66	3.13	3.69	2.59	0.16
Early September, 1991- after first mungo harvest, four months fallow, and after initial clipping of hedgerow	6.61	2.78	4.17	2.76	0.15
Early January, 1992- after second corn harvest and before second mungo crop	6.24	2.79	5.03	2.95	0.24

[1] Values are means of three composite soil samples taken from the bottom, middle, and top portions of the experimental site.

4.4 Discussion

The results of the study highlight basic concerns in sampling hedgerow roots, pruning biomass and nutrient management, intra- and inter-species competition, and establishment and treatment of hedgerows to enhance their delivery of benefits to the alley crops.

In theory, higher root densities (mg/dm^3 or number of roots/dm^2) could be obtained from more dense within-row spacings and higher number of hedges per contour line because the degree of overlap and competition of roots among neighboring plants is more intense (Caldwell and Richards, 1983; Caldwell, 1987; Atkinson, 1976). Dense hedgerows would tend to deplete limited soil resources faster and produce more branched roots resulting in higher root densities (Fitter, 1987). The results of the trench profile method for sampling hedgerow roots confirm the above theory. The highest root densities (number of roots/dm^2) were obtained from the 5 and 10 cm within-row spacings in both the single and double hedgerows at a fixed distance of 50 cm from the hedgerow base. From the hedgerow base up to 50 cm towards the alley, the highest root densities also came from the 5 and 10 cm within-row spacings. At these within-row spacings, root densities were also negatively correlated with soil depth at a fixed distance of 50 cm from the hedgerow. Only the root densities in the double hedgerow 5 cm within-row spacing were highly correlated with distance from the hedgerow base towards the alley at all depths.

On the other hand, root densities (mg/dm^3) from the first and second samplings with an auger at various distances from the hedgerow towards the alley at a soil depth of 30 cm were not significantly affected by within-row spacing and the number of hedges per contour line. They appeared to be inconsistent with the theory and findings from the trench profile sampling of hedgerow roots. However, the grand means of root densities across treatments and sampling positions (lower and upper hedgerows) linearly declined with the distance from the hedgerow base at a depth of 30 cm ($r = -0.73$; $p < 0.05$).

The non-significant effect of number of hedges per contour line and within-row spacing on root densities (mg/dm^3) might be attributed to the inability of augers to capture root growth plasticity and heterogeneity. Roots are known to change their growth orientation and turn downwards or sidewise when they detect intense competition for soil resources. This behavior may be triggered by a hormonal mechanism which controls the geotrophic curvature of roots (Russel, 1977; Taylor, Blake, and Pharis, 1982; van Noordwijk et al., 1988). Some roots may also invest more in developing deeper roots or forming clumped roots while others may grow shallower in the soil (Berendse, 1979; Passioura, 1988). This growth tendency of roots would render sampling with auger a bit problematic. Timing of sampling becomes crucial and is further complicated by an already heterogenous soil environment.

The plasticity of root growth, soil heterogeneity, and dominance of fine roots in the top soil, as found in the trench profiles, might have contributed to the high CVs of root densities from the auger sampling method. The root's compensatory growth away from compacted (Smucker, 1990) or highly competitive areas and movement towards the areas of least resistance, more fertile soils or moist spots, or areas relatively free from competition (Lyr and Hoffman, 1967), could produce high variability of roots extracted from borehole to borehole with auger. The high CVs also might have been caused by the frictional resistance of the corer's inner wall, which may partly force soil with roots away during the sampling (Schuurman and Goedewaagen, 1965). Furthermore, in root sampling with an auger, there is high probability that in one of several boreholes, larger diameter roots would be included in the core. The weight of these roots would cause large variability in the results of soil sampling.

Thus, it is not surprising why Caldwell (1987) lamented that some results of root studies vary widely and the errors incurred are often sizeable. With an auger, it would even be possible to obtain false impression from the results (Sylvester-Bradley, 1979). Smucker (1990) pointed out that results of root measurements are a function of the method selected.

Accordingly, other root sampling techniques could be more effective in determining hedgerow root densities and their distribution. Installation of minirhizotrons may provide a clearer graphic presentation of root competition in an alley cropping system. The method has been designed to observe roots' compensatory and plastic behavior in response to perceived stresses (Hendrick, 1992; Upchurch and Ritchie, 1983; Smucker, 1984). Indirect observations of the performance of alley crops may provide further inferential, but qualitative information on the behavior of roots (Solera, 1992; Ong, Rao, and Mathuva, 1992) as long as other effects are minimized or controlled (i.e. incident light, space). As found in the present study, the classic trench profile mapping technique (Boehm, 1979; Caldwell and Richards, 1983) may still be the most appropriate method of assessing root densities in developing countries, where equipment availability is limited but labor is abundant and inexpensive.

The high root densities in the 5- and 10- cm within-row spacings from both the single and double hedges explain why these hedgerows yielded the highest initial and subsequent pruning biomass. Thus, it is suspected that these hedgerows invested a large portion of their photosynthate on roots (Cannell, 1985). Given that root density is closely related to nutrient and water uptake of plants (Russell, 1977), the densely-planted hedgerows were able to maximize the use of above- and below-ground resources per unit area for their growth. These plants, however, suffered high mortality due to strong intraspecies competition. The densely-planted hedgerows attained the lowest total height and diameter growth in one year. But, due to their extensive root systems, these hedgerows were able to yield the highest periodic pruning biomass when cut at 2.0-m high. They might even have contributed the largest amount of root litter in the soil because of their high mortality rates.

High biomass (from prunings and root turnover) and control of soil erosion in sloping areas during intense rainfall are the major benefits from densely-planted hedgerows (Laquihon et al., 1991). For instance, the hedgerows from the 5- and 10-cm within-row spacing produced an average of 1.24 dry kg/m^2 alley area from young twigs and leaves in the initial clipping. Based on the tissue analysis of *G. sepium,* this would be equivalent to about 33.4g N, 3.4g P, and 35.6g K per m^2 alley area. On the average, the hedgerows from all within-row spacing in the single and double hedgerows produced a total dry biomass of 1.08 kg/m^2 of alley area. If this amount of one-year biomass from the two parallel hedgerows is divided and applied in the two adjacent alleys, it would translate into a total of 144 kg N, 14kg P, and 154 kg K per ha. Thus, it is not surprising that despite the nutrient removal of the second corn and mungo crops, the result of the soil analysis showed that N, P, K gradually increased after the fallow period, initial clipping, and subsequent pruning of the hedgerows.

The less than one-year-old hedgerows were still ineffective in minimizing sheet erosion during high rainfall; hence, the initial decline of OM. The general decline of OM in an alley cropping system was also observed by Lal (1989a) over a period of five years. Young (1991), however, argued that with leucaena, hedgerows were able to maintain soil carbon at a satisfactory level in the alleys over six years through added prunings and crop residues. Perhaps, in the present study the biomass from the initial clipping and subsequent pruning stabilized the OM condition in the experimental site and prevented its loss during the rainy months (June, 1991-November 1991). Any firm conclusion from the present study on the pattern of OM content, however, is too early to make. Another two or three years of measurement will give more meaningful insights.

The gradual decline of N up to the third sampling period (August 1991) may be attributed to sheet erosion which caused the loss of top soil during the first year, the consumption of N by the first corn crop that was not fertilized, the inadequacy of the crop residues (corn and mungo) and *G. sepium* litterfall to maintain N at the original level, and the consumption of the hedgerows themselves. However, in the fourth sampling, N increased as soon as initial clippings and subsequent prunings decomposed in the alleys, even with the N removal of the second corn crop.

The decline of soil pH, P, and K in the second sampling and their increases in the third sampling, reveal the contribution of hedgerow litterfall during the fallow period as well as biomass from the initial clippings and subsequent prunings, in improving soil fertility. The decrease of soil pH, however, in the fourth sampling reflected the depletion of cations from a cycle of leaching or erosion, uptake, and recycling of bases from deep subsoil to surface horizons (Lal, 1989a). The observation on P, however, contradicted those of Yamoah et al. (1986) and Garrity (1992) who reported that the *G. sepium* hedgerows were not able to replenish the removal of P after a maize crop. Garrity's work was done in acid upland soil, where pumping of P from deeper soil layers is limited by aluminum toxic subsoils and low subsoil P reserves. On the other hand, Kang et al. (1981) found that P and K were able to accumulate over a period of six years when leucaena hedgerows and maize crops were grown together.

The pattern of horizontal and vertical distribution of *G. sepium* hedgerow roots was better defined from the eight trench profiles than from the sampling with an auger. The dominance of roots < 1.0-mm diameter, the declining root densities with distance from the hedgerow base towards the alley, and the inverse relationship of root densities with increasing soil depth were detected from the trench profiles, especially with the 5 and 10-cm within-row spacings in double hedgerows. On the other hand, the auger sampling revealed the possible effect of repeated prunings on root production over time. These findings have implications on hedgerow-crop competition for nutrients and water and strategies to minimize competitive hedgerow-root systems. They confirm the notion that higher root densities at the hedgerow/crop interface (Huxley et al., 1989; Buck, 1986) would escalate inter-specific competition for limited below-ground resources.

At a fixed lateral distance of 50 cm from the hedgerow base and from the hedgerow base toward the alleys at different soil depths, almost 90 percent of the *G. sepium* roots belonged to the < 1-mm diameter class. More than 70 percent of all roots occurred within the top 30 cm of the soil profile. Within this stratum, root densities tended to decline towards the alley and with greater depths, especially in more dense within-row spacing and in double hedgerows. This rooting pattern and distribution may be explained by the tendency of roots to occupy fertile top soil, provided moisture is adequate, especially during the early stage of vigorous growth (St. John, Coleman, and Reid, 1983; Lyr and Hoffman, 1967; Kang et al., 1985). Dhyani, Narain, and Singh (1990) also observed this pattern of root distribution in five multipurpose species. In their case, they considered roots < 2-mm diameter as fine roots. In acid and volcanic soils, Solera (1992), who excavated roots of several hedgerow species, found that majority of the roots were located between 0-20 cm soil depth; but, the lateral distribution varied with species. Roots of *G. sepium* hedgerows in volcanic soils were observed to be within the top 20 cm of soil up to a lateral distance of 100 cm.

Under a condition where most roots were found in the plow layer and were < 1-mm diameter, the nitrogen-fixing *G. sepium* could potentially compete with alley crops for available soil resources, especially P, moisture, and K (Garrity, 1992). Clearly, the *G. sepium* rooting pattern and distribution in this study contradicts the hypothesis that hedges have a deeper rooting pattern than those of alley crops (Kang and Wilson, 1987; Young, 1991; Szott, Fernandez, and Sanchez, 1991) Therefore, the crop would be forced to invest more of its carbon resources in roots to survive the competition process (Berendse, 1979; Caldwell, 1987), and yield will decline. The crop will reallocate photosynthates that would otherwise be used for biomass accumulation or grain production (Dickmann and Pregitzer, 1992). Young (1991) and Garrity (1992) mentioned that this danger -- roots of perennial hedgerows robbing nutrients from the systems of annual crops -- would cause more problems when tree roots extend laterally beneath the area planted to crops. However, the extent of damage from this process and strategies of co-existense in an alley cropping system are still very much unknown. Each alley crop might have a "threshold" level of competition. Again, the question of the "minimum" root density of a hedgerow that will be acceptable by a certain alley crop needs an answer.

Other studies do not give much light on the unfavorable consequences of competition between roots of hedgerows and the alley crop. Using crop yield as the main indicator, Kang et al. (1981) and Torres (1983) contended that maize yields were not significantly affected by the roots of leucaena hedgerows at 0-20 cm depth and up to 100 cm lateral distance from the hedge. Solera (1992), who worked with upland rice, concluded that pruning the roots of *G. sepium* and *Cassia spectabilis* had no significant effect on the growth and development of upland rice compared with those plots that were not pruned. The MBRLC Editorial Staff (1993) and Laquihon et al. (1991) reported that after a decade of experience with their sloping agricultural land technology (SALT), maize yields from their experimental farm continued to increase and were shown to provide higher incomes. Analysis of root patterns and distribution, however, were not available.

Ong (1989) and Johnson et al. (1988) concluded that hedgerows of leucaena and other species would compete with maize and other crops for nutrients and water in areas that experience seasonality of rainfall. In acid soils, Garrity (1992) found that yields of maize and rice were reduced when intercropped with hedgerows of *G. sepium* or napier grass. The roots of the hedgerows spread laterally at a shallow depth of 20-30 cm into the alleys.

Atta-krah (1983) and Ong, Rao, and Mathuva (1992) postulated that roots of hedgerows had minor influence on the tree-crop interaction. The latter installed root barriers (galvanized iron sheets which were buried between leucaena and maize to a depth of one m) which had only minor effects on the crop yield. The authors argued that the differences of crop yield in the alleys could be attributed to competition for light. The pattern of vertical and horizontal root distribution of *G. sepium* hedgerows in the top 30 cm of soil, the linearly decreasing root densities toward the alley and deeper soil layers, and the dominance of fine roots found in the present study pose a challenge on how to manipulate hedgerow roots so that they will first grow downwards below the topsoil, spread laterally, and function as "safety net" that could intercept leached nutrients (Young, 1991; van Noordwijk et al., 1988). Root and shoot treatments may be performed to minimize competition and influence the allocation of carbon to increase yield or the harvest index (Dickmann and Pregitzer, 1992; Cannell, 1985).

Based on the observed pattern and distribution of *G. sepium* at a fixed distance of 50 cm from the hedgerow base, the roots could be pruned down to a soil depth of 15-30 cm especially in hedges at within-row spacings of 5 and 10 cm. In this way, the roots belonging to < 1.0 mm and 1-2 mm diameter classes will become part of root litter production and improve soil fertility (Szott, Fernandez, and Sanchez, 1991). Repeated root prunings may even condition the hedgerow roots to develop downwards because of their plastic and compensatory response (Russel, 1977; Smucker, 1990; Bowen, 1985). Continuous and periodic root prunings may temporarily check shoot growth and, eventually, reduce the aggregate shading effect of hedgerows on the alley crop (Cannell, 1985). Root pruning, however, has a cumulative effect of reducing top pruning biomass production for recycling into the top soil. For example, periodic top pruning reduced the mean root densities of hedgerows based on the first and second sampling of roots with auger. It confirmed the notion that top pruning checks root growth (Cannell, 1985).

Barriers (galvanized iron, plastic, trenches) between the hedges and the crops may be installed to keep the hedgerow roots from tapping soil resources in the alleys (Ong, Rao, and Mathuva, 1992; Solera, 1992). Putting these barriers, however, is laborious and impractical. Farmers might prefer plowing along and close to the hedgerows to reduce hedgerow/crop competition near the hedges. A study will have to examine whether or not regular plowing along and at least 50 cm away from the contour hedgerows will minimize hedgerow/crop competition. The linearly decreasing root densities from the hedgerow base up to 50 cm towards the alley within the top 30 cm indicates that plowing or hilling up along the contour will control lateral growth of dense *G. sepium* hedgerow roots. Plowing may even "force" the hedgerows to develop roots in deeper soils. A no-tillage practice in the alley, on the other hand, will only encourage lateral growth of hedgerows and will be unfavorable for crop growth.

In the long term, evaluating and breeding promising hedgerow species such as *G. sepium* for their deep rooting characteristics may be a logical option (Dickmann, Gold, and Flore, 1994). Development of and application of a hedgerow-specific root growth inhibitor during the critical stage of growth of an alley crop may be another alternative. In any case, any treatment of hedgerow roots should be targeted towards minimizing the unfavorable effect of increased hedgerow-crop competition for limited soil resources.

Lastly, hedgerows may be planted at 20- and 40-cm within-in row spacings to obtain low initial root densities at the tree/crop interface and less competition with the alley crops. These widely-spaced hedgerows had the lowest mean root densities compared with those spaced at 5 and 10 cm, but they did not optimize soil resources per unit of stem volume. At these within-row spacings, however, the hedgerows will not be as effective as the dense hedgerows in controlling soil erosion. Moreover, they had the highest diameter and height growth; hence, there is the possibility that they eventually would aggressively grow more roots vertically and horizontally at the expense of the alley crop to meet their demands for nutrients and moisture.

4.5 Conclusions

1. Root densities of *G. sepium* hedgerows were not significantly affected by number of hedges per contour line, within-row spacing, and pruning height based on root samples taken with the auger equipment at 30 cm depth. However, root densities were highly correlated (e.g. declining) with distance from the hedgerow base

towards the alley. Based on the high CVs of the samples, there is doubt whether or not root sampling with an auger will be the appropriate method of determining root distribution and densities in an alley cropping experiment.

2. Up to 90 percent of the roots belong to < 1.0-mm diameter class and more than 70 percent were located in the top 30 cm of the soil based on the trench profile method. Clearly, this pattern of root distribution requires proper management of contour hedgerows to minimize their unfavorable impact on the alley crops.

3. Root densities were found to be negatively correlated with distance from the hedgerow base up to 50 cm towards the alley and with soil depths for single and double hedgerows at 5- and 10-cm within-row spacings. In more dense hedgerow plantings, root densities were more predictable with respect to soil depth and distance from the hedgerow base towards the alley. The root densities of less-dense hedgerows (20- and 40-cm within-in row spacings) were less predictable with respect to soil depth and distances from the hedgerow base. The negative correlations imply certain practices in hedgerow establishment and management (i.e. root treatments) to minimize tree-crop competition in the interface.

4. Average N, P, K, and pH initially declined after site clearing and the first maize crop. Values for these elements, however, gradually increased after the hedgerows were established and soil erosion declined, and after incorporation of initial hedgerow pruning biomass in the alleys. OM declined and stabilized even after the initial hedgerow clipping and subsequent prunings.

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Chapter 5

WATER POTENTIAL OF THE HEDGEROWS

Abstract

The day-time and pre-dawn water potentials (ψ) of nine-month and 32-month-old *Gliricidia sepium* hedgerows were measured in a 0.22-ha alley cropping field experiment at Mt. Makiling, University of the Philippines at Los Banos, College, Laguna, Philippines. The treatments for the nine-month-old hedgerows were the number of hedges per contour line and within-row spacing. An additional treatment in the 32-month-old *G. sepium* hedgerows was pruning height.

In the nine-month-old hedgerows, the most negative mean day-time and pre-dawn ψ was obtained from the 5-cm within-in row spacing. The number of hedges per contour line did not significantly affect ψ of the hedgerows. Towards the end of the dry season, the nine-month-old *G. sepium* hedgerows were water stressed, indicated by pre-dawn ψ more negative than - 0.5 MPa.

The number of hedges per contour line, combinations of pruning height and within-row spacing, and their interaction significantly affected the day-time ψ of 32-month-old hedgerows. Although there was an indication that ψ was more negative with more dense within-row spacing and lower pruning height, Fisher's Protected LSD test ($p < 0.05$) and regression analysis did not show a clear pattern of ψ response with respect to number of hedges per contour line, pruning height, and within-row spacing. It appeared that in fully-established *G. sepium* hedgerows, the demand for water to meet transpiration requirements was not singly influenced by any of the treatments.

The number of hedges per contour line, combination of pruning height and within-row spacing, and their interaction did not significantly influence the pre-dawn ψ of 32-month-old hedgerows. The measurements were performed in the middle of the 1993 dry season.

The results of the study indicate that in newly-established *G. sepium* hedgerows, competition for water in the tree-crop interface will be high in densely-planted hedgerows. This competition will partly deprive intercrops of their needed water. In established hedgerows, competition for water occurred regardless of the number of hedges per contour line, pruning height, and within-row spacing.

5.1 Introduction

In alley cropping, hedgerows compete for incident light and space aboveground, and nutrients, space and water below ground. This intraspecies competition directly affects the growth of hedgerows and indirectly influences the productivity of the alley crop because both share the same resource pools in the environment (Buck, 1986). Since hedgerows provide a service function in alley cropping, gains from intraspecies competition should be optimized and its unfavorable effects on intercrops minimized. Hedgerows serve as one of the means to improve upland productivity and enhance environmental stability.

Intraspecies competition for water among hedgerow plants and how this affects intercrops are the least-studied aspect of alley cropping. Early work focused on establishing hedgerows to control soil erosion and improve soil fertility (Kang, 1990; Laquihon, 1988; Watson, 1983), and, to a certain extent, crop yield. In the Philippines, alley cropping was developed in response to expanding deforestation, destructive slash-and-burn farming in logged-over areas, and degradation in open and grassland sites (Watson and Laquihon, undated; Granert and Sabueto, 1985; Sajise, 1985). Now that the role of hedgerows in controlling soil erosion and restoring soil fertility has been more or less established (Young, 1991; Tacio, 1993), inter- and intra-species interactions for water and nutrients have to be examined to test the validity of earlier assumptions on the servicing roles of hedgerows in an alley cropping (Huxley, 1983; Buck, 1986; Kang and Wilson, 1987; Kang et al., 1990; Ong, 1991). The phase of refining the technology of alley cropping has come. Hopefully, this refinement process will provide a deeper understanding of the hedgerows' service function to obtain sustainable intercrop yield.

Hedgerows have been documented to capture rainfall from canopy interception, increase soil water infiltration, and improve microclimatic condition (Kang and Wilson, 1987; Huxley et al., 1989). In MBRLC, for instance, they reported that SALT plots had infiltration rates seven times faster than the non-SALT ones. Moreover, by using moisture probes buried at 15-cm depth, the workers observed that the alley plots with contour hedgerows had higher soil moisture compared with non-SALT plots (Laquihon et al., 1991). These moisture-related improvements or increases in the alleys and the extent that they become self-serving to the hedgerows are least understood. Huxley et al. (1989) observed that the aggressive lateral roots of nearby *Cassia siamea* hedgerows intruded into the alleys and might have partly deprived castor beans of needed moisture for growth and transpiration. They also found that the soil near and below a hedge of *Grevillea robusta* dried almost to the wilting point but not at the deeper layers beneath the maize crop. Moisture improved with increasing lateral distance from the hedge.

Huxley (1983) suggested the measurement of hedgerow water potential (ψ) to obtain a better understanding of the tree/crop interface in agroforestry systems. The leaf ψ of hedgerows under a given condition would indicate the rate of water uptake which reflects transpiration rate, size of the root system, and amount of available water in the soil (Kozinka, 1989). The ψ will show the extent of potential competition for water among hedgerows and between the hedges and the intercrop. By comparing the ψ of several species, their suitability as a hedgerow in alley cropping may also be evaluated.

Accordingly, this study attempted to measure hedgerow ψ as affected by different number of hedges per contour line and various combinations of pruning height x within-row spacing. The study hypothesized that the ψ of hedgerows becomes more negative with increasing density (more hedges per contour line and closer within-row spacing) and with higher pruning. The hedgerows with very low (more negative) ψ would cause intense intraspecies competition for water, and would deplete available soil moisture intended for the intercrops.

5.2 Materials and Methods

5.2.1 Sampling Procedure

The first measurement of water potential occurred towards the end of the dry season in 1991 (May 25, June 1, and June 8), while the second was done at the middle of the dry season in 1993 (April 8-10). In both sampling periods, no major precipitation occurred at least two weeks before the measurement, except with the June 8 measurement when a slight rain fell in the area four days before the sampling.

The hedgerows were about nine-months old during the first measurement. The measurement was performed before the initial clipping in August 1991. In the second measurement, the hedgerows were about 32-months old. Between the first and second measurements, the one-year old hedgerows were cut to 30 cm above ground in August 1991; periodically pruned back to 30 cm above ground upon reaching 1.0-, 1.5-, and 2.0-m heights between November 1991 to May 15, 1992; allowed to grow until September 1992 after which they were cut back to 30 cm above ground; and periodically pruned back to 30 cm above ground between November, 1992 to March 1993 upon reaching 1.0-, 1.5-m, and 2.0-m heights.

The treatments during the first sampling were only the number of hedges per contour line and within-row spacing. Accordingly, in each main plot the sub-plots which represented a within-row spacing treatment were selected for sampling. This was done for each replicate. Thus, for each measurement, a total of 24 sub-plots were sampled per day. In each sub-plot, two hedgerow plants were randomly selected, one each from the lower and upper hedgerows. Three compound leaves were cut from each plant for water potential measurement. As suggested by Garrity (1991a), the leaves that were cut for measurement were those considered morphologically mature and active in photosynthesis. With *G. sepium*, these leaves normally start with the fifth to seventh leaf below the youngest leaf at the tip of the plant. The ψ was determined in a total of six leaves for each sub-plot, 24 leaves per main plot, 48 leaves per replicate, or 144 leaves per measurement.

In the first measurement, the day-time leaf ψ of the hedgerows was completed three times, one full sampling per day. The day-time measurement started at 9:30 AM on May 25, 1991, 8:30 AM on June 1, 1991, and 10:15 AM on June 8, 1991. The measurements were over between noon to about 2:00 PM. The pre-dawn ψ measurement, however, was only done on June 1, 1991. The measurement started at 5:00 AM and ended at about 6:30 AM. Since there was only one- and a half-hour to do the measurements, only one hedgerow plant per sub-plot was selected. In each plant, three leaves were cut for ψ determination. Thus, a total of 24 leaves were sampled for pre-dawn ψ measurement.

The second ψ measurement was conducted on April 8-10, 1993. In this measurement, all 12 sub-plots per main plot were sampled. This was done to take into account the possible effects of number of hedges per contour line and the various combinations of pruning height and within-row spacing. Accordingly, only one replicate (composed of sub-plots from the single and double hedgerows) was completed per day. A total of 24 sub-plots, 48 hedgerow plants, and 144 leaves were sampled each day during the day measurement. In the second measurement, the number of plants and leaves, and location of the leaves for sampling, were the same as the first measurement.

The pre-dawn measurement of ψ was conducted each day from April 8-10, 1993. Instead of sampling all sub-plots, however, only the number of hedges per contour line and within-row spacing were considered treatments in selecting sub-plots to be sampled. Only one hedgerow plant and three leaves per plant were measured at each sub-plot. Again, this procedure was adopted to maximize the one- and a half-hour sampling window at pre-dawn. During the three consecutive days, pre-dawn ψ measurements started at 5:00 AM and were completed on or before 7:00 AM. Thus, for the pre-dawn measurements, only four hedgerow plants were sampled per main plot, a total of eight plants per replicate, or 24 leaves per measurement.

5.2.2 Equipment and Procedure

Equipment. The pressure chamber method as described by Slavik (1974) was used in determining the water potential of the *G. sepium* hedgerow plants. A pressure chamber made by PMS Instruments, Corvallis, Oregon, USA was borrowed from the Agroecology Division of the International Rice Research Institute (IRRI), College, Laguna, Philippines. However, since the small nitrogen gas tank was not made available, a 50-kg nitrogen tank and required fittings were procured from a local supplier.

Procedure. Before the actual ψ measurement, pre-sampling of *G. sepium* leaves with the use of the pressure chamber was performed to gain familiarity with the use of the equipment and to gain an estimate of the amount of time to complete measuring one leaf sample. The research aide was also taught and shown how and where to cut a leaf sample from the hedgerow plant. A day before the scheduled measurement, the nitrogen gas system was set and its locations established. The gas tank and the pressure chamber were located in the middle of the main plots at each replicate. The pressure chamber was placed on top of a small table that was firmly put on the ground.

A two to three-person team conducted the measurement of hedgerow ψ. The research aide cut the leaf with a blade from the hedgerow plant and took the leaf to the person operating the pressure chamber. The third person would hold the table or the chamber when it was being sealed or closed for reading. He also acted as an alternate runner person to get the leaf from the research aide. The whole sequence of activities took 3-5 minutes per sample, depending on the distance of the hedgerow plant to the pressure chamber. The pressure chamber operator gave the research aide a go signal to cut the leaf when he was ready for another sample measurement. I operated the pressure chamber throughout the ψ determination in both sampling periods.

For the initial pressure chamber measurement, a hand lens was used in detecting the appearance of sap droplets on the cut surface of the leaf petiole. Over time, however, the determination of time when sap droplets appeared on the cut surface of the petiole was done with the naked eye. On a clear day, the use of a hand lens and a close examination by eye of the sap appearing on the cut surface of the leaf would almost give the same level of accuracy. In the pre-dawn measurements, a flashlight was used to see the appearance of sap droplets on the cut surface of the leaf petiole.

5.2.3 Statistical Analysis

The data from the first and second measurements were converted from bars into megapascal units, MPa, using the conversion of one bar = 0.1 MPa. Results from the three samplings in the first measurement were subjected to analysis of variance and, when found significant, to the Fisher's Protected LSD multiple range test. The average of the six leaf samples was used in the analysis; each set of averages from the three sampling dates were analyzed separately. The values from the three sampling dates were also averaged and analyzed.

In the second sampling, the daily results of the day-time and pre-dawn ψ measurement were separately subjected to analysis of variance and LSD multiple range test, when applicable. Accordingly, the ψ values from the hedgerow plots in top, middle, and bottom of the slope were individually analyzed. In each case, the average water potential values from each hedgerow plant were used as a replicate. Ultimately, however, the average data from the top, middle, and bottom plots were combined for analysis. Hedgerow ψ values from the top, middle, and bottom plots were also pooled in running the regression analyses to determine the linear relationship between ψ, within-row spacing, and pruning height.

All the data were entered into the LOTUS 1-2-3 spreadsheet, converted into ASCII files, and analyzed with the use of MSTATC/SYSTAT software. The derived figures were all generated with PLOTIT software.

5.3 Results

5.3.1 Water Potential in the First Measurement

Means of three leaves per replicate were used in the analysis of variance in all the three sampling dates. Based on the result, hedgerow ψ on May 25 was not significantly affected by the treatments and their interaction (Table 5.1). However, on June 1, ψ of the hedgerows was significantly affected by the interaction of number of hedges per contour line and the within-row spacing ($p < 0.01$). On June 8, within-row spacing significantly affected ψ of the hedgerows ($p < 0.01$). The F-test on the average ψ from the three sampling dates yielded significant effects from within-row spacing and the interaction ($p < 0.01$). In all the three sampling dates and the average, the hedgerow ψ was not significantly influenced by the number of hedges per contour line.

The number of hedges per contour line and the interaction did not significantly affect pre-dawn ψ at $p < 0.01$ (Table 5.2). However, the within-row spacing treatments significantly affected pre-dawn hedgerow ψ ($p < 0.01$).

In both the June 8 and average from the three sampling dates, the day-time ψ means from the 5-cm within-row spacing were significantly lower (more negative) than those from the 10-, 20-, and 40-cm within-row spacing (Figure 5.1).

The mean ψ from the 5-cm within-row spacing was found to be significantly lower than those in the 10-, 20-, and 40-cm within-row spacings (Figure 5.2). The average pre-dawn ψ of the hedgerows on June 1 was - 0.51 MPa, below the average water potential of the soil at field capacity (- 0.1 MPa) (Kramer, 1969).

Table 5.1. F-values of analysis of variance[1] of day-time hedgerow water potential on May 25, June 1, and June 8, 1991.

Source of Variation	**May 25**	**June 1**	**June 8**	**Average**
Number of hedges/line	0.07	0.06	0.40	0.00
Within-row spacing	0.45	1.73	6.07***	5.09***
Interaction	0.82	6.15***	1.54	4.03***

[1] *** Significant at one percent probability

Table 5.2. Analysis of variance[1] of pre-dawn hedgerow water potential on June 1, 1991.

Source of Variation	**F-Value**
Number of hedges/line	1.49
Within-row spacing	7.10***
Interaction	2.85

[1] *** Significant at one percent probability

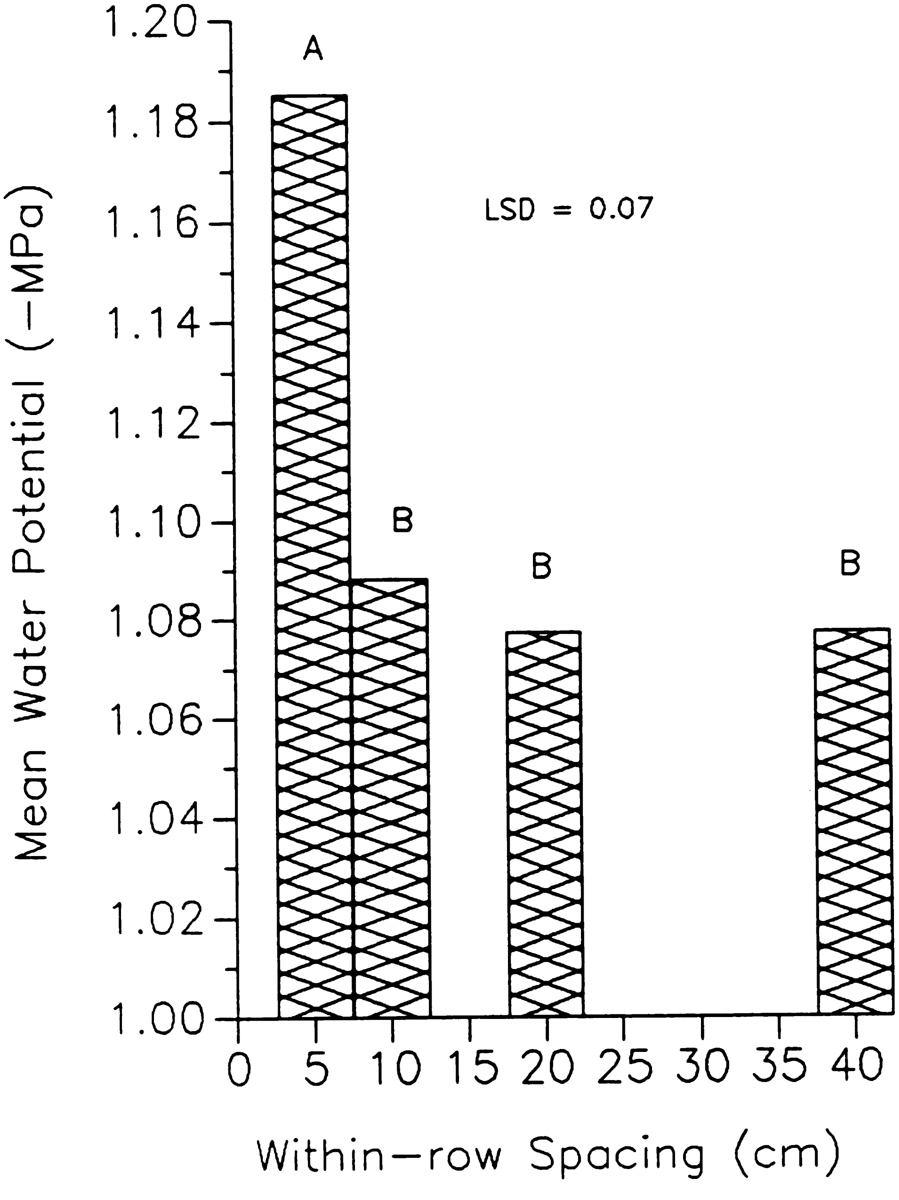

Figure 5.1. Day-time water potential (mean of three sampling dates) of hedgerows from different within-row spacing. Bars topped with the same letter are not significantly different (LSD, $p < 0.05$).

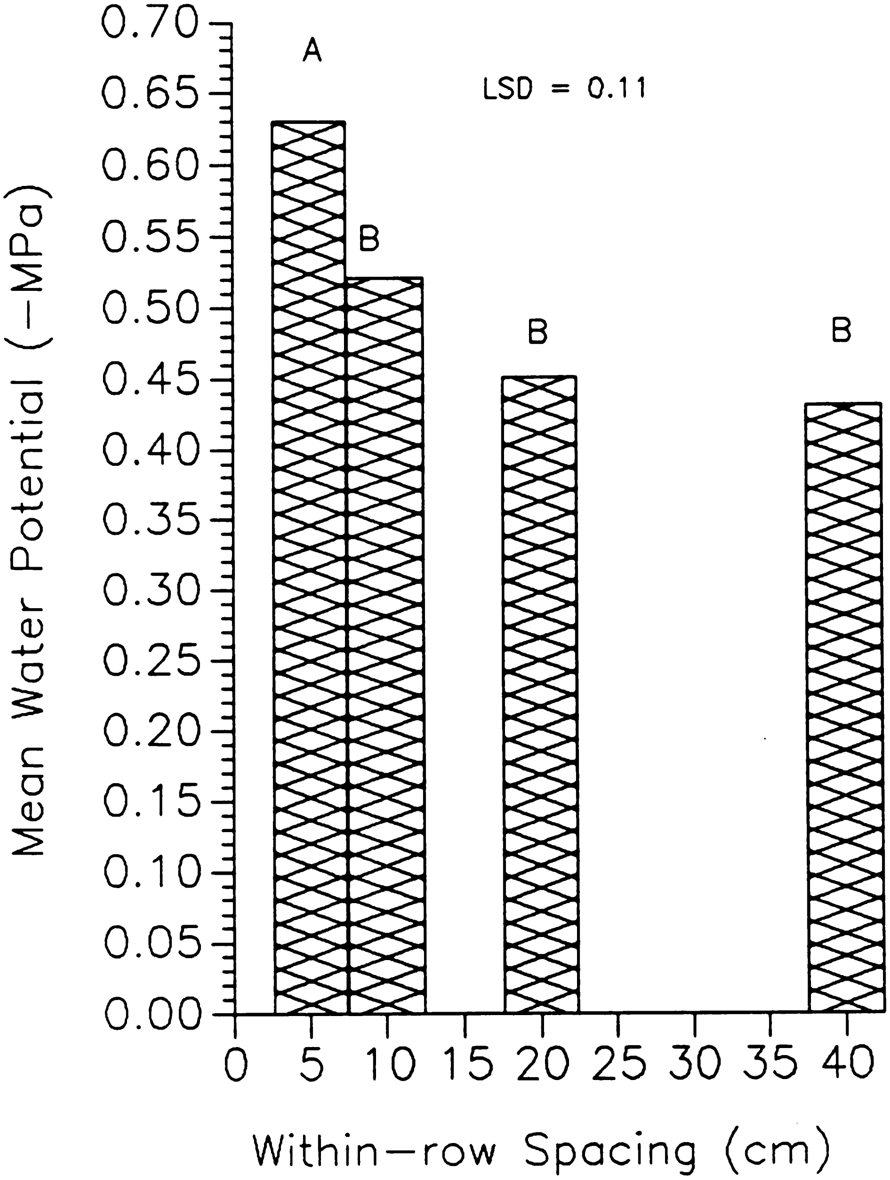

Figure 5.2. Means of pre-dawn water potential of hedgerows at different within-row spacing on June 1, 1993. Bars topped with the same letter are not significantly different (LSD, $p < 0.05$).

5.3.2 Water Potential in the Second Measurement

The effect of pruning height x within-row spacing on day-time ψ of hedgerows at the top of the slope was significant at $p < 0.01$ (Table 5.3). The interaction effect was also significant at $p < 0.05$. At the middle of the slope, the number of hedges per line, pruning height x within-row spacing, and the interaction significantly affected the day-time ψ of the hedgerows ($p < 0.01$). At the bottom of the slope, the number of hedges per contour line and pruning height x within-row spacing significantly influenced hedgerow ψ at $p < 0.05$ and $p < 0.01$, respectively. There was no significant interaction effect. When the average ψ values from the three sampling dates were further averaged, the treatments and the interaction showed no significant effects on the day-time ψ of hedgerows.

The ψ from the different slope locations of the hedgerows (top, middle, and bottom) did not greatly vary (-1.18 MPa from the middle; -1.18 MPa from the bottom; and -1.13 from the top). It should be noted that the plots at the top of the slope are shaded starting at about 2:30-3:00 PM.

At the middle and bottom of the slope, the hedgerow plots were significantly affected by the number of hedges per contour line. The single hedgerows had more negative mean ψ (-1.22 MPa) than the double hedgerows (-1.13 MPa) because the plots are more exposed to sunlight. In the middle plots, however, the double hedgerows had more negative ψ (-1.27 MPa) than those in the single hedgerow plots (-1.09 MPa).

The number of hedges per contour line, pruning height x within-row spacing, and interaction did not significantly affect pre-dawn ψ of the hedgerows in any slope location of the plots (Table 5.4). The mean pre-dawn ψ of hedgerows at the middle of the slope was -0.32 MPa, followed by those in the top (-0.29 MPa), and bottom of slope (-0.26 MPa).

Some treatment means from the top, middle, and bottom of the slope had significant differences from each other; however, these differences did not show a definite pattern or trend. Perhaps, the strong interaction effect of number of hedges per contour line and pruning height x within-row spacing complicated the pattern of mean differences. Nevertheless, a matrix was prepared to determine the frequency of occurrence of the most and least mean ψ at different pruning height and within-row spacing (Table 5.6). The most negative mean ψ occurred the highest at 5- and 10-cm within-row spacings at 1.0- and 1.5-m pruning heights. The least negative ψ occurred the greatest in the 20- and 40-cm within-row spacings at 1.0- and 1.5-m pruning heights.

In the top plots, where hedgerows get shaded from the afternoon sunlight as early as 2:30 PM, the hedgerows with 1.5-m PH x 5-cm within-row spacing had the least negative ψ (-1.03 MPa); the most negative was obtained from the 1.5-m pruning height x 10-cm within-row spacing plots (-1.31 MPa). In the middle plots, where hedgerows get most of the afternoon sunlight, the 1.0-m pruning height x 40-cm within-row spacing had the most negative ψ (-1.29 MPa) and the least was from the 1.5-m pruning height x 20-cm within-row spacing (-0.99 MPa). Most treatment

Table 5.3. F-values of analysis of variance[1] of day-time water potential of hedgerows from April 8-10, 1993.

Source of Variation[2]	**Top**	**Middle**	**Bottom**	**Average**
Number of hedges/line	2.97	256.76***	47.81**	0.34
PH x WRS	5.11***	10.69***	5.91***	0.87
Interaction	2.84**	11.41***	1.41	0.78

[1] *** Significant at one percent probability;
** Significant at five percent probability

[2] PH = Pruning height; WRS= Within-row spacing; Top= Main plots at the top of the slope; Middle= Main plots at the middle of the slope; Bottom= Main plots at the bottom of the slope; Average= Average water potential from the top, middle, and bottom plots.

Table 5.4. F-values of analysis of variance[1] of pre-dawn hedgerow water potential on April 8-10, 1993.

Source of Variation[2]	**Top**	**Middle**	**Bottom**
Number of hedges/line	3.77	3.19	0.36
Pruning height x within-row spacing	2.78	0.34	3.03
Interaction	1.76	1.88	0.71

[1] None of the F-values are significant at $P < 0.05$.

[2] Top = Main plots at the top of the slope; Middle= Main plots at the middle of the slope; Bottom= Main plots at the bottom of the slope.

Table 5.5. Fisher's Protected LSD test[1] for the means of day water potential of hedgerows in - MPa on April 8-10, 1993.

Treatment[2]	Top-Means Ranked Order	Treatment[2]	Middle-Means Ranked Order	Treatment[2]	Bottom-Means Ranked Order
1.5-PH x 10-WRS	1.31 A	1.0-PH x 40-WRS	1.29 A	1.0-PH x 5-WRS	1.32 A
1.5-PH x 40-WRS	1.21 AB	1.5-PH x 5-WRS	1.23 AB	1.5-PH x 20-WRS	1.30 A
1.0-PH x 10-WRS	1.20 BC	1.5-PH x 10-WRS	1.22 B	2.0-PH x 5-WRS	1.29 A
1.5-PH x 20-WRS	1.16 BCD	2.0-PH x 20-WRS	1.22 B	1.5-PH x 5-WRS	1.24 AB
2.0-PH x 40-WRS	1.12 BCDE	2.0-PH x 40-WRS	1.21 BC	1.0-PH x 40-WRS	1.22 ABC
1.0-PH x 40-WRS	1.11 BCDE	1.0-PH x 5-WRS	1.21 BC	1.0-PH x 10-WRS	1.20 ABCD
2.0-PH x 5-WRS	1.11 BCDE	2.0-PH x 10-WRS	1.18 BC	2.0-PH x 10-WRS	1.15 BCDE
2.0-PH x 10-WRS	1.11 CDE	1.0-PH x 10-WRS	1.18 BC	1.5-PH x 10-WRS	1.13 BCDEF
1.0-PH x 20-WRS	1.10 CDE	2.0-PH x 5-WRS	1.17 BC	1.0-PH x 20-WRS	1.10 CDEF
2.0-PH x 20-WRS	1.06 DE	1.5-PH x 40-WRS	1.15 C	2.0-PH x 20-WRS	1.09 DEF
1.0-PH x 5-WRS	1.06 DE	1.0-PH x 20-WRS	1.08 D	2.0-PH x 40-WRS	1.04 EF
1.5-PH x 5-WRS	1.03 E	1.5-PH x 20-WRS	0.99 E	1.5-PH x 40-WRS	1.03 F

[1] Values followed by the same alphabetic letter are not significantly different.

[2] PH = Pruning height; WRS= Within-row spacing

Table 5.6. Occurrence of the significant most and least negative mean water potential in different pruning height and within-row spacing.

PH/ WRS[1]	**1.0-m PH**		**1.5-m PH**		**2.0-m PH**		**Total**	
	MN[2]	**LN**[3]	**MN**	**LN**	**MN**	**LN**	**MN**	**LN**
5 cm	1	1	1	1	1		3	2
10 cm	1		1				2	0
20 cm		2	1	1			1	3
40 cm	1			1		1	1	2
Total	3	3	3	3	1	1	7	7

[1] PH= Pruning height; WRS = within-in row spacing

[2] MN= Most negative ψ

[3] LN= Least negative ψ

means in the rest of the hedgerow plots were found to be not significantly different from each other. In the bottom plots, the most negative mean ψ was taken from 1.0-m pruning height x 5-cm within-row spacing (-1.32 MPa); the least negative came from 1.5-m pruning height x 40-cm within-row spacing (-1.03 MPa).

To obtain possible linear relationships between ψ and pruning height, and between ψ and within-row spacing, regression analyses were conducted using the pooled values from all the plots. The T-test gave a non-significant result; thus, there is insufficient evidence to say that there is a linear relationship between ψ and pruning height ($p < 0.10$; $r = 0.10$). The same result was obtained from the T-test between ψ and within-row spacing ($p < 0.10$; $r = 0.08$).

5.4 Discussion

In the first measurement of day-time ψ of nine-month old hedgerows, the effect of within-row spacing was significant. There was no significant influence of the number of hedges per contour line on the hedgerow ψ or an interaction. In the measurement of 32-month old hedgerows, the number of hedges per contour line, pruning height x within-row spacing, and the interaction influenced the ψ of hedgerows at different locations of the slope. The effect of the number of hedges per contour line, pruning height x within-row spacing, and interaction on hedgerow ψ existed; however, how the treatments account for that effect could not be explained by the multiple range test and the regression analyses.

There were significant differences in the pre-dawn ψ of the nine-month old hedgerows but this was not observed in the 32-month old hedgerows. The first measurement was taken towards the end of the dry season; hence, the plants experienced more stress and had more negative pre-dawn ψ (average of - 0.51 MPa). The nine-month old hedgerows were already water stressed at the beginning of the day before the transpiration process began. The pre-dawn ψ during the second measurement, which was done in the middle of the dry season, had an average of - 0.29 MPa, slightly below the water potential of soil at field capacity (-0.1 MPa), but still within the optimum range of soil matric potential (-0.1 to -0.5 MPa). At this level of pre-dawn ψ, the hedgerows in the second measurements were not as water stressed as in the first measurements. None of the mean water potential values from the first and second measurements exceeded the limit of the wilting coefficient (-1.5 MPa).

The ψ values of the nine-month old hedgerows became more negative with more dense plantings because at closer within-row spacing, there are more plants per unit area and, therefore more transpiring leaf surface area

(Kramer and Kozlowski, 1979). In fact, the hedgerows in 5-cm within-row spacing had the most negative pre-dawn ψ values. They suffered water stress which resulted in high mortality and reduced height and diameter growth. These hedgerows were not able to acquire enough soil water to fully rehydrate at night and equilibrate to a ψ level similar with hedgerows from less dense within-row spacing (Huck, 1984), despite the fact that these hedgerows had high root densities. In fact, the hedgerows at closer within-in row spacing consumed more water and depleted soil water faster compared with those in the less dense within-in row spacing because they had more roots/dm^2 (Tables 4.7 and 4.14, Chapter 4). The root density of the hedgerows from the 5-cm within-row spacing was also negatively correlated with soil depth ranging from 0 cm (surface layer) down to 60 cm. The dense hedgerows invested more carbon in developing an extensive root system to supply the high demand for water during their transpiration period.

In similar studies, yields of maize and upland rice in rows near hedgerows were reduced despite regular pruning of above-ground biomass to reduce competition for light and some root pruning to reduce competition for nutrients and water (Ong, Rao, and Mathuva, 1992; Solera, 1992; Lal, 1989; Laquihon et al., 1991). My results confirm the observation of Huxley et al. (1989) that soil moisture near and below hedgerows up to a lateral distance of 0.5-1.5-m and depth of 200 cm could be reduced by the hedgerows. My findings also provide empirical evidence to support Garrity's (1991) suspicion that the lateral spread of hedgerows of *G. sepium* and napier towards the alley and beneath the plow layer will rob much of the soil moisture intended for the intercrops.

The high water demand of densely-planted hedgerows was probably the reason why mungbean yield from the first crop was the lowest in 5-cm within-row spacing. There was intense competition for water in the tree/crop interface. Thus, at closer within-row spacing of hedgerows, the intercrop's net gain from intraspecies competition for water in the hedgerows was negative. The major positive gains were production of a high volume of biomass to be used as soil amendment and reduction of water evaporation from the soil surface because of shading and cover.

The results of the ψ measurement in the 32-month-old hedgerows give an insight into how hedgerows make alley cropping productive. In the medium-term, after the hedgerows were initially cut and subsequently pruned several times, *G. sepium* hedgerows still intensely competed for water among themselves and gradually depleted available soil water for the intercrop. This statement is clearly reflected in the mean ψ values obtained at different number of hedges per contour line, within-row spacing, and pruning height. The vague response pattern and weak linear relationship of ψ and within-row spacing and pruning height treatments imply that intraspecies competition for water became a factor in the hedgerows. Established hedgerows appeared not to be singly affected by within-row spacing, number of hedges per contour line, and pruning height. The effect of these variables on ψ of hedgerows existed; but their strong interaction renders accounting of the effect on ψ difficult. There was indication, however, that ψ was still significantly influenced by within-row spacing in established hedgerows. It is obvious that the hedgerows were controlling soil erosion, enhancing microclimatic condition, and providing organic matter for the intercrops, while also depriving the crops of water. This is the trade-off in adopting alley cropping system in the uplands.

Based on the ψ pattern of the 32-month *G. sepium*, fully-established hedgerows appeared to have developed roots in both the lateral and vertical direction to meet the demand for water by the transpiring leaves. At this age, hedgerow planting density ceased to be a factor and the limit of the resource-supplying power of the environment (Harper, 1977) took over. Available water and growing space for expansion in the soil became the limiting factors.

Therefore, the question of how to manipulate the hedgerows to reduce their demand for water to a level that will not jeopardize the intercrop becomes the issue. Will more regular and frequent prunings check root growth (Cannell, 1985) and result in a temporary reduction of water consumption by the hedgerows? Will periodic root prunings minimize interspecies competition for water between the hedgerows and the intercrops (Solera, 1992; Ong, Rao, and Mathuva, 1992)? Will it be feasible to select hedgerow species based on a definition of the idealized rooting pattern and transpiration rate as part of the "hedgerow ideotype" (Dickmann, 1992; Dickmann, Gold and Flore, 1994; Young, 1991)? Will some *G. sepium* provenances and strains adapt better in seasonally dry areas with deep rooting patterns (Glover, 1986)? Definitely, these questions need answers that this study on water potential cannot provide.

Given the reality of intraspecies competition for water among hedgerow plants which threatens alley crops, but the need for the benefits of hedgerows, the results of this ψ study suggest that crops must be evaluated in terms of their productivity, threshold for interspecies competition for water, complementary rooting pattern, and response to improving the benefits of hedgerows (i.e. pruning). Alley crops, however, should be evaluated not in the context of strictly agricultural intercropping, such as corn/bean/squash system (Amador and Gliessman, 1991), but rather on their performance as crops or perennials growing together with contour hedgerows. Through this process, a system may evolve where synergism and complementarity between the hedgerows and intercrops are the norm.

5.5 Conclusions

Based on the results and analysis of ψ at different ages and hedgerow culture, the following can be concluded:

1. In the short-term, newly-established *G. sepium* hedgerows will compete for water with the intercrops the most if they are planted at very close within-row spacing. Dense hedgerows have high demand for water owing to their large transpiring leaf surface areas. Therefore, intense intraspecies competition for water in the hedgerows will deprive the intercrops of their needed soil moisture.

2. Fully-established *G. sepium* hedgerows will compete for water with intercrops to a similar degree regardless of the number of hedges per contour line, within-row spacing, and pruning height. Effects of these variables on hedgerow ψ were sporadically significant; but, they could hardly be predicted. A clear pattern of response in hedgerow ψ did not emerge as a result of increasing or decreasing within-row spacing and pruning height. It is speculated that the strong interaction effect clouded possible linear relationships between water potential, within-in row spacing, and pruning height.

3. Hedgerows do not only provide benefits that enhance intercrops' productivity, conserve top soil from further erosion, and restore soil fertility. In the process of providing these benefits, the hedgerows' strong intraspecies competition for water partly deprived the intercrops of needed water. Therefore, I suggest that hedgerows must be dealt with as a competitor, not only as a provider of benefits in an alley cropping system. The hedgerow's high demand for water should be considered in promoting alley cropping with contour hedgerows in seasonally dry areas.

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Chapter 6

SUMMARY

Contour hedgerows hold the key to the future of alley cropping in the Philippine uplands. If properly managed, they can fulfill at least four major functions: improve and sustain crop productivity through the restoration and improvement of soil fertility via the application of top prunings and turnover of roots; produce forage for livestock production; control soil erosion; and increase water infiltration that would gradually recharge ground acquifers. The first two functions would directly benefit resource-limited upland farmers. The last two will profit on-site the upland farmers who cultivate alley farms and off-site the lowland farmers/residents who are the beneficiaries of soil and water conservation practices. These function may be used as a justification by the government to subsidize training of farmers and provide inputs during the initial establishment of contour hedgerows.

In this study, I evaluated tree-crop interactions in an alley cropping with *Gliricidia sepium* hedgerows as the source of pruning biomass for the alley crop. The study was anchored on the rationale that contour hedgerows are established in alley farms to serve the intercrops - simultaneously supplying high volume of green manure and causing minimum competition in the tree/crop interface. Accordingly, hedgerows were established at different number of hedges per contour line and within-row spacings and were subjected to three pruning heights. The growth, pruning biomass, decomposition rate, mortality, root densities, and water potential of the hedgerows were determined. In addition, the yields from the two croppings of maize and mungbean were ascertained.

The hedgerows from the 5- and 10-cm within-row spacings produced the highest initial clipping and subsequent pruning biomass when cut at 30 cm and 2-m, respectively. These hedgerows were the shortest and had the smallest stem diameter; hence, they produce less shade but they suffered the highest mortality, and probably contributed the largest volume of dead roots in the soil. Thus, from the point of view of crop production, densely-planted hedgerows have the greatest potential to provide nutrients and enrich the soil in the alleys. This conclusion can be partly inferred from the results of periodic soil analysis. The pruning biomass and, possibly, root turnover increased and sustained soil fertility (pH, N, P, K, OM) after two cropping seasons, even in the face of soil erosion after clearing and establishment of the research plot. In short, the densely-planted hedgerows were able to optimize the use of incident light, space, and below-ground resources, produced the highest biomass, and had the least threat of shading the alley crop.

The densely-planted hedgerows had the highest root density. In general, root densities were negatively correlated with distance from the hedgerow base up to 50 cm towards the alley and with soil depth. Ninety percent of roots counted were < 1-mm diameter and 70 percent of these were found in the top 30 cm of the soil. This explains why the newly-established hedgerows in the 5- and 10-cm within-row spacings produced the highest volume of biomass and had the most negative water potential. Their intense intraspecies competition forced them to optimize and explore nearby available soil resources for nutrients and water. It was possible that the hedgerows that were producing biomass to enrich the soil were also consuming most of the nutrients that they have contributed in the alleys. Thus, densely-planted hedgerows will probably deprive alley crops of soil resources, especially in crop rows planted near the hedges. Unfortunately, densely-planted hedgerows are also more effective in controlling soil erosion.

While the maize crop yields from two croppings and mungbean yield from the second cropping were not significantly affected by number of hedges per contour line, within-row spacing, and pruning height, there is suspicion that in established hedgerows, competition will clearly deny alley crops of needed nutrients and moisture, especially in the tree/crop interface. This was partly shown by the lowest mungbean yield obtained from the 5-cm within-row spacing during the first crop. The interaction of number of hedges per contour line, within-row spacing, and pruning height significantly affected the water potential of the 32-month old hedgerows. At this time, however, there were no significant differences in water potential of hedgerows from different within-row spacing, number of hedges per contour line, and pruning height. Nonetheless, there was strong intraspecies competition for moisture in the hedgerows, posing a definite threat to the alley crops. From this, it can be deduced that strong intraspecies competition within hedgerows will increase intercrop competition for limited resources in the alleys.

Therefore, reducing intra- and inter-species competition is the ultimate action to optimize the net gain of the alley crops from the hedgerows in addition to benefits from control of erosion. This can only be done by developing a set of "root silvicultural prescriptions" that are geared towards minimizing unfavorable competitive effects of hedgerows on the crop. These prescriptions may include the following: periodic plowing along and at a distance of 50 cm from the hedgerow, application of root growth inhibitors during the critical stage of growth of a high value alley crop, heavy top prunings to check root growth before and during the growth of the crop, and crop fertilization only after root prunings. In the long term, however, the answer to alley farming will be to screen and develop hedgerow and crop ideotypes and use them in breeding new hedgerow cultivars that would fit the requirements and specifications of the system. These ideotypes would co-exist with and complement crop varieties in a highly competitive environment while allowing the hedgerows to perform other environmental services.

APPENDIX

Appendix Table 3.1. Treatments and respective area of sub-plots (m^2 alley).

Treatment and respective code [1]	Area (m^2 alley)
TOP 1 - Two hedges per contour line	
B3C1- PH of 2-m x 5-cm WRS	11.3
B2C3- PH of 1.5-m x 20-cm WRS	8.8
B1C4- PH of 1-m x 40-cm WRS	12.3
B3C2- PH of 2-m x 10-cm WRS	12.6
B3C3- PH of 2-m x 20-cm WRS	13.0
B2C4- PH of 1.5-m x 40-cm WRS	12.3
B1C1- PH of 1-m x 5-cm WRS	12.4
B3C4- PH of 2-m x 40-cm WRS	12.3
B1C3- PH of 1-m x 20-cm WRS	13.6
B2C2- PH of 1.5-m x 10-cm WRS	12.5
B2C1- PH of 1.5-m x 5-cm WRS	12.9
B1C2- PH of 1-m x 10-cm WRs	12.2
TOP 2 - One hedge per contour line	
B3C1- PH of 2-m x 5-cm WRS	8.0
B1C1- PH of 1-m x 5-cm WRS	8.3
B3C2- PH of 2-m x 10-cm WRS	7.9
B3C4- PH of 2-m x 40-cm WRS	8.8
B2C4- PH of 1.5-m x 40-cm WRS	10.3
B2C3- PH of 1.5-m x 20-cm WRS	10.3
B3C3- PH of 2-m x 20-cm WRS	10.0
B2C1- PH of 1.5-m x 5-cm WRS	10.0
B2C2- PH of 1.5-m x 10-cm WRS	10.0
B1C4- PH of 1-m x 40-cm WRS	9.8
B1C3- PH of 1-m x 20-cm WRS	8.5
B1C2- PH of 1-m x 10-cm WRS	9.0
Sub-plot Control Number 1	13.5

[1] PH = Pruning height; WRS = Within-row spacing;

Appendix Table 3.1. (cont'd).

Treatment and respective code[1]	Area (m^2 alley)
MIDDLE 1- One hedge per contour line	
B3C2- PH of 2-m x 10-cm WRS	10.4
B2C2- PH of 1.5-m x 10-cm WRS	10.0
B3C3- PH of 2-m x 20-cm WRS	11.0
B3C1- PH of 2-m x 5-cm WRS	8.4
B3C4- PH of 2-m x 40-cm WRS	11.4
B1C4- PH of 1-m x 40-cm WRS	9.0
B1C1- PH of 1-m x 5-cm WRS	12.0
B1C2- PH of 1-m x 10-cm WRS	11.5
B2C1- PH of 1.5-m x 5-cm WRS	11.3
B2C4- PH of 1.5-m x 40-cm WRS	8.8
B1C3- PH of 1-m x 20-cm WRS	10.9
B2C3- PH of 1.5-m x 20-cm WRS	10.9
MIDDLE 2- Two hedges per contour line	
B2C3- PH of 1.5-m x 20-cm WRS	9.4
B3C2- PH of 2-m x 10-cm WRS	8.0
B2C1- PH of 1.5-m x 5-cm WRS	9.4
B1C4- PH of 1-m x 40-cm WRS	8.1
B1C3- PH of 1-m x 20-cm WRS	5.3
B3C1- PH of 2-m x 5-cm WRS	5.2
B3C4- PH of 2-m x 40-cm WRS	5.5
B3C3- PH of 2-m x 20-cm WRS	6.8
B2C4- PH of 1.5-m x 40-cm WRS	7.4
B1C1- PH of 1-m x 5-cm WRS	6.9
B2C2- PH of 1.5-m x 10-cm WRS	7.0
B1C2- PH of 1-m x 10-cm WRS	5.3
Sub-plot Control Number 2	12.3

[1] PH = Pruning height; WRS = Within-row spacing

Appendix Table 3.1. (cont'd).

Treatment and respective code[1]	Area (m^2 alley)
BOTTOM 1- Two hedges per contour line	
B1C1- PH of 1-m x 5-cm WRS	12.3
B2C3- PH of 1.5-m x 20-cm WRS	11.8
B2C1- PH of 1.5-m x 5-cm WRS	10.5
B1C2- PH of 1-m x 10-cm WRS	13.9
B1C4- PH of 1-m x 40-cm WRS	11.7
B3C1- PH of 2-m x 5-cm WRS	11.0
B3C4- PH of 2-m x 40-cm WRS	12.0
B2C4- PH of 1.5-m x 40-cm WRS	11.0
B2C2- PH of 1.5-m x 10-cm WRS	10.0
B1C3- PH of 1-m x 20-cm WRS	10.0
B3C2- PH of 1.5-m x 10-cm WRS	10.0
B3C3- PH of 1.5-m x 20-cm WRS	8.8
BOTTOM 2- One hedge per contour line	
B1C3- PH of 1-m x 20-cm WRS	10.0
B3C4- PH of 2-m x 40-cm WRS	14.4
B3C2- PH of 2-m x 10-cm WRS	14.3
B2C4- PH of 1.5-m x 40-cm WRS	12.2
B3C3- PH of 2-m x 20-cm WRS	10.0
B1C2- PH of 1-m x 10-cm WRS	10.7
B3C1- PH of 1.5-m x 5-cm WRS	13.0
B1C4- PH of 1-m x 40-cm WRS	12.6
B2C2- PH of 1.5-m x 10-cm WRS	10.3
B1C1- PH of 1-m x 5-cm WRS	9.5
B2C3- PH of 1.5-m x 20-cm WRS	11.0
B2C1- PH of 1.5-m x 5-cm WRS	10.4
Sub-plot Control Number 3	10.5

[1] PH = Pruning height; WRS = Within-row spacing

Appendix Table 3.2. Coefficient of variations (CVs) in the analyses of variance of different above-ground parameters.

Parameter	**Coefficient of Variation (%)**
Six-mo height of hedgerows (m)	4.76
12-mo height of hedgerows (m)	5.70
Six-mo diameter of hedgerows (cm)	3.65
12-mo diameter of hedgerows (cm)	7.46
18-mo diameter of hedgerows (cm)	10.10
Six to 12-mo % mortality	57.37
12 to 18-mo % mortality	105.18
Initial clipping (dry kg/m^2 alley)	19.42
First pruning (dry kg/m^2 alley)	27.54
Second pruning (dry kg/m^2 alley)	26.05
Shelled maize from first crop (g/m^2)	20.25
Stover of maize from first crop (g/m^2)	16.40
Shelled maize from second crop (g/m^2)	21.86
Stover of maize from second crop (g/m^2)	18.37
Mungbean yield from first crop (g/m^2)	10.02
Mungbean yield from second crop (g/m^2)	29.73