ALLEY CROPPING AND GREEN MANURING FOR UPLAND CROP PRODUCTION IN WEST SUMATRA

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ABSTRACT

Green manuring and alley cropping were studied as means of improving crop production and reducing lime requirements in Sitiung, West Sumatra. Two experiments were conducted between 1985 and 1988 on acid, high aluminum soil (pH of 4.2 to 4.7 and Al+H saturation of 70 to 90 %). Low levels of external inputs were used in these experiments.

In the alley cropping experiment, three tree species *Paraserianthes falcataria*, *Calliandra calothyrsus*, and *Gliricidia sepium* and a no tree control were compared as well as three lime rates of zero, 750 kg ha^{-1}, and liming to 25% Al+H saturation. Paraserianthes and Calliandra both grew vigorously (producing about 3 T leaf ha^{-1} $year^{-1}$) and showed no consistent response to lime, even at Al+H saturations of greater than 70%. Gliricidia grew poorly (producing about 0.5 T leaf ha^{-1} $year^{-1}$) with growth especially limited at high soil Al+H saturation.

Upland rice (*Oryza sativa*) and cowpea (*Vigna unguiculata*) crops responded to both lime and green leaf manure (GLM) application. Paraserianthes GLM application doubled rice yields and quadrupled cowpea yields as compared to control plots. However, overall yields declined over the study period, possibly due to increasingly sporadic rainfall distribution. Also, Paraserianthes hedges began to die after four years while Calliandra hedges remained vigorous. Ongoing studies are needed to evaluate sustainability.

Economic analyses procedures were developed for comparing alley cropping and liming practices. The Paraserianthes + Low lime rate treatment was shown to be most profitable. If lime is not available,

alley cropping with Paraserianthes may be more profitable than farmer's current practices.

In the second experiment, Crotalaria usaramoensis, Calopogonium mucunoides and Centrosema pubescens were grown as green manure crops during two dry seasons and were applied to a rotation of upland rice or maize followed by peanuts. Upland rice did not respond to either liming or green manure application, probably because it is tolerant of high soil acidity. Subsequent maize (Zea mays) and peanut (Arachis hypogaea) growth increased with liming, but overall there was little yield increase due to green manure application and little or no increase with inorganic N application. Therefore, the value of herbaceous green manures is questionable in farming systems in Sitiung, while alley cropping may have potential for improving crop yields on limited resource farms.

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CHAPTER 1

GENERAL INTRODUCTION

1.1 RESEARCH CONTEXT

Upland crop production in humid areas of the tropics is often constrained by acid and infertile soil conditions, the limited resources of many of the farmers in these regions, and the lack of appropriate agricultural technologies. In many areas, burgeoning populations and the need to increase food production have led to agricultural expansion into tropical forest areas. Productive and sustainable use of these cleared areas would be facilitated by the development of agricultural systems which make efficient use of available resources in a socially acceptable manner. Alley cropping and green manuring were studied in a previously forested transmigration area in West Sumatra as a part of the Tropsoils Indonesia Project to determine whether these are appropriate technologies for increasing agricultural production.

Many agricultural researchers in the tropics mention the importance of managing organic materials in maintaining soil fertility (Buurman, 1980; Swift and Sanchez, 1984; von Uexkull, 1984). Green manuring is a time honored practice of growing and incorporating a soil improving crop which is receiving renewed research interest (Yost and Evans, 1988). Alley cropping is a related practice involving the intercropping of tree hedges and food crops (Kang et al., 1984). These practices may have special merit for farmers with limited resources since they can afford only small amounts of external inputs.

As stated by Satari (1985), the head of the Indonesian Agency for Agricultural Research and Development (AARD), the main objectives for agricultural development in Indonesia are to attain self sufficiency in production of major food crops, increase production of export crops, improve the utilization and conservation of land and water resources and increase the social and economic well-being of rural farmers. As a part of this effort, the national transmigration program is an attempt to achieve a more even distribution of population throughout the country and to develop the productive potential of the outer islands (Hardjono, 1977). In this context, the TropSoils Indonesia Project (hereafter called TropSoils) has been conducting soil management research in the Sitiung transmigration area of West Sumatra since July 1983.

TropSoils functions in Indonesia as a collaborative soil research program among three institutions; the Center for Soil Research (CSR) which is a division of AARD, the University of Hawaii as the lead institution and, up until 1986, North Carolina State University. Funding is provided jointly by the Government of Indonesia (GOI) and the United States Agency for International Development (USAID) under the framework of a Collaborative Research Support Project (CRSP). The overall objective of TropSoils is to develop improved soil management technology that is agronomically and socio-economically sound for developing nations in the tropics. To accomplish this, TropSoils follows a Farming Systems Research and Development philosophy (Shaner et al., 1982) as a basis for developing appropriate technology. To date, most of TropSoil's field research has been conducted in the Sitiung Transmigration area in West Sumatra.

1.2 AGRICULTURAL PRODUCTION IN THE INDONESIAN TRANSMIGRATION PROGRAM

Indonesia's transmigration program is an ambitious effort to resettle hundreds of thousands of families from the densely populated islands of Java, Madura, Bali, and Lombok to the less populated outer islands in the Indonesian archipelago. The largest of these outer islands, which have received the majority of the transmigrants, are Sumatra, Kalimantan, Sulawesi, and Irian Jaya. This effort, results from the desire of the Government of Indonesia to achieve a more even distribution of population throughout the country and to develop the productive potential of the outer islands (Hardjono, 1977; Guiness, 1977). This process began in the early 1900's under a Dutch program called "colonization" and was continued by the Republic of Indonesia soon after independence under the name "transmigration" . These resettlement efforts have undergone many changes in program emphasis and implementation over time.

Many difficulties are faced in the intensive agricultural development of transmigration areas. The relatively unsettled lands of the outer islands are not heavily populated and intensively cultivated, as is Java, for very good reasons. Most importantly, many of the soils in these areas are acidic, very low in plant nutrients and high in soluble aluminum which is toxic to plant growth (Buurman, 1980). Hardjono (1977) attributed the less intensive land use patterns of the outer islands to soil infertility, resulting from intense rainfall and the lack of volcanic activity to enrich the soils, and the presence of swamps and dense forests which restricted human movement.

Since these areas historically were not attractive to settlement, communications and agricultural trade were difficult. Transportation was mainly restricted to coastal and river traffic, since roads were non-existent and markets for goods were totally undeveloped (Hardjono, 1977). Even though progress has been made in recent years in the development of road networks (especially in Sumatra and Kalimantan) and in recommended fertilizer and cropping practices (McIntosh et al. 1980), the task of developing these areas remains daunting. Many transmigrant settlements are quite isolated from supplies of agricultural inputs and access to markets for their produce (Hardjono, 1977; Perry, 1985).

Crop yields in many settlements are very low without fertilizers and decrease over time, due primarily to soil infertility. This forces many transmigrants to depend on off-farm labor for their subsistence needs (Guiness, 1977; Bogor Agricultural University, 1983). On these soils, many of which developed under rain forests, most of the nutrients are concentrated in the shallow surface layer. Productivity is greatly reduced when this layer is lost and the highly infertile subsoil is exposed by erosion. These soils are generally well drained and crop yield reductions from drought stress are common due to shallow rooting depths. Maintenance of soil fertility is greatly enhanced by permanent vegetation or by covering the soil with mulch to reduce soil loss.

Research has shown that upland crop production in transmigration areas of Indonesia can be greatly improved by application of lime and fertilizers (Bevan, 1985; Thomas, 1981; Wade et al., 1988). McIntosh and colleagues (1980) also stressed that improved techniques for crop and pest management are also important to permit economic upland crop production in transmigration areas. Their research in South Sumatra has shown that intercropping and relay planting of annual crops, returning of all crop residues, and application of pesticides and inorganic fertilizers can improve farmer's yields. However, this entails a heavy reliance on external inputs and and consequently increases the risk that the farmer faces. Alternative cropping and soil management practices that do not require high levels of external inputs or intensive management are also needed.

1.3 FARMING SYSTEMS IN SITIUNG

Farming systems in Sitiung, West Sumatra have been described by the author and other researchers with the TropSoils Project (Evensen et al., 1986). There are a variety of farming systems in the Sitiung Transmigration area of West Sumatra because of the diversity of soil environments, resources, and goals of transmigrant farmers and the indigenous Minangkabau communities. The farming systems of the transmigrants especially, are in a state of flux as the new communities mature and the farmers gain experience in the area. Other changes result from the introduction of new government programs (such as the national liming for soybean production program) and the expansion of irrigated areas.

The Sitiung Transmigration area consists of six administrative units (Sitiung I - VI) which lie approximately along the Trans-Sumatran Highway and the Batang Hari River. Settlement started in Sitiung I and II in 1976 and 1977, respectively, with Transmigrants moved from the district of Wonogiri in Central Java. The other four Sitiung units were settled successively by poor (often landless) people from other areas on Java as well as by a small proportion of local Minangkabau people (hereafter referred to as Minang) in Sitiung V and VI.

The soils and general climatic patterns in Sitiung were described in detail by Trangmar et al. (1984) and the Soil Research Institute (1979). Briefly, the soils consist of fairly level Oxisols (in Sitiung I), moderately rolling Oxisols (in Sitiung II, III and IV) and steeper, more highly dissected Ultisols (in Sitiung V and VI). These soils are consistently acid, infertile (low in bases, P, organic matter, and CEC) high in aluminum, deep and well drained. Thus, similar management practices of liming, phosphate fertilization, and organic matter and crop residue management are dictated for all, although the Oxisols in Sitiung I require higher P and lime rates for good crop growth (Wade et al., 1988). Along the river flood plains are more fertile Entisols which are largely farmed by the indigenous Minang population, while isolated river and stream back swamps consist mostly of unfarmed Histosols.

Sitiung has a humid tropical climate with annual rainfall of about 2500 mm and a short dry period with rainfall of about 100 mm $month^{-1}$ during June, July, and August. Rainfall generally increases from August to October and is high through May, usually reaching peaks of 300-400 mm $month^{-1}$ in November and April (SRI, 1979). However, variations in this rainfall pattern occur commonly, resulting in deviations in crop planting patterns and sometimes in total crop failures (Perry, 1985). Mean daily temperatures are relatively constant, averaging 26 oC.

The cropping patterns (i.e. temporal and spatial arrangement of crops and crop management practices) of transmigrant farmers in Sitiung are imposed in part by government allocations of land. Every transmigrant family was given 0.25 ha for a homegarden (surrounding their government supplied house) and 1.0 ha for field crops at a distance of about 1 to 2 kilometers from their house. Only Sitiung I has irrigated fields (which are used for flooded rice production), although an irrigation scheme is also under development in Sitiung II. All other areas have only rainfed upland fields. In addition, all transmigrant families are promised another 0.75 ha plot of land, although up until 1986 only those in Sitiung I had received this land. These additional plots were allocated in 1984 (eight years after the arrival of the farmers) and had not been utilized by 1987, because they are far away (up to 5 km from their house), uncleared, and the farmers lack labor to develop them.

The allocated land holdings were cleared mainly by bulldozing in the earlier settlements (Sitiung I-IV) but mechanical clearing was discontinued in the more recent settlements (Sitiung V and VI) due to the soil damage that such clearing causes (Lal, 1986; Suwardjo, 1986). The surface horizons of these soils, which developed mostly under tropical rainforest, have more favorable chemical and physical properties than the subsoils (SRI, 1979) and mechanical clearing tends to remove these surface soil layers. The transmigrant farmers recognize this damage and in Sitiung V, when given the choice of government provided bulldozers for tree and stump removal or individual clearing by cutting and burning, most chose the latter (Carol Colfer, 1985, personal communication).

Along with these land holdings, farmers were allocated small amounts of fertilizer, with different settlements getting different amounts. In Sitiung V, for example, farmers were allotted 100 kg urea and 100 kg TSP per hectare and in Sitiung II and III, 50 kg urea, 100 kg TSP, and 50 kg KCl per hectare (Mike Wade, 1985, personal communication). These allotments are very modest and probably inadequate amounts for crop production, especially since there was no lime provided at that time.

The general cropping pattern consists of vegetables, fruit trees, cassava, and some pulses in home gardens (pekarangan) and rice and various legumes (soybean, peanut, mung bean, and cowpea) in unirrigated, upland fields (ladang). Sitiung I is the only area with extensive plantings of irrigated rice (sawah) in addition to upland fields. The homegardens are an important source of food and income in this scheme, providing between 28% and 60% of the total cash value of agricultural produce in various communities in Sitiung (Colfer, et. al., 1985). Because homegardens are near the house, they can be more intensively managed than upland fields (often receiving applications of manure and kitchen waste) and are primarily managed by women. They are usually a complex mixture of intercropped perennial and annuals, while the upland fields are generally monocultures, or at most simple combinations of two or three annual crops.

The indigenous Minang farms in the Sitiung area follow a similar pattern of a homegarden surrounding their house and various outlying agricultural fields, which are generally planted to either irrigated rice or rubber (Woods, 1984; Naim et al., 1987). The homegardens tend to be somewhat larger than those of the transmigrants and are predominantly composed of mature perennial species. Also, some wild rubber trees are commonly tapped. In one study, rubber harvests accounted for 93 percent of farmer income among farmers participating in a rubber replanting scheme and 62 percent of income for non-participating farmers (Woods, 1984). Rubber appears to be quite profitable in Sitiung and perennial crops in general provide relatively stable and low risk agricultural income while also protecting the soil (Thomas, 1981; Perry, 1985). It is likely that much can be learned from observing indigenous crop production practices.

Rice is usually planted in upland fields at the beginning of the rains in September or October. Sometimes maize is interplanted with the rice at wide spacings or occasionally a pulse crop like soybean or peanut is planted instead of rice. In fertile areas, upland rice may be followed by peanuts, soybeans, mung beans, or cowpeas in February-March but there is usually no third crop to grow into the dry season. Sometimes, only one crop of upland rice is grown per year and land is left fallow after harvest. Two crops per year of irrigated rice are often grown in Sitiung I and the Minang communities, with transplanting periods occurring in October-November and March-April.

The homegardens, in contrast, are constantly occupied by a mixture of perennial trees, short-lived perennial, and annual crops. Sometimes large sections of the homegarden are planted to upland rice, pulses, or cassava. However, intercropping of a number of crops seems most common, with planting of annuals occurring whenever space opens up and rains are adequate. The tree crops typically grown in homegardens include; jackfruit, rambutan, banana, papaya, coconut, clove, coffee, guava, kapok, and jengkol. Vegetables and pulses are commonly planted and include long bean, chili, vegetable amaranth, swamp cabbage, taro, sweet potatoe, soybean, peanut, cowpea, mung bean, pigeon pea, and curcurbits (see APPENDIX I for a list of English, Indonesian, and Latin names). Cassava, katuk, and pineapple are commonly planted as borders, while sugarcane occurs as random patches (Colfer et al., 1985).

Livestock ownership is widespread in Sitiung (Pulungan, et. al., 1984; Perry, 1985), especially among the older communities, however, forage plantings are uncommon and improved pastures are unknown. Stall feeding with grass cut from non-agricultural fields and grazing of animals on public lands are the norm. Due to increasing livestock populations in Sitiung I, the oldest community, family members have to travel increasing distances to collect feed. There are some small plantings of forage grasses on homegarden plots. Whether larger forage plantings or pastures are appropriate to this social, economic, and cropping environment is unknown.

CHAPTER 2

ALLEY CROPPING IN WEST SUMATRA, PART I. TREE GROWTH AND RESPONSE TO SOIL FERTILITY

2.1 INTRODUCTION

Fast growing species of trees are a common component of humid tropical farming systems and in Asia, such trees are used widely for a variety of purposes. They can provide sources of feed for animal grazing, cut and carry feed, fencing, fuel, shade, soil improvement, and soil stabilization (Ivory et al., 1986; Wiersum and Dirdjosoemarto, 1987; Bray et al., 1987). Leguminous trees play an especially important role in such agricultural systems due to their ability to fix nitrogen, which is transferred to plants grown in association through leaf litter or prunings. In this chapter, I report on the growth and productivity of three leguminous trees, Paraserianthes falcataria (L.) Nielsen (syn. Albizia falcataria), Calliandra calothyrsus Meissn., and Gliricidia sepium (Jacq.) Walp. grown in an alley cropping system in Sitiung, West Sumatra, Indonesia. The growth of the associated food crops is reported in Chapter 3.

Growth and productivity of trees under hedgerow management has been reported by various researchers for Calliandra and Gliricidia (Baggio and Heuveldop, 1984; Horne et al., 1986; Kang and Mulongoy, 1987). However, similar data on growth and productivity of Paraserianthes under hedgerow management has not been reported. All three of these species are valued in Indonesia for various products and are widely used in forestry and agricultural systems. Calliandra and Gliricidia both have the reputations of being able to restore soil fertility in degraded soils (Prayitno and Wijaya, 1979). Paraserianthes is considered to be the fastest growing tree in the Indonesian archipelago in forestry plantings (Sprinz, 1977). Other evaluations of the growth and productivity of these trees in Indonesia are currently underway (Ivory et al., 1986; NFTA, 1988).

An excellent review of the uses of Gliricidia in Asia has been provided by Wiersum and Dirdjosoemarto (1987). They also compared the growth of Gliricidia to that of other tree species, including Paraserianthes and Calliandra, and found all three to be the most productive on differing sites. They indicated that Gliricidia is adapted to a wide range of conditions; it grows from sea level to 1200 m elevation, at average temperatures ranging from 22 - 30 ^{o}C, and average annual rainfall of at least 1500 mm. They also mention that Gliricidia can grow on acid soils of low fertility, but that no precise information is available on the nutrient requirements of the tree.

The specific objectives of the study reported here were: 1) to determine Al tolerance of three legume tree species under Sitiung conditions; 2) to relate tree growth to soil fertility parameters; and 3) to determine leaf and wood production and nutrient contents of the tree species under hedgerow intercropping ("alley cropping") conditions. This research was conducted over the period of December 1984 to May 1988 and was supported by the TropSoils Indonesia Project in conjunction with the Indonesian Center for Soil Research.

2.2 MATERIALS AND METHODS

2.2.1 Site Characteristics

The experiment was conducted in the transmigration village of Sitiung Vc (Aur Jaya) in West Sumatra. This site is at 1^{o}S latitude and 160 m elevation and has a mean annual temperature of 26^{o}C with little seasonal variation (Soil Research Institute, 1979). Rainfall averages about 2600 mm per year and is fairly evenly distributed, although a short dry season occurs in June, July and August. The experimental site was located in a farmer's field along the main road entering the village of Sitiung Vc (Aur Jaya) in West Sumatra.

The soil is classified as a clayey, kaolinitic, isohyperthermic Tropeptic Haplorthox; soil data from an uncleared forest site 50 m from the experiment is presented in Table 3.1 in Chapter 3 (John Kimble, 1986, personal communication). The soil is characterized as clayey, aluminum toxic, with low effective cation exchange capacity (ECEC), and low K reserves (Ceak) in the Fertility Capability Classification system (Sanchez et al.,1982). The original primary forest had been cleared by chainsawing and bulldozing trees into windrows during the 1982/83 wet season. The site had never been cultivated, except for scattered plantings of cassava.

2.2.2 Experimental Design and Statistical Analysis

The experiment was laid out in a split-plot design with four replications. The test crops grown in the alleys were a rotation of upland rice followed by cowpea. The treatments were as follows:

Main Plots - Tree Species

1) *Paraserianthes falcataria* (syn *Albizia falcataria*) (grown from seed)
2) *Calliandra calothyrsus* (grown from seed)
3) *Gliricidia sepium* (grown from hardwood cuttings)
4) No trees (control)

Subplot - Liming Levels

1) No lime
2) Low liming rate (375 kg lime/ha applied in December 1984 and in September 1985, but none applied in 1986, 1987, or 1988)
3) High liming rate to reduce Al+H saturation to 25 % (2 T lime/ha applied in December 1984; 240 to 810 kg lime/ha, varying with individual plots, in September 1985; 500 to 1810 kg lime/ha, varying with replications, in September 1986; no lime applied in 1987 or 1988).

Main plots consisted of three hedgerows of a single tree species planted 4 m apart. Subplot size was 5.5 m x 12 m for the alley-cropped plots and 5.5 m x 6 m for the treeless plots. The harvest area of the subplots consisted of the central 3 m of the center tree hedge and 2 m to either side of the hedge for food crop yields. The harvest area for the treeless subplots was also the central 3 x 4 m of the subplot. The plots were laid out to exclude stumps, soil mounds, and tree-throw holes where possible. Gliricidia was planted from cuttings rather than from seeds because cuttings are the usual planting material for this species in Indonesia (Wiersum and Dirdjosoemarto, 1987).

A split-plot design was chosen to gain precision in the test of the Tree Species x Lime Level interaction as well as to reduce the likelihood of deep rooted tree species from encroaching on adjoining main plots. The following orthogonal comparisons were planned at the initiation of the experiment:

Tree Species Effects:

1) Gliricidia (GLI) vs Other Trees	-	to compare the larger leaved Gliricidia planted from cuttings to the smaller leaved Paraserianthes and Calliandra planted from seed.
2) Calliandra (CAL) vs Paraserianthes (PAR)	-	to compare Calliandra with its high tannin content and tiny leaflets to Paraserianthes with its larger leaflets.

Lime Level Effects:

1) Lime vs No Lime	-	to assess the effects of lime addition.
2) Low vs High Lime	-	to compare liming at a low rate which provided calcium as a nutrient to liming at a high rate to eliminate Al toxicity for the Al tolerant upland rice and cowpea crops.

In addition to these general comparisons of main effects, specific comparisons were planned at each lime rate between No Tree treatments and each tree species. These comparisons were planned to determine the value of alley cropping with the three tree species at three levels of soil aluminum saturation and calcium availability. Fisher's protected LSD at the 0.05 level of probability was chosen as the test statistic due to its power in detecting significant differences in paired comparisons (Chew, 1976). The danger of increased experiment-wise error rates was of less concern than the risk of making Type II errors. Since this was preliminary research on a site with high soil variability (which inflates experimental error) more conservative multiple comparison tests were not used.

2.2.3 Experiment and Hedge Management

The experiment was initiated in December 1984. The lime rates were broadcast over the subplots on 22 December 1984 along with a blanket application of Triple Super Phosphate (TSP) at 40 kg P ha^{-1}. To establish the tree hedges, TSP was applied at 10 g m^{-1} in 25 cm wide strips to provide the equivalent of 80 kg ha^{-1} of P in the strips. Thereafter, TSP and Muriate of Potash (KCl) were broadcast and incorporated with hoes in the alleys at rates of 10 kg P ha^{-1} and 25 kg K ha^{-1} before planting each upland rice or cowpea crop in the alleys. Details on determination of liming and fertilizer rates are presented in Chapter 3.

The trees were planted in hedgerows over the fertilized strips on 29 and 31 December 1984. Intra-row spacing between hills of Paraserianthes and Calliandra was 12.5 cm with 2 seeds planted at about 2 cm depth in each hill. Gliricidia cuttings were planted 25 cm apart within rows. Gliricidia cuttings of 2.5 to 4.0 cm in diameter, 45 to 50 cm in length, and taken from the basal portions of stems were used as suggested by Chadhokar (1982) to give optimal rooting and establishment. The cuttings were obtained from a farm located about 75 km northwest from Sitiung along the Trans-Sumatran Highway. Slanting cuts were made at the base of the cuttings and straight cuts at the tops to indicate proper geotropic orientation.

Paraserianthes seed was scarified for 15 minutes and Calliandra seed for 12 minutes in concentrated sulfuric acid and then thoroughly washed. The seeds were coated just prior to planting with a mixed tree legume inoculum obtained from the NifTAL Project (Paia, Hawaii). The soil at the base of the Gliricidia cuttings was drenched with a suspension of the inoculum after planting.

Non-sprouted Gliricidia cuttings were replaced with sprouted cuttings from a nursery bed on 28 March 1985, making sure that there were no gaps in the harvest areas (the central 3 m of the center row in each subplot). There were a few missing plants only in the outer hedges of Gliricidia plots after March 1985 because of insufficient cuttings to replant all gaps. A few Paraserianthes and Calliandra seedlings were also transplanted into gaps at this time from thickly populated sections of the border hedges.

The trees were first pruned on 17 September 1985, nine months after planting and before planting the upland rice crop at the beginning of the rainy season. The trees were cut to 40 cm stump heights and the prunings were spread in the alleys to dry. After four days, the wood was removed from the plots. Thereafter, the trees were pruned during the growth of the upland rice crop (in November), before planting the cowpea crop (in February), and during the growth of the cowpea crop (in March/April). Prunings during the growth of food crops were made when the most vigorous hedges were about 1 to 1.5 m in height to reduce shading of the food crops.

During the 1985/86 season, prunings were done on 17 September, 26 November, 18 February, and 12 April. During the 1986/87 season, prunings took place on 4 September, 1 November, 7 February, and 29 March. During the 1987/88 season, drought delayed normal pruning and crop planting practices so that prunings took place on 5 October, 21 December, 22 February, and 29 May. Prunings done before planting the alley crops (in September and February) were dried in the alleys, the wood removed, and the leaf incorporated into the soil to about 15 cm depth. Prunings done during crop growth (November and March/April) were mulched without removing the small amounts of wood produced at those times.

At each pruning, samples were taken to determine leaf fraction (GLM), wood fraction, and dry matter content. In the 1985/86 and 1986/87 seasons, two samples were taken from each plot, each consisting of 3 to 6 randomly selected branches. In the 1987/88 season, only one sample was taken per plot due to time constraints. Each sample was separated by hand into leaf (leaflet and rachises) and wood (twig and stem) fractions. Paraserianthes and Calliandra samples were generally about 400 to 600 g fresh weight of total leaf and wood while Gliricidia samples were about 100 to 300 g fresh weight (because there were fewer Gliricidia prunings available). Samples were sun dried to constant weight and two randomly selected leaf and two wood samples per tree species were oven dried at 60 ^{o}C to calculate oven-dry weights.

Tree leaf tissue samples from selected prunings were also analyzed for nutrient contents. Air-dried samples were oven dried at 60 ^{o}C and then ground to pass a 1 mm mesh in a Wiley mill. Total elemental analysis was done at the University of Hawaii Agricultural Diagnostic Service Center using an X-ray fluorescence quantometer for the September 1985 pruning and an ICP Spectrometer for subsequent prunings. Nitrogen was determined using a semi-automated indophenol blue colorimetric method (Suehisa, 1980). Descriptions of soil sampling and analysis procedures are given in Chapter 3.

2.2.4 Tree Species Assessment

As a follow-up to the main alley cropping experiment, a tree species assessment trial was conducted in Sitiung Vc. The objectives of this study were: 1) to assess the growth and productivity of various fast growing tree species under the soil and climatic conditions in Sitiung; 2) to select the most promising tree species for future agroforestry research; 3) to provide a source of seeds and cuttings of the desired tree species; and 4) to serve as an educational planting to familiarize local researchers and farmers with the species, their growth habits and uses.

Seed for this trial was obtained from the Nitrogen Fixing Tree Association (NFTA in Waimanalo, Hawaii) as a part of their effort to assess fast growing legume trees under various environmental conditions. The trial was established in two sites, at which different numbers of species and unequal plot sizes were used. The main planting was made at the Center for Soil Research Office complex near Gunung Medan, West Sumatra and consisted of large (6m x 20m) unreplicated plots of trees at 1m x 1m spacing. Thirteen tree species were planted in the following order; Acacia auriculiformis, A. mangium, A. mearnsii, Paraserianthes falcataria (syn. Albizia falcataria), A. procera, Calliandra calothyrsus, Cassia siamea, Gliricidia sepium, Leucaena diversifolia (K156), L. leucocephala (K8), Pithecellobium dulce, Albizia saman, and Sesbania grandiflora. The trial was designed to add on new species as seed became available. A secondary planting was made at a homegarden site in Sitiung Vc village. At this site, plots were 4m x 7m with trees at 1m x 1m spacing and the species planted were A. auriculiformis, P. falcataria, A. procera, C. calothyrsus, G. sepium, L. diversifolia, L. leucocephala, and S.saman

The trees were grown from seed planted on 3 September 1985 in plastic bags in a medium consisting of 4 parts soil and 1 part manure with a small amount of Triple Super Phosphate. The Gunung Medan site was prepared by cutting and burning brush and small trees and removing small stumps. The Sitiung Vc site was cleared land and only required weeding. No fertilizer was applied in either site, nor was the soil tilled. Seedlings were transplanted on December 18, 1985 at the Gunung Medan site and on January 2, 1986 at the Sitiung Vc site. Many of the A. mearnsii died within two months from transplanting and the Sesbania were transplanted too late and had become root bound. Therefore, data were not collected from these two species. The Gunung Medan site was weeded in February and in April 1986 and thereafter, the most vigorous species began to shade out weeds while the less vigorous species were allowed to compete with weeds. The Sitiung Vc site was weeded about once a month for the first three months and occasionally thereafter.

Tree height and basal diameter were measured at 4, 6, 9, 12, and 19 months after transplanting at the Gunung Medan site and at 6 and 12 months at the Sitiung Vc site. Twenty trees were measured in the center two rows in each plot at the Gunung Medan site and ten trees in the center two rows at the Sitiung Vc site. After 19 months, growth differences between species were well established so no further measurements were made of the trees.

2.3 RESULTS AND DISCUSSION

2.3.1 Tree Growth and Green Leaf Manure Yields

Paraserianthes was the most productive tree species in the first pruning, but in the February and April prunings, Calliandra was the most vigorous and productive species. Mean yields of tree species are presented since the effects of lime rates and lime x species interactions on yields were not significant (Tables 2.2 and 2.3). Due to large amounts of leaf and wood produced by the Paraserianthes during early growth, this species produced highest yields during the first season of pruning (from planting in December 1984 to the last pruning of the 1985/86 season in April 1986). Paraserianthes wood yields were much higher than the other species, however, the wood is soft, with a specific gravity of 0.24 - 0.49 (NAS, 1983), and is not as desirable as fuelwood to local farmers as is Calliandra. The tree yields were calculated on the basis of total intercropped land area, not just yield per hedgerow area.

Gliricidia hedges were far less vigorous and productive; this species is probably not as well adapted to the acid and infertile soils in Sitiung. However, the Paraserianthes and Calliandra were grown from seed and therefore had the benefit of strong taproots. Since the alleys were cultivated twice per year to 15 cm depth, this may have disrupted the root systems of Gliricidia more than the other species. Cuttings often produce more fibrous roots which grow laterally than do seedlings (Hartmann and Kester, 1975). However, root distributions of the tree species were not studied in this experiment and the potential for greater disruption of Gliricidia root systems due to alley cultivation remains hypothetical.

Analysis of variance of leaf yields are presented in Table 2.2 and of wood yields in Table 2.3 for the 1985/86 season. Leaf and wood yields were significantly lower for Gliricidia hedges than for the other species. As already mentioned, Paraserianthes yields were highest in the first pruning while Calliandra yields were highest in the last two prunings. Lime rates had no significant effect on yields of leaf or wood. However, there was a non-significant tendency for Gliricidia yields to increase with increasing liming levels (see Appendix II, Tables II.1 and II.2).

Yields of leaf and wood and heights of hedges at pruning for the 1986/87 season are shown in Tables 2.4 a, b, and c, respectively. Unlike the 1985/86 season, Calliandra produced more total biomass than Paraserianthes in this season. However, at the first pruning in September both Calliandra and Paraserianthes produced about the same amounts of leaf and wood. This was the most important GLM application since it was the largest and preceded the first crop of the season. GLM application at this time would probably allow complete decomposition and availability of nutrients for the crops. Gliricidia again produced lowest yields at all prunings.

Analysis of variance of yields in the 1986/87 season (Tables 2.5 and 2.6) shows that Calliandra yields were significantly higher in the November, February, and March prunings but were not significantly different from Paraserianthes yields in the September pruning. Interestingly, in the November and March prunings, liming produced significantly higher leaf yields than not liming. As can be seen in Appendix II, Table II.3, both Calliandra and Gliricidia leaf yields increased with lime application but Paraserianthes leaf yields did not. Wood yields did not increase with lime application.

Yields of leaf and wood and heights of the hedges at pruning for the 1987/88 season are shown in Tables 2.7 a, b, and c, respectively. A prolonged dry spell (May to September 1987) preceded this season of growth and delayed the first hedge pruning until 5 October 1987. The alley crop of upland rice was not planted until 17 November and subsequent tree prunings were each about a month later than in the two previous seasons. As in the 1986/87 season, the highest leaf and wood yields were produced by Paraserianthes hedges in the first pruning while Calliandra yields were highest in the three subsequent prunings (Tables 2.7, 2.8, and 2.9). Total leaf yields for the season were highest for Calliandra hedges, while total wood yields for the season were equal for Calliandra and Paraserianthes.

The analysis of variance of leaf yields in the 1987/88 season (Table 2.8) indicate that there was a significant response to lime and a significant lime x species interaction only for leaf yields in the May 1988 pruning. Paraserianthes leaf yields did not differ with varying rates of lime. Gliricidia leaf yields tended to increase with lime application, while Calliandra leaf yields only increased occasionally (Appendix II). These occasional leaf yield responses to lime indicate that Calliandra and Gliricidia may be less tolerant to soil acidity than is Paraserianthes. Based on these data, the species can be tentatively ranked in terms of response to lime as: Gliricidia >> Calliandra > Paraserianthes.

In greenhouse trials in Nigeria using four tree species growing in an acid Ultisol, Duguma (1982, cited in Kang and Mulongoy, 1987) found that Gliricidia responded more strongly to lime application than did Calliandra. Kang and Mulongoy (1987) in a review of literature indicate that well-drained, fertile soils are required for best growth of Gliricidia and that it is not as well adapted to high Al or low Ca levels as is Calliandra. They also found that on good sites, Gliricidia can produce up to 15 tons DM ha^{-1} $year^{-1}$ in dense stands and over 5 tons DM ha^{-1} $year^{-1}$ in 4 m wide hedgerows in West Africa. These yields are far above yields of Gliricidia attained in this experiment and are probably related in large part to more fertile soils in the African sites. Similar data on yields of Paraserianthes hedgerows have not been reported.

Kid and Taogaga (1984; 1985) studied alley cropping with taro (Colocasia esculenta) on a slightly acidic soil (pH range of 5.4 to 6.7) in Western Samoa. In two years of pruning management, Calliandra calothyrsus yielded the highest pruning biomass (12.2 tons DM ha^{-1} $year^{-1}$), followed by Leucaena leucocephala (10.7 tons DM ha^{-1} $year^{-1}$) and Gliricidia sepium (7.9 tons DM ha^{-1} $year^{-1}$). They also noted that Calliandra could be pruned more frequently (every 5 - 6 weeks) than could Gliricidia (every 8 weeks) due to the slower growth rate of the latter.

Atta-Krah and Sumberg (1987) report that among tree species tested in Nigeria by the International Livestock Center for Africa

(ILCA), Gliricidia is second only to Leucaena in leaf and wood yields in humid areas with non-acid soils. Both have multiple uses as green manure, nutritious livestock feed, fuelwood, and sources of poles. However, neither Leucaena nor Gliricidia appear to be adapted to extremely acid soils. Although Gliricidia is often thought to be tolerant of low soil fertility, it does not appear to be as tolerant as are Paraserianthes or Calliandra, which appear to be better species for agroforestry development for soils similar to those in Sitiung.

2.3.2 Leaf Nutrient Concentrations

Concentrations of nutrients in green leaf manure (GLM) were determined by analysis of the leafy fractions at five prunings. At the first pruning in September 1985, Gliricidia GLM contained the highest concentrations of N, P, Ca, and S, while concentrations of K were equivalent to Paraserianthes GLM (Table 2.10). Calliandra GLM had the lowest concentrations of all nutrients, although it was not significantly lower than Paraserianthes in P, Ca, Mg, and S (Table 2.11). Paraserianthes had the highest concentration of Mn.

Increasing lime rates caused a significant decrease in K concentration in Gliricidia GLM and similar (nonsignificant) trends for the other species. This may be due to competition between Ca and K for plant uptake (Mengel and Kirkby, 1982). Also the decreasing K concentration in Gliricidia GLM may also indicate a dilution effect (Jarrell and Beverly, 1981) associated with increased tree growth at higher lime rates. Ca concentrations increased in GLM of all three species with increasing lime rates.

At the September 1986 pruning, concentrations of only P and Ca were highest in Gliricidia GLM while K, Mg, and Mn were highest in Paraserianthes GLM (Tables 2.12 and 2.13). Concentrations of N, K, and Mg were lowest in Calliandra GLM. Application of lime caused significant increases in Ca concentrations in all three species and a decrease in Mg concentration in Gliricidia GLM. There was also a lime x species interaction for P concentration. P in GLM increased with increasing lime rates for Gliricidia but not for the other species. This increasing P level in Gliricidia GLM probably indicates that root systems were more vigorous and extensive at the higher lime rates. More Gliricidia roots were observed in the limed plots during soil cultivation.

Table 2.14 presents nutrient concentrations in GLM at three additional prunings which together with the September 1985 and 1986 data span the range of harvest periods occurring in this study. Nutrient concentrations within species are surprisingly similar for the three harvest intervals, except that concentrations of N, K, and Ca are slightly lower at the longer harvest intervals. Between the two productive tree species, Paraserianthes had higher nutrient contents than did Calliandra. Yields of nutrients per hectare at the various prunings are reported in Chapter 3.

Nutrient contents of tree leaves have been reported for some tree species which are used for forage and browse (Gohl, 1981; Skerman, 1977), but of the three species studied here, only the leaf nutrient concentrations of Gliricidia have been well documented. Chodhokar (1982) reported generally higher nutrient concentrations in Gliricidia leaves. He found K, Ca, and Mg concentrations of 28.0, 17.5, and 4.0 g kg^{-1} respectively at 3 month harvest intervals and 30.0, 13.8, and 4.1 g kg^{-1} respectively at 6 month harvest intervals. In alley cropping studies on an Alfisol in Nigeria, Kang et al. (1984) reported P, K, Ca, and Mg concentrations in Gliricidia prunings of 2.9, 34.3, 14.0 and 4.0 g kg^{-1} respectively. Wiersum and Dirdjosoemarto (1987) reported Ca levels of 13.2 g kg^{-1} in Gliricidia foliage used for animal feed in Indonesia. These values are much higher than concentrations reported here and may indicate that Gliricidia requires higher availability of these nutrients for good growth. Also, these higher nutrient concentrations in Gliricidia foliage from other areas suggests that in this study Gliricidia was under severe nutrient stress.

Although these leafy materials were used as organic fertilizer, they make nutritious fodder and could have been fed to livestock (Chadhokar, 1982; Ivory et al., 1986; Atta-Krah and Sumberg, 1987). N concentrations of 28 to 48 g kg^{-1} are equivalent to approximately 17.5 to 30 % crude protein. Since hedges remained green through the dry season, hedgerow prunings may make especially valuable feed supplements at that time. Thompson and Evensen (1985), evaluated the productivity of 21 accessions of herbaceous forage legumes in Sitiung from the genera Aeschynomene, Calopogonium, Centrosema, Desmodium, Macroptilium, Pueraria, Stylosanthes, and Zornia. The following ranges of nutrient concentrations (in g kg^{-1}) were found in these different forages: N, 11.6-26.3; P, 0.7-2.0; K, 2.8-16.0; Ca, 1.3-11.1; Mg, 1.1-2.0; and S, 0.7-1.6. Nutrient concentrations in Paraserianthes and Calliandra leaves were equivalent or higher than the highest concentrations in these herbaceous forages. Therefore, these tree species may have good potential as nutritious forage for livestock production in humid areas with acid soils. However, proximate analysis and digestibility of Paraserianthes and Calliandra forage should be determined before their value as feed can properly be assessed.

2.3.3 Tree Yield Response to Soil Fertility

An objective of this study was to relate tree growth to soil test data. Soil analyses are presented in Chapter 3 in conjunction with food crop yield data. However, to provide an indication of the relationship between tree growth and soil fertility, total biomass yields (leaf + wood) were regressed on various soil test parameters based on soil samples taken to 15 cm depth from the harvest areas.

Correlation coefficients for the 1985/86 season are presented in Table 2.15a and for the 1986/87 season in Table 2.15b. In the 1985/86 season, increasing Paraserianthes yields were most strongly related to exchangeable K and Calliandra yields were strongly related to exchangeable Mg, although none of the regressions for these two species were significant. Gliricidia biomass yields, however, were significantly related to exchangeable Ca as well as to percent acid (Al+H) saturation. The range of soil test values for each sampling is also presented.

In the 1986/87 season, additional soil measurements were made for pH(water), % organic carbon, and % total nitrogen. Paraserianthes biomass yields were significantly related to % organic matter and to % total N. Calliandra biomass yields were significantly related to exchangeable Mg. Gliricidia biomass yields were strongly related to exchangeable Ca, extractable acidity, and to % acid saturation. Thus, in both seasons, exchangeable Ca was the best predictor of Gliricidia growth.

Using this information, predictive models were developed relating tree biomass growth in the 1986/87 season to soil test parameters. A stepwise regression procedure was used (Draper and Smith, 1981) with "best" regression equations selected based on increases in R^2, reduction of residual sum of squares, and partial F-values of predictor variables with probability values of less than the 0.10 level. For Paraserianthes, the selected regression equation included % organic carbon and extractable P terms and accounted for 66 % of the variation in biomass yields. The selected model for Calliandra included only a exchangeable Mg term and accounted for 39 % of the biomass yield variation. Gliricidia yields were most strongly correlated with exchangeable Ca and the regression equation selected accounted for almost 87 % of the biomass yields in the 1986/87 season. However, these equations only apply to the ranges of soil test values indicated in Table 2.15.

These regressions provide indications of the adaptability of the different tree species to sites with varying soil fertility. Calliandra and Paraserianthes both appear to be species which tolerate acidic soils with low base status. Calliandra, however, may respond to Mg application on such soils. Gliricidia is clearly responsive to Ca applied as lime. Graphs of Gliricidia yields suggest critical soil Ca levels of about 1 $cmol_cL^{-1}$ and critical acid saturations of about 65 %, although determination of such critical levels requires more thorough testing at multiple sites. These results are consistent with those of Glover (1986) who, in provenance trials using several Gliricidia lines tested at four sites, found a linear relationship between soil Ca levels and tree growth. She also noted that tree growth was less on high Al soils.

Dalmacio (1987) characterized the productivity of forestry stands of Paraserianthes falcataria in the Philippines and related soil factors to site index, which is a function of tree height and age. He found that depth of topsoil, % sand, % silt, and exchangeable K content were positively correlated with the site index, while % clay and organic matter content of the topsoil were negatively correlated. This differs from the present study in which K did not correlate well with Paraserianthes yield and % organic carbon was positively related to yields. Dalmacio hypothesized that the decrease in site index associated with increasing % organic matter and clay content was related to poor aeration in this very wet region (with an average annual rainfall of 4654 mm). It may be that the positive correlation of site index to K indicates higher K requirements for large trees (average heights were 25 m) because of large amounts of K in the standing wood biomass.

Bray et al. (1988) are presently studying the adaptability of Calliandra, Gliricidia, and Leucaena under hedgerow management to acid and infertile soils in four sites in Indonesia and Australia. The sites were chosen so that all have low exchangeable Ca and so that one site in each country has low and the other has high aluminum saturation. This research is unique in that the response of the trees to P, Ca, trace elements, and the alleviation of Al toxicity are all being studied.

Preliminary results from the first pruning of the study by Bray and his colleagues indicate that all three species responded to P application. Calliandra did not respond to Ca applied as gypsum while Gliricidia did. Both species responded to lime application at only one of the sites, a Paleudult in South Sumatra which had the highest Al saturations of any site. However, the lime response at this site was confounded by the use of lime with a 10 % Mg content. These results indicate that Gliricidia may require Ca as a nutrient rather than as a liming material for the reduction of Al toxicity.

2.3.3 Trends in Yields and Tree Longevity Under Hedgerow Management

Yields of leaf and wood followed a cyclic pattern which was related to the season of growth and the length of harvest intervals. Figure 2.1 shows the yields of leaf (GLM) at each pruning over a three year period. The leaf yields of all three species were highest at the first pruning of each season (September/October). This pruning followed the longest period of hedge regrowth (4 - 5 months) each year, since the trees were left uncut through the dry season (June - August). Paraserianthes yields were the highest of the three species at the September 1985 pruning, after which Calliandra yields were equal or higher at all subsequent prunings. Gliricidia yields were consistently lowest.

Wood yields of the three tree species over three years (Figure 2.2) followed a similar pattern to leaf yields. Wood yields were highest at the longer harvest intervals (September/October and February prunings) at which time large amounts of wood were removed from the Paraserianthes and Calliandra plots. This wood could provide a valuable fuel or pole wood source to farmers and was dry and could be easily transported in bundles. Diameters of the main stems of Paraserianthes and Calliandra at the September prunings ranged from about 15 - 50 mm, which are convenient sizes for home cooking fuel. Small quantities of wood were produced at the shorter harvest intervals (November and April/May prunings) which were left in the plots to decompose.

The relationship of pruning time and harvest interval to percent leafy fraction of the prunings is shown in Figure 2.3. The proportion of leaf in the prunings increased with decreasing intervals between prunings. Duguma et al. (1988) also observed an increase in the leafy fraction at more frequent prunings of Gliricidia, Leucaena, and <u>Sesbania grandiflora</u> in alley cropping studies in Nigeria. This change in leaf to wood ratio, favoring leaf production at shorter harvest intervals, has been well documented for leucaena (Savory and Breen, 1979; Osman, 1981; Evensen, 1984).

Data was collected on the survival of trees in the harvest areas over time and is presented in Figure 2.4. Up until 29 months after planting the hedges (May 1987), Paraserianthes and Calliandra hedges survived well and grew vigorously. Both species were planted by direct seeding in hills 12.5 cm apart with 2 seeds per hill (ie. at a rate of

16 seed per meter). By nine months after planting (September 1985), the 3 meter long harvest areas averaged 28.6 Paraserianthes plants (1.2 plants per hill) and 22.8 Calliandra plants (about 1 plant per hill). No thinning was done since it was assumed that farmers would probably not thin seedlings since they do not usually thin any of their crops. Tree survival data was not collected in the 1987/88 season.

Gliricidia, however, suffered significant mortality between the 9th and 20th month after planting and continued to decline thereafter. Cuttings were initially planted 25 cm apart within rows, giving 12 plants per 3 m in the harvest areas. Mortality appeared to be greater in the unlimed plots, although differences between lime levels were not significant due to small sample size (4 replications per lime level) and a consequent lack of precision in testing the differences.

Tom Dierolf, who took over the experiment in August 1988, reported on the survival of the trees in October 1988 (Dierolf, 1988a). Gliricidia trees had continued to die, especially in the unlimed plots in which only about 11 % of the original stand had survived. Also, Paraserianthes had suffered high mortality and large gaps were present in the hedgerows, while Calliandra hedgerows were vigorous and fairly uniform. Dierolf (1988b) also conducted an informal survey of researchers working with hedgerow management of trees in Indonesia and found that several respondents reported dieback of Paraserianthes with frequent pruning and low pruning heights. Gliricidia was also reported to have fairly shallow roots which were damaged by soil cultivation in studies in the Philippines.

Factors besides low soil fertility and intensive pruning have reduce tree survival in other studies. Kid and Taogaga (1984) noted that survival of Calliandra trees in hedgerow management in Western Samoa was higher (83 %) than Gliricidia trees (64 %) after frequent pruning with "bush knives", dry weather, and weed competition over a 19 month period. The damage due to blunt knives and "over-zealous" pruners was sometimes severe but was thought to simulate what would be done by farmers.

Clearly, well adapted tree species and careful management of the hedges are required for long-term survival of trees in alley cropping systems. The dieback of Paraserianthes in the fifth year after planting is of serious concern, since it was very productive in the early years of the experiment and was associated with the highest food crop yields from 1985 to 1988 (Chapter 3). Satjapradja and Sukandi (1981) report that the lifespan of Calliandra trees under coppice management in forestry plantings in Indonesia is estimated to be 10 - 15 years. It seems likely that Calliandra is better adapted to intensive pruning than is Paraserianthes.

2.3.4 Tree Species Assessment

Height and basal diameter measurements are shown in Table 2.17 for the Gunung Medan site and in Table 2.18 for the Sitiung Vc site. The most vigorous species were *Paraserianthes falcataria*, *Acacia mangium*, *Cassia siamea*, and *Calliandra calothyrsus*. These species produced large amounts of wood and leaves and seem to be the most promising for future agroforestry work in areas with soils and climatic conditions similar to Sitiung.

Gliricidia grown from seed obtained from NFTA was far less vigorous than Paraserianthes or Calliandra at both sites. This suggests that poor growth of Gliricidia in the alley cropping study was not just due to planting of cuttings or an unproductive variety of Gliricidia. Since all tree species were grown from seed and managed equally, this study supports the contention that Gliricidia is not as well adapted to acid and infertile soils as are Paraserianthes and Calliandra, even when all species were started from seeds. Soil analyses from samples taken on 6 May 1986 are presented in Table 2.19. These soil test results are generally representative of those commonly found in the Sitiung region.

Sudjadi, et al. (1985) compared 16 tropical tree species grown for 21 months at 1 m x 1 m spacing on an acid and infertile soil in Lampung, South Sumatra. They reported the species with the fastest growth and highest wood production was Acacia mangium (46 m^3 wood ha^{-1} $year^{-1}$), followed by P. falcataria (28 m^3 wood ha^{-1} $year^{-1}$), and Cassia siamea (21 m^3 wood ha^{-1} $year^{-1}$). However, a prolonged dry period of 5 months duration (with monthly rainfall below 50 mm) was experienced during the experiment and would have decreased growth of a moisture demanding species such as Paraserianthes (NAS, 1983). Calliandra calothyrsus and Gliricidia sepium were both much lower yielding (4.4 and 1.1 m^3 wood ha^{-1} $year^{-1}$, respectively).

Wiersum and Dirdjosoemarto (1987) reviewed several studies in Java which reported higher leaf and wood production for Gliricidia and

Calliandra plantings than for Paraserianthes. They also suggested that Gliricidia may be better adapted to "degraded sites" than is Calliandra, but did not provide soil analyses of the sites. The Nitrogen Fixing Tree Association (1988) reported that preliminary results from an international network of tree species assessment trials show great differences in species performance on various sites. On humid sites with acid soils, performance of Paraserianthes, Calliandra, and Gliricidia were inconsistent, alternately outgrowing each other. These studies indicate that there are strong tree species by site interactions which need to be better characterized before accurate species recommendations can be given.

2.4 RECOMMENDATIONS FOR FUTURE RESEARCH

An urgent research need identified in these studies is to determine the pruning management of Paraserianthes and Calliandra to optimize the production of leaf and wood, long term survival of the trees, and yields of intercropped food crops. These separate criteria are somewhat incompatible. For example, highest tree biomass production is achieved with pruning heights of over 1 m for many tree species (Horne et al., 1986; Duguma et al., 1988) while lower pruning heights reduce shading effects of the hedgerows on intercropped food crops (Kang et al., 1984). Intensive pruning may also reduce the longevity of trees. Different pruning strategies may be required for different tree species to optimize the various outputs from alley cropping systems.

Less frequent prunings (1 - 2 times per year) of Paraserianthes should be studied to determine the effects on tree yields and longevity. In additions, higher prunings heights (height of the stump after pruning) may allow longer survival of hedges. In the alley cropping study reported here, pruning heights of 40 cm were maintained at each pruning. It may be beneficial to cut the hedges higher initially or to raise the pruning height at each subsequent pruning. Also, intercropping of taller growing crops such as maize, cassava, or tree crops would allow use of higher pruning heights without excessive competition for light. Periodic "resting" periods where the hedges are allowed to grow uncut for a year or more may also increase longevity of Paraserianthes hedges.

Conversely, more frequent pruning and lower pruning heights of Calliandra hedges should be studied to try to reduce competition with alley crops. The appropriate number of prunings per year depends on the alley crop to be grown, but prunings as frequent as monthly may be tolerated by this species. However, increasing labor costs of the more frequent prunings must also be considered. (See Chapter 4 for a discussion of the effects of labor costs on the profitability of alley cropping.)

Studies of alternate tree species for alley cropping in humid environments with acidic soils is also urgently needed. Other species of legumes with potential for hedgerow management on humid lowland sites with acid soils include; Acacia angustissima, A. vilosa, Cassia festula, C. siamea, Desmodium gyroides, Enterolobium cyclocarpum, Erythrina poeppigiana, Flemingia macrophylla, Inga edulis, Leucaena spp., *Mimosa scabrella*, *Sesbania bispinosa*, and *S. sesban* (Nair et al., 1984; Salazar and Palm, 1987; Dierolf, 1988b). Hedgerow management and intercropping with food crops on a number of sites would provide realistic means of assessing their value as alley cropping species. The possibility of combining several species in a hedgerow (or in alternate hedgerows) should also be studied to increase the range of tree products from a system. Also, information on nutrient diagnostic levels in plant tissue and soils, especially critical levels for optimal growth, is needed to select tree species for specific environments and to assess their fertilizer requirements.

2.5 CONCLUSIONS

This research on tree productivity in an alley cropping system in Indonesia has shown that *Paraserianthes falcataria* and *Calliandra calothyrsus* are well adapted to acid and infertile soils, while *Gliricidia sepium* may not be. Calliandra produced the largest amounts of green leaf manure in the 1986/87 and 1987/88 seasons, in contrast to the 1985/86 season in which Paraserianthes was most productive. Calliandra tended to grow back very rapidly from cutting and produced a very dense canopy. Both tree species produced approximately the same amount of wood annually, although the seasonal distribution of yields were different. Overall, Calliandra hedges were more productive and vigorous and had greater longevity. However, since the more vigorous growth shaded intercrops more (Chapter 3), Calliandra may require more frequent pruning than Paraserianthes in alley cropping systems.

Gliricidia grew relatively poorly and produced small amounts of leaf and wood. It was apparently adversely affected by the high acidity and infertility of the soil and responded strongly to increasing soil Ca availability. Conversely, Paraserianthes and Calliandra seem well adapted to such soil conditions. However, best Paraserianthes growth was associated with higher soil organic carbon levels while best Calliandra growth was associated with higher soil Mg availability.

If early productivity and short longevity of trees would be desirable, Paraserianthes is clearly the best choice among the species studied in this research. Such characteristics might be desirable immediately following forest clearing in establishing a transmigration site. Rapid early growth would be important to conserve soil nutrients following clearing, while several years after settlement, transmigrants may desire to convert alley cropped land to alternate uses such as fruit tree or pasture production. If trees hedges in an alley cropping system were declining in vigor at that time, the trees could be removed or allowed to die. However, it is assumed that short lifespans of trees in alley cropping systems are generally undesirable.

"Optimal" management of tree hedges in alley cropping depends on the products desired from the system. If maximum production of food crops is most important, trees should be pruned frequently and at low pruning heights. This will reduce shading of crops but will also reduce leaf and wood yields of most tree species. If leaf production is mainly desired from hedges, then short harvest intervals may be desirable which result in a high proportion of leafy to woody fractions of the prunings. However, if wood is the main product desired, longer harvest intervals of four months or more are required.

In many cases, farmers want all of these products; this is an important reason for growing "multipurpose trees". Such trees provide farmers with the flexibility to change management practices to produce varying amounts of leaf, wood, and food crops at different times to meet their changing needs. Therefore, maximal production of any single component of an alley cropping system may not be desired, but rather optimal production of the desired mix of products from the system. The option to choose various products (leaf, wood, or crops) and to change management practices to produce different combinations of products may make alley cropping attractive to farmers. Determining how to achieve this optimal mix of products with a range of tree species and food crops is a great challenge for agroforestry researchers in their efforts to improve the welfare of farmers with limited resources.

Table 2.1. Yields of tree hedgerows during the 1985/86 season.

a. Leaf Yield[1]

Tree Species	Sept.'85	Nov.'85	Feb.'86	Apr.'86	Total: 4 Prunings
	Tree Pruning Date				
	kg ha^{-1}				
Paraserianthes	1489	538	264	220	2511
Calliandra	397	531	590	332	1850
Gliricidia	172	196	90	68	526
LSD (0.05)	335	154	141	87	600

b. Wood Yield[1]

Tree Species	Sept.'85	Nov.'85	Feb.'86	Apr.'86	Total: 4 Prunings	Fuel[2] Wood
	Tree Pruning Date					
	kg ha^{-1}					
Paraserianthes	2685	416	408	101	3610	3093
Calliandra	496	391	460	150	1497	956
Gliricidia	180	111	77	23	391	257
LSD (0.05)	969	120	139	30	1092	1069

c. Tree heights at pruning

Tree Species	Sept.'85	Nov.'85	Feb.'86	Apr.'86
	Tree Pruning Dates			
	cm			
Paraserianthes	253	161	173	92
Calliandra	131	143	174	94
Gliricidia	109	94	98	57
LSD (0.05)	71	20	23	9

[1] Yield in kg/ha is calculated in the basis of total intercropped land area, not just yield per hedgerow. (To calculate kg yields per meter of hedgerow, multiply yields/ha x 0.0004).

[2] Fuel wood is the sum of only the Sept.'85 and Feb.'86 harvests, since the wood was taken off the plots only at these times.

Table 2.2. Analysis of variance for leaf yields in the 1985/86 season.

Source	df	Tree Pruning Date: Sep'85	Nov'85	Feb'86	Apr'86	Total: 4 Prunings
		P Values				
Rep	3	0.179	0.969	0.572	0.566	0.389
Tree Spp.	(2)	0.000	0.002	0.000	0.001	0.001
GLI. vs Others	1	0.001	0.001	0.001	0.001	0.000
PAR. vs CAL.	1	0.000	0.917	0.001	0.020	0.036
Error A	6					
Lime Rates	(2)	0.377	0.748	0.368	0.191	0.532
Lime vs No lime	1	0.345	0.468	0.751	0.085	0.303
Low vs High lime	1	0.303	0.844	0.173	0.589	0.674
Lime * Tree Spp.	4	0.751	0.390	0.462	0.587	0.723
Error B	18					
CV (%) Main-plot		49	37	45	42	37
CV (%) Subplot		55	38	35	25	36

Table 2.3. Analysis of variance for wood yields in the 1985/86 season.

Source	df	Tree Pruning Date: Sep85	Nov85	Feb86	Apr86	Total: 4 Prunings	Fuel[1] Wood
		P Values					
Rep	3	0.254	0.942	0.246	0.554	0.238	0.252
Tree Spp.	(2)	0.001	0.001	0.001	0.000	0.001	0.002
GLI. vs Others	1	0.006	0.000	0.000	0.000	0.001	0.003
PAR. vs CAL.	1	0.001	0.616	0.389	0.007	0.003	0.003
Error A	6						
Lime Rates	(2)	0.456	0.966	0.730	0.734	0.572	0.559
Lime vs No lime	1	0.588	0.806	0.726	0.443	0.622	0.643
Low vs High lime	1	0.263	0.935	0.483	0.914	0.355	0.336
Lime * Tree Spp.	4	0.724	0.480	0.402	0.597	0.770	0.794
Error B	18						
CV (%) Main-plot		87	39	44	33	60	75
CV (%) Subplot		83	47	43	33	57	69

1 Fuelwood is the sum of only the September and February harvests, since the wood was taken off the plots only at these times.

Table 2.4. Growth and yields of tree hedges during 1986/87

a. Leaf Yield[1]

Tree Species	Sept.'86	Nov.'86	Feb.'87	Mar.'87	Total: 4 Prunings
	Tree Pruning Date				
	kg ha^{-1}				
Paraserianthes	1027	217	292	189	1725
Calliandra	1248	550	948	446	3192
Gliricidia	101	122	86	70	379
LSD (0.05)	271	123	254	96	628

b. Wood Yield[1]

Tree Species	Sept.'86	Nov.'86	Feb.'87	Mar.'87	Total: 4 Prunings	Fuel[2] Wood
	Tree Pruning Date					
	kg ha^{-1}					
Paraserianthes	2680	45	508	75	3308	3188
Calliandra	2640	185	919	197	3941	3559
Gliricidia	133	31	79	21	264	212
LSD (0.05)	928	44	113	60	1155	1075

c. Tree heights at pruning

Tree Species	Sept.'86	Nov.'86	Feb.'87	Mar.'87
	Tree Pruning Dates			
	cm			
Paraserianthes	317	95	189	89
Calliandra	264	117	200	102
Gliricidia	101	66	88	65
LSD (0.05)	42	10	25	16

1 Yield in kg/ha was calculated on the basis of total intercropped land area, rather than yield per hedgerow. (To calculate kg yields per meter of hedgerow, multiply yields/ha x 0.0004).

2 Fuel wood is the sum of only the Sept.'86 and Feb.'87 harvests, since the wood was taken off the plots only at these times.

Table 2.5. Analysis of variance for leaf yields in the 1986/87 season.

Source	df	Tree Pruning Date: Sep'86	Nov'86	Feb'87	Mar'87	Total: 4 Prunings
		P Values				
Rep	3	0.373	0.543	0.501	0.117	0.399
Tree Spp.	(2)	0.000	0.000	0.000	0.000	0.000
GLI. vs Others	1	0.000	0.001	0.001	0.000	0.000
PAR. vs CAL.	1	0.094	0.001	0.001	0.001	0.002
Error A	6					
Lime Rates	(2)	0.547	0.010	0.139	0.016	0.130
Lime vs No lime	1	0.412	0.004	0.119	0.014	0.054
Low vs High lime	1	0.470	0.263	0.203	0.097	0.568
Lime * Tree Spp.	4	0.658	0.296	0.318	0.158	0.361
Error B	18					
CV (%) Main-plot		34	42	55	41	38
CV (%) Subplot		34	34	43	29	28

Table 2.6. Analysis of variance for wood yields in the 1986/87 season.

Source	df	Tree Pruning Date: Sep86	Nov86	Feb87	Mar87	Total: 4 Prunings	Fuel[1] Wood
		P Values					
Rep	3	0.848	0.579	0.578	0.254	0.807	0.825
Tree Spp.	(2)	0.001	0.000	0.001	0.001	0.001	0.001
GLI. vs Others	1	0.000	0.002	0.001	0.002	0.000	0.000
PAR. vs CAL.	1	0.918	0.000	0.010	0.003	0.261	0.465
Error A	6						
Lime Rates	(2)	0.745	0.228	0.460	0.208	0.800	0.836
Lime vs No lime	1	0.787	0.093	0.398	0.108	0.550	0.630
Low vs High lime	1	0.479	0.801	0.363	0.459	0.783	0.732
Lime * Tree Spp.	4	0.819	0.633	0.812	0.396	0.775	0.804
Error B	18						
CV (%) Main-plot		51	51	53	62	49	49
CV (%) Subplot		37	51	43	33	33	33

1 Fuelwood is the sum of only the September and February harvests, since the wood was taken off the plots only at these times.

Table 2.7. Growth and yields of tree hedges during 1987/88.

a. Leaf Yield[1]

Tree Species	Tree Pruning Date: Oct.'87	Dec.'87	Feb.'88	May'88	Total: 4 Prunings
	kg ha^{-1}				
Paraserianthes	2423	458	884	261	4026
Calliandra	1838	783	1741	722	5084
Gliricidia	220	163	365	57	805
LSD (0.05)	490	118	327	166	780

b. Wood Yield[1]

Tree Species	Tree Pruning Date: Oct.'87[2]	Dec.'87	Feb.'88	May'88	Total: 4 Prunings
	kg ha^{-1}				
Paraserianthes	4586	673	240	177	5676
Calliandra	3517	1121	507	504	5649
Gliricidia	279	191	85	35	590
LSD (0.05)	1429	211	79	134	1647

c. Tree height at October pruning.

Tree Species	Oct.'88
	-- m --
Paraserianthes	3.51
Calliandra	2.69
Gliricidia	0.95
LSD (0.05)	0.74

1 Yield in kg/ha was calculated on the basis of total intercropped land area, rather than yield per hedgerow. (To calculate kg yields per meter of hedgerow, multiply yields/ha x 0.0004).

2 Fuel wood was removed from the plots only at the October harvest, since the usual pruning schedule was delayed and the three subsequent prunings had to be applied as mulch.

Table 2.8. Analysis of variance for leaf yields in the 1987/88 season.

Source	df	Tree Pruning Date: Oct'87	Dec'87	Feb'88	May'88	Total: 4 Prunings
		P Values				
Rep	3	0.603	0.327	0.397	0.395	0.381
Tree Spp.	(2)	0.000	0.000	0.000	0.000	0.000
GLI. vs Others	1	0.000	0.000	0.000	0.000	0.000
PAR. vs CAL.	1	0.026	0.001	0.001	0.000	0.016
Error A	6					
Lime Rates	(2)	0.090	0.419	0.439	0.002	0.052
Lime vs No lime	1	0.058	0.265	0.427	0.376	0.083
Low vs High lime	1	0.250	0.486	0.317	0.001	0.073
Lime * Tree Spp.	4	0.750	0.166	0.073	0.035	0.244
Error B	18					
CV (%) Main-plot		33	25	33	48	24
CV (%) Subplot		29	44	41	38	26

Table 2.9. Analysis of variance for wood yields in the 1987/88 season.

Source	df	Tree Pruning Date: Oct'87[1]	Dec'87	Feb'88	May'88	Total: 4 Prunings
		P Values				
Rep	3	0.867	0.572	0.252	0.206	0.877
Tree Spp.	(2)	0.001	0.000	0.000	0.000	0.000
GLI. vs Others	1	0.000	0.000	0.000	0.001	0.000
PAR. vs CAL.	1	0.117	0.002	0.000	0.001	0.969
Error A	6					
Lime Rates	(2)	0.305	0.040	0.212	0.064	0.141
Lime vs No lime	1	0.244	0.055	0.201	0.859	0.170
Low vs High lime	1	0.310	0.076	0.218	0.021	0.143
Lime * Tree Spp.	4	0.545	0.139	0.293	0.663	0.486
Error B	18					
CV (%) Main-plot		51	32	28	56	41
CV (%) Subplot		30	31	42	51	28

1 Fuelwood is the sum of only the September and February harvests, since the wood was taken off the plots only at these times.

Table 2.10. Nutrient concentrations in green leaf manure sampled during the September 1985 pruning (260 days after tree planting).

TREATMENT		N	P	K	Ca	Mg	S	Mn
		-------------		$(g\ kg^{-1})$			------------	$(mg\ kg^{-1})$
Paraseri- anthes *	No lime	31.4	1.43	16.4	5.35	2.28	2.30	231
	Low lime	33.1	1.43	15.5	6.35	2.53	2.33	235
	High lime	33.7	1.48	14.9	8.93	2.05	2.48	205
Calliandra *	No lime	30.2	1.28	8.1	5.30	1.73	2.13	171
	Low lime	27.5	1.43	7.8	6.35	1.53	2.08	166
	High lime	27.2	1.25	5.5	8.13	1.10	2.08	137
Gliricidia *	No lime	38.9	2.28	16.5	7.85	1.63	2.95	60
	low lime	39.3	2.28	14.0	9.48	1.35	2.95	61
	High lime	39.8	2.40	11.0	12.97	1.77	3.10	62
SPECIES MEANS:								
Paraserianthes		32.7	1.44	15.6	6.88	2.28	2.37	224
Calliandra		28.3	1.32	7.1	6.59	1.45	2.09	158
Gliricidia		39.3	2.31	14.1	9.84	1.56	2.99	61
LIME RATE MEANS:								
No Lime		33.5	1.66	13.6	6.17	1.88	2.46	155
Low Lime		33.3	1.71	12.4	7.39	1.80	2.45	154
High Lime		33.5	1.65	10.4	9.74	1.63	2.50	141
LSD(0.05) BETWEEN:								
-Species means		2.7	0.14	2.2	0.94	0.91	0.30	31
-Lime rate means		ns	ns	1.9	1.52	ns	ns	ns
-Lime means for same sp.		ns	ns	3.3	2.64	ns	ns	ns
-Species means for same or different lime rates		3.5	ns	3.5	2.35	ns	ns	ns

Table 2.11. Analysis of variance of nutrient concentrations in green leaf manure sampled during the September 1985 pruning.

Source	df	N	P	K	Ca	Mg	S	Mn
		--------------			P values		-------------	
Rep	3	.281	.353	.149	.643	.613	.645	.239
Tree Spp.	(2)	.000	.000	.000	.000	.121	.001	.000
GLI. vs PAR.+CAL.	1	.000	.000	.023	.000	.322	.000	.000
PAR. vs CAL.	1	.007	.076	.000	.490	.067	.069	.002
Error A	9							
Lime Rates	(2)	.954	.556	.015	.000	.255	.609	.383
Lime vs No lime	1	.935	.288	.015	.001	.240	.650	.482
Low vs High lime	1	.771	.958	.065	.003	.221	.371	.224
Lime * Tree Spp.	6	.085	.258	.557	.815	.515	.923	.930
Error B	24							

Table 2.12. Nutrient concentrations in green leaf manure sampled during the September 1986 pruning (146 days from the previous pruning).

TREATMENT		N	P	K	Ca	Mg	Mn	Al
		----------	(g kg^{-1})		-----------		(mg kg^{-1})	
Paraseri- anthes *	No lime	40.8	1.55	9.5	4.00	2.75	185	200
	Low lime	39.4	1.43	10.5	5.05	3.10	196	246
	High lime	39.1	1.63	11.0	7.20	2.68	177	202
Calliandra *	No lime	27.8	1.00	4.8	3.30	2.00	116	185
	Low lime	30.8	1.10	5.2	5.40	1.48	82	204
	High lime	33.1	1.20	4.1	6.10	1.10	56	221
Gliricidia *	No lime	37.6	1.78	7.2	8.43	3.35	40	302
	low lime	40.6	2.55	11.4	10.53	1.58	23	249
	High lime	43.2	3.08	10.4	13.90	1.63	22	242
SPECIES MEANS:								
	Paraserianthes	39.7	1.53	10.3	5.42	2.84	186	216
	Calliandra	30.6	1.10	4.7	4.93	1.53	85	203
	Gliricidia	40.5	2.47	9.7	10.95	2.18	28	264
LIME RATE MEANS:								
	No Lime	35.4	1.44	7.2	5.24	2.70	113	229
	Low Lime	36.9	1.69	9.0	6.99	2.05	100	233
	High Lime	38.5	1.97	8.5	9.07	1.80	85	221
LSD(0.05) BETWEEN:								
-Species means		3.7	0.61	1.5	0.87	0.63	47	87
-Lime rate means		2.5	0.30	ns	0.74	0.73	ns	ns
-Lime means for same sp.		4.3	0.52	ns	1.29	1.26	42	53
-Species means for same or different lime rates		5.1	0.74	ns	1.37	1.20	58	97

Table 2.13. Analysis of variance of nutrient concentrations in green leaf manure sampled during the September 1986 pruning.

Source	df	N	P	K	Ca	Mg	Mn	Al
		---------------			P values		-------------	
Rep	3	.679	.471	.257	.313	.134	.618	.025
Tree Spp.	(2)	.001	.004	.000	.000	.006	.001	.271
GLI. vs PAR.+CAL.	1	.007	.002	.007	.000	.999	.001	.127
PAR. vs CAL.	1	.001	.134	.000	.224	.002	.002	.729
Error A	9							
Lime Rates	(2)	.059	.007	.190	.000	.048	.069	.730
Lime vs No lime	1	.039	.006	.082	.000	.019	.050	.896
Low vs High lime	1	.205	.071	.619	.000	.479	.193	.440
Lime * Tree Spp.	6	.131	.018	.440	.021	.182	.343	.042
Error B	24							

Table 2.14. Nutrient concentrations in green leaf manure tissue sampled during three prunings in 1986 and 1987.

Pruning Date (Harvest interval)[1]	TREATMENT		N	P	K	Ca	Mg
			----------		$(g\ kg^{-1})$		----------
12-4-86 (53 days)	Paraseri- * anthes	No lime	48.5	2.50	15.3	3.60	3.20
		Low lime	46.0	2.10	17.4	4.60	3.60
		High lime	46.4	2.20	14.2	6.20	3.00
	Calliandra *	No lime	41.4	2.20	10.1	4.30	2.00
		Low lime	39.5	2.00	8.8	7.10	1.80
		High lime	43.0	2.10	8.1	8.60	1.40
	Gliricidia *	No lime	43.5	2.90	17.5	6.60	1.60
		low lime	43.2	2.70	16.5	7.60	1.10
		High lime	43.7	2.90	17.3	10.60	1.30
11-11-86 (58 days)	Paraseri- * anthes	No lime	42.5	2.40	15.3	3.40	2.90
		Low lime	39.8	2.40	15.4	4.90	3.90
		High lime	40.7	2.40	14.0	6.50	3.80
	Calliandra *	No lime	40.5	2.20	11.1	4.20	2.10
		Low lime	36.2	2.00	10.4	6.30	1.80
		High lime	40.3	2.20	8.5	9.20	1.00
	Gliricidia *	No lime	37.4	2.40	16.0	6.80	1.40
		low lime	36.0	2.60	20.9	8.90	0.90
		High lime	37.6	2.70	18.4	13.10	1.10
7-2-87 (98 days)	Paraseri- * anthes	No lime	39.9	2.10	11.9	5.10	2.80
		Low lime	38.4	2.20	13.3	6.80	3.50
		High lime	39.7	2.30	12.5	8.50	3.20
	Calliandra *	No lime	33.4	1.30	6.9	4.80	2.10
		Low lime	35.3	1.60	6.3	8.90	1.60
		High lime	37.8	1.50	4.8	10.90	1.10
	Gliricidia *	No lime	41.0	2.40	12.6	7.40	1.30
		low lime	41.2	2.60	11.4	10.50	1.00
		High lime	42.0	3.00	12.2	13.30	1.00

[1] Harvest interval is the period in days between consecutive prunings.

Table 2.15. Correlation coefficients for total tree biomass regressed on various soil test parameters in two cropping seasons.

a. 1985/86 Season[1]

Soil Test Parameter	Ranges in Soil Test Values	----- Correlation Coefficients (r) ----- Paraserianthes	Calliandra	Gliricidia
Al+H[2]	0.33 - 2.35 $cmol_c L^{-1}$	0.010	0.022	0.484
Ca[2]	0.09 - 2.38 $cmol_c L^{-1}$	0.210	0.210	0.615*
Mg[2]	0.04 - 0.39 $cmol_c L^{-1}$	0.391	0.518	0.156
K[3]	0.11 - 0.32 $cmol_c L^{-1}$	0.504	0.266	0.016
P[3]	2 - 8 $mg\ kg^{-1}$	0.263	0.176	0.344
Acid Sat.[4]	12 - 84 %	0.190	0.124	0.615*

b. 1986/87 Season[1]

Soil Test Parameter	Ranges in Soil Test Values	----- Correlation Coefficients (r) ----- Paraserianthes	Calliandra	Gliricidia
Al+H[2]	0.77 - 2.58 $cmol_c L^{-1}$	0.224	0.244	0.836***
Ca[2]	0.18 - 1.71 $cmol_c L^{-1}$	0.041	0.168	0.932***
Mg[2]	0.03 - 0.40 $cmol_c L^{-1}$	0.385	0.627*	0.604*
K[3]	0.09 - 0.27 $cmol_c L^{-1}$	0.275	0.062	0.204
P[3]	2.37 - 8.63 $mg\ kg^{-1}$	0.059	0.147	0.083
Acid Sat.[4]	29 - 86 %	0.030	0.242	0.925***
pH[5]	4.13 - 4.83	0.116	0.322	0.566
OC[6]	1.26 - 2.27 %	0.707**	0.188	0.010
Total N[7]	0.11 - 0.23 %	0.646*	0.039	0.110

*, **, *** Significant at the 0.05, 0.01, and 0.001 levels, respectively.

1 Soil analyses are for samples taken on 12 April 1986 for the 1985/86 season and on 28 February 1987 for the 1986/87 season.
2 Extracted with 1 N KCl.
3 Extracted with Mehlich I (double acid) extractant.
4 Calculated as ((Al + H) / (Al + H + Ca + Mg + K)) x 100.
5 Measured in a 1:2.5 soil to water suspension.
6 Measured as Walkley-Black organic carbon.
7 Micro-Kjeldahl N.

Table 2.16. "Best" regression equations[1] relating annual tree biomass yields (Y) to soil test parameters in the 1986/87 season.

Species	Equation	R^2	P value of regression
Paraserianthes	Y = 1175 + 2412(OC) - 230(P)	0.664	0.007
Calliandra	Y = 2070 + 41046(Mg)	0.393	0.029
Gliricidia	Y = -460 + 1615(Ca)	0.868	0.000

1 The criteria for the selection of "best" regression equations were increases in R^2, reduction of residual sum of squares, and partial F-values of predictor variables with probability values of less than the 0.10 level.

Table 2.17. Tree heights (Ht) in cm and basal diameters (Bd) in mm at Gunung Medan.

Species	4 months		6 months		9 months		12 months		19 months	
	Ht	Bd	Ht	Bd	Ht	Bd	Ht	Bd	Ht	Bd
P. falcataria	256	32	445	45	625	51	736	56	891	63
A. mangium	94	16	218	29	368	38	499	39	758	58
C. siamea	102	19	185	26	316	36	436	40	675	57
C. calothyrsus	179	19	258	26	324	32	367	36	477	44
A. auriculiformis	86	10	129	14	210	21	279	26	462	34
L. diversifolia	108	12	142	13	179	14	177	15	265	19
L. leucocephala	90	13	125	15	150	17	173	18	214	19
G. sepium	67	15	71	19	91	20	110	23	159	28
P. dulce[2]	65	8	79	9	90	12	106	14	--	--
A. procera[1]	35	10	34	12	35	14	37	13	--	--

1 Shaded heavily by adjoining plots after 6 months. Data collection discontinued after 1 year.
2 Very thorny; data collection discontinued after 1 year.

Table 2.18. Tree heights (Ht) in cm and basal diameters (Bd) in mm at Sitiung Vc.

Species	---- 6 months ----		---- 12 months ----	
	Ht	Bd	Ht	Bd
P. falcataria	357	37	651	58
C. calothyrsus	193	18	311	29
A. auriculiformis	120	12	272	25
L. leucocephala	175	17	262	22
L. diversifolia	165	13	227	19
G. sepium	95	19	196	28
A. saman	103	24	161	33
A. procera [1]	29	14	40	15

[1] Shaded heavily by adjoining plots after 6 months.

Table 2.19. Soil analyses of samples taken on 6 May 1986 for the tree assessment trial.

Site	Al+H[1]	Ca[1]	Mg[1]	K[2]	ECEC	P[2]	Acid[3] Sat.
	---------- cmol kg^{-1}				----------	mg kg^{-1}	%
Gunung Medan	3.33	1.36	0.46	0.26	5.41	3	62
Sitiung Vc	1.76	1.00	0.25	0.28	3.41	0	52

[1] Extracted with 1N KCl
[2] Extracted with Mehlich 1 extractant
[3] % Acid Saturation = (Al+H/ECEC) * 100

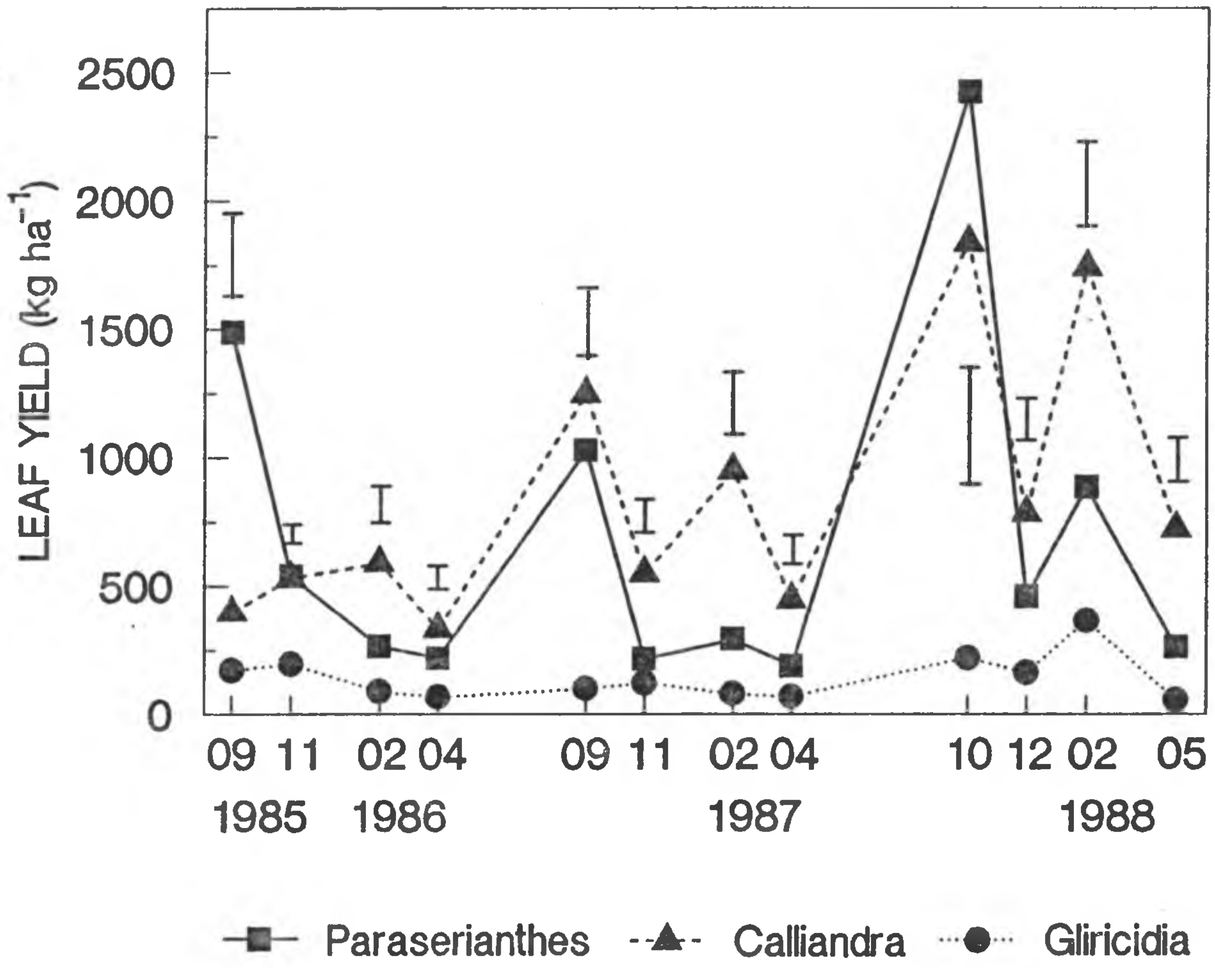


Figure 2.1 Trends in leaf (GLM) yields over three years. Vertical lines are LSD (0.05) values to compare species means at each harvest.

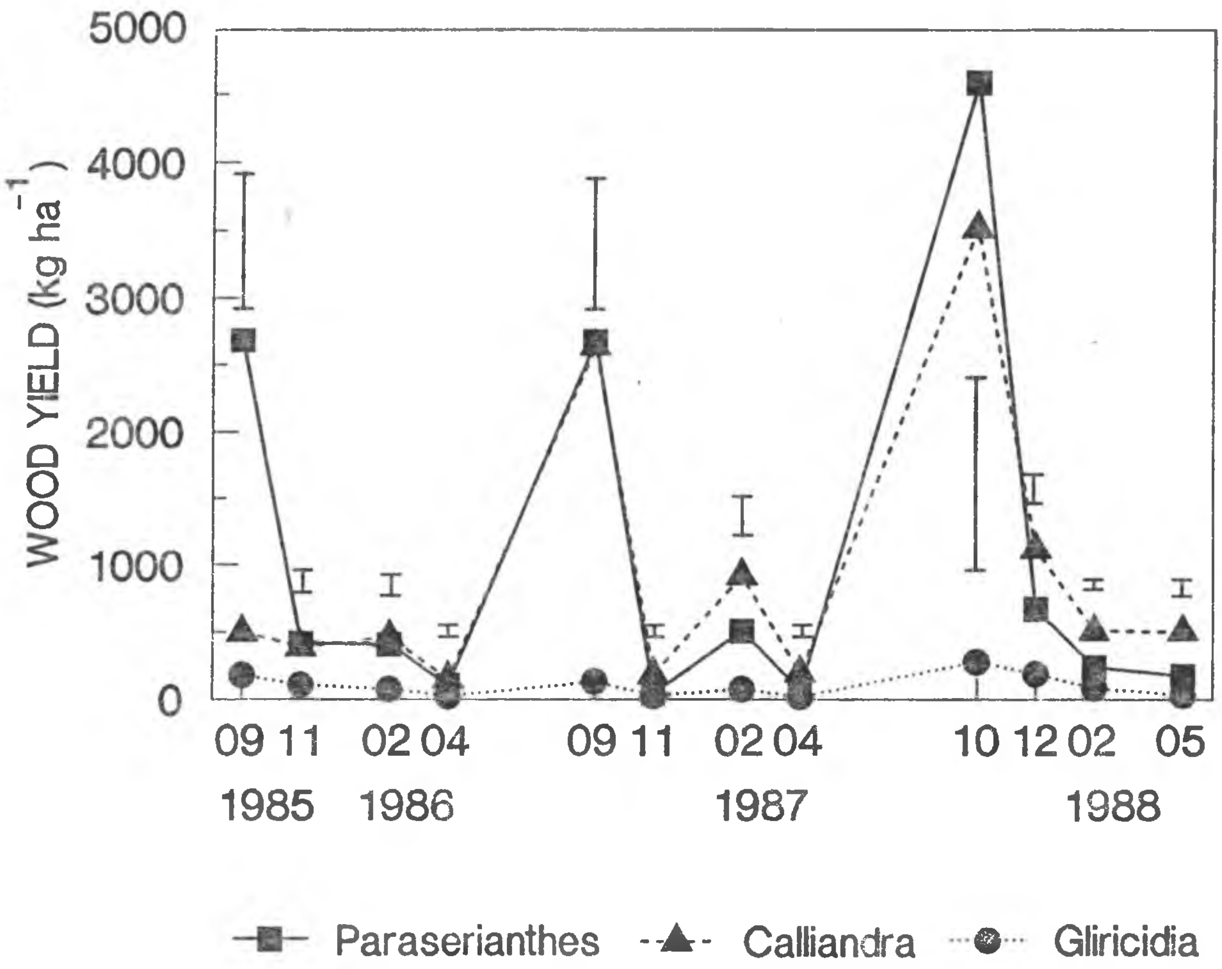


Figure 2.2 Trends in wood yields over three years. Vertical lines are LSD (0.05) values to compare species means at each harvest.

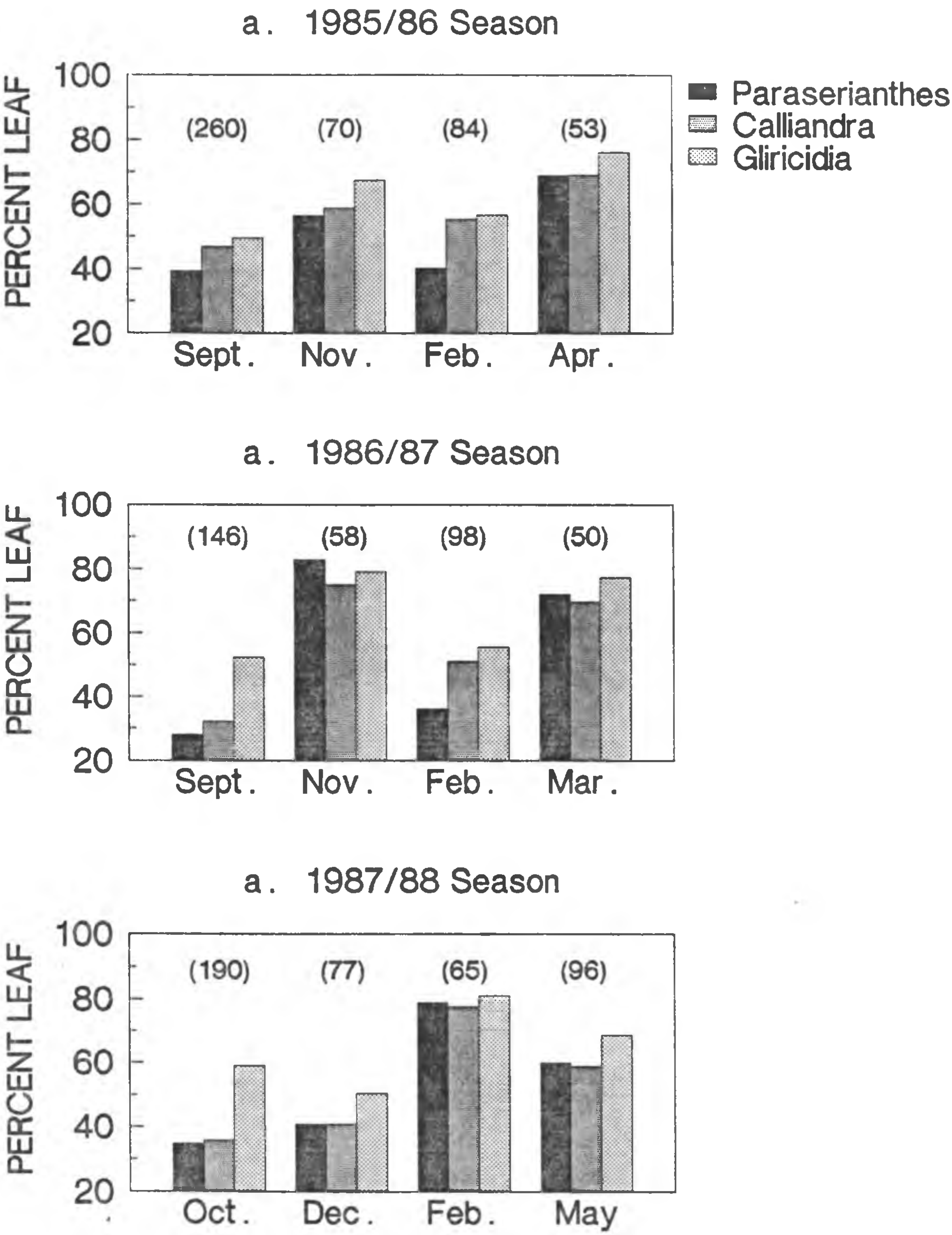
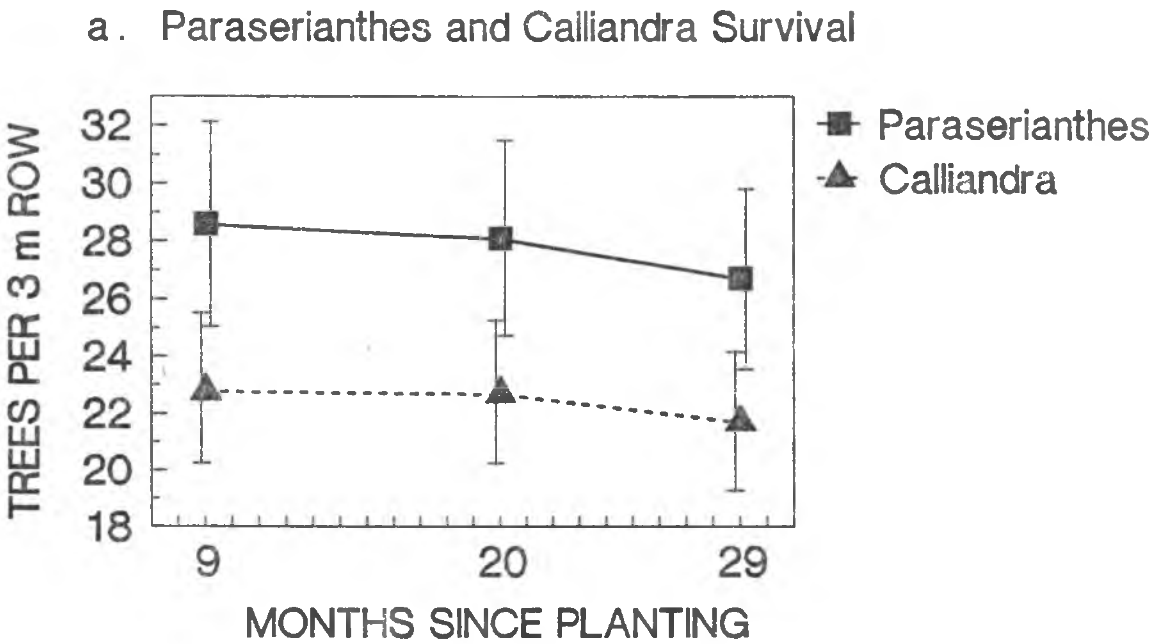


Figure 2.3 Percent leafy fraction of prunings over three years. Values in parentheses are harvest intervals in days. The first harvest interval in September 1985 includes tree establishment.



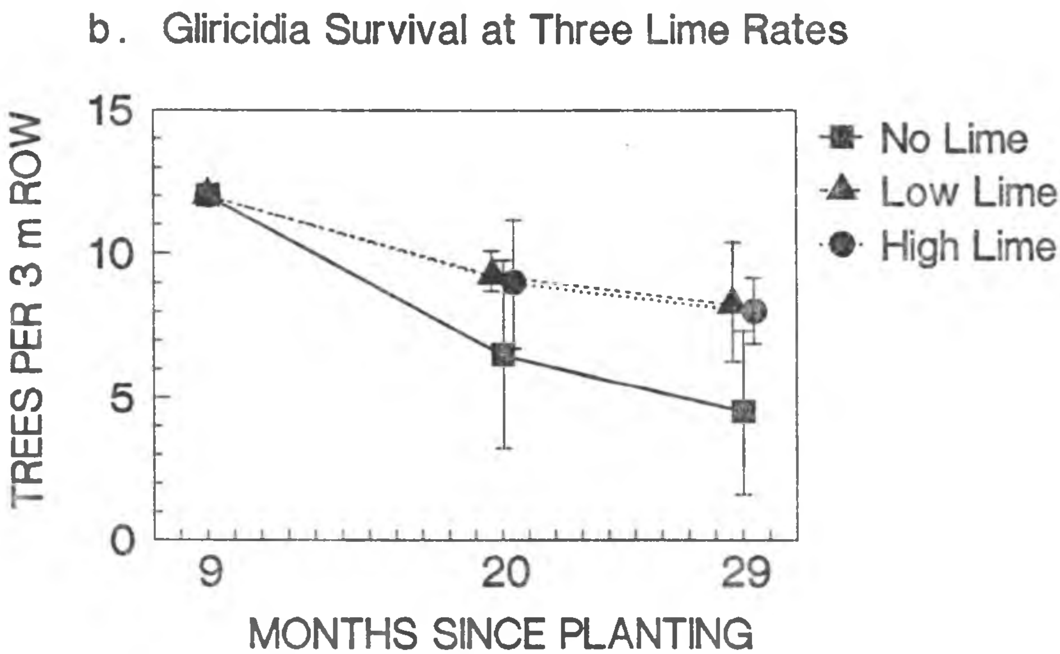


Figure 2.4 Trends in mean tree survival per 3 m row for (a) Paraserianthes and Calliandra and (b) Gliricidia at three lime rates. Vertical lines are 95% confidence intervals.

CHAPTER 3

ALLEY CROPPING IN WEST SUMATRA, PART II. FOOD CROP RESPONSE TO GREEN LEAF MANURING

3.1 INTRODUCTION

In the agricultural development of the outer islands of Indonesia (Sumatra, Kalimantan, Sulawesi, and Irian Jaya), soil acidity and infertility are major limitations to crop production. Highly leached, acidic soils predominate in these areas (Buurman, 1980), which historically have supported tropical rainforests and low-productivity, extensive forms of traditional agriculture, such as slash and burn (Terra, 1958). However, due to large scale Transmigration (resettlement) schemes, greater demands are being placed on these soils to produce food crops to provide for income generation and the settler's subsistence needs. Reliable agricultural systems for sustained production of food crops are required. An experiment is reported here which tested the potential of alley cropping to improve food crop yields in the Sitiung transmigration area of West Sumatra.

Alley cropping has been studied most extensively at the International Institute of Tropical Agriculture (IITA) in Nigeria (Kang et al., 1984; Wilson et al., 1986). The benefits of alley cropping are well documented under controlled experimental conditions. Alley cropping functions as a nutrient source (especially nitrogen) for food crops through green leaf manure (GLM) additions (Kang et al., 1981; Kang and Duguma, 1985; Read et al., 1985; Yamoah et al. 1986a). Alley cropping has also been shown to improve soil physical properties (Yamoah et al., 1986b), reduce erosion (Metzner, 1976; Paningbatan, 1987; Watson and Laquihou, 1987), and improve animal nutrition (Atta-Krah and Sumberg, 1987).

Published data on the performance of alley cropping on highly acid and infertile soils is limited. Palm (1988) studied GLM decomposition, nitrogen mineralization, and yield response of upland rice in alley cropping with Inga edulis, Cajanus cajan, and Erythrina sp. on an acid and high Al soil in Yurimaguas, Peru. She found that mineralization rates and availability of nitrogen were inversely related to the content of polyphenolic compounds in the leaves of the tree species. However, these differences in decomposition rates did not cause differences in rice yields.

In a related study, Szott et al. (1987) assessed growth and alley cropping potential of six leguminous tree species. They found that Inga edulis and Erythrina sp. grew most vigorously, Cajanus cajan was short-lived, and Leucaena leucocephala, L. diversifolia, and Cedrelinga catenaeformis grew poorly on this acid soil. However, low rice and cowpea yields were obtained with all species. Competition between the trees and food crops were the suspected cause of these low yields. The potential of alley cropping for improving crop production through the alleviation of soil acidity problems has not been adequately studied. Additions of organic materials to the soil have been shown to reduce Al toxicity in laboratory and greenhouse studies (Hoyt and Turner, 1975; Ahmad and Tan, 1986; Hue et al., 1986) and may be important in field crops. Nutrient recycling by trees in an alley cropping system may also reduce loss of cations by leaching. Soil and crop growth data were collected in this experiment to assess these factors through a study of the interaction of liming and GLM addition in alley cropping on an acid and high aluminum soil.

The objectives of this experiment were: 1) to measure the effects of green leaf manure produced in an alley cropping system on upland rice and cowpea yields; 2) to measure effects of these additions of organic matter on soil chemical properties and interactions with crop growth; and 3) to select appropriate legume tree species and liming levels for farmer testing.

3.2 MATERIALS AND METHODS

3.2.1 Site Characteristics

The experiment was conducted in the transmigration village of Sitiung Vc (Aur Jaya) in West Sumatra. This site is at 1^{o}S latitude and 160 m elevation and has a mean annual temperature of 26^{o}C with little seasonal variation (Soil Research Institute, 1979). Rainfall averages about 2600 mm per year and is fairly evenly distributed, although a short dry season occurs in June, July and August. (See Figure 3.12 for monthly rainfall distribution.)

The soil is classified as a clayey, kaolinitic, isohyperthermic Tropeptic Haplorthox. Soil data from an uncleared forest site 50 m from the experiment is presented in Table 3.1 (John Kimble, 1986, personal communication). The soil is characterized as clayey, aluminum toxic, with low effective cation exchange capacity (ECEC), and low K reserves (Ceak) in the Fertility Capability Classification system (Sanchez et al.,1982).

The experimental site was located in a farmers field along the main road entering the village of Sitiung Vc (Aur Jaya) in West Sumatra. This site was chosen since it was highly visible to anyone entering the village and therefore would be a useful demonstration of introduced technologies. The field was available indefinitely because the owner was a local Minangkabau (indigenous inhabitants of the Sitiung area) who had returned to his home village but retained ownership of the land. The original primary forest had been cleared by chainsawing and bulldozing trees into windrows during the 1982/83 wet season. The site had never been cultivated, except for scattered plantings of cassava. The soil was moderately eroded as indicated by the lack of the dark brown surface horizon in parts of the field, especially in replication number 3.

3.2.2 Experimental Design and Statistical Analysis

The experiment was laid out in a split-plot design with four replications. The test crops grown in the alleys were a rotation of upland rice followed by cowpea. The treatments were as follows:

Main Plots - Tree Species

1) *Paraserianthes falcataria* (syn. *Albizia falcataria*) (grown from seed)
2) *Calliandra calothyrsus* (grown from seed)
3) *Gliricidia sepium* (grown from hardwood cuttings)
4) No trees (control)

Subplots - Liming Levels

1) No lime
2) Low liming rate
   (375 kg lime/ha applied in December 1984 and in September 1985, but none applied in 1986, 1987, or 1988)
3) High liming rate to reduce Al+H saturation to 25 %
   (2 T lime/ha applied in December 1984; 240 to 810 kg lime/ha, varying with individual plots, in September 1985; 500 to 1810 kg lime/ha, varying with replications, in September 1986; no lime applied in 1987 or 1988).

Main plots consisted of three hedgerows of a single tree species planted 4 m apart. Subplot size was 5.5 m x 12 m for alley-cropped plots and 5.5 m x 6 m for the treeless plots. Harvest areas of subplots consisted of the central 3 m of the center tree hedge and 2 m to either side of the hedge for food crop yields. Harvest areas for the treeless subplots were also the central 3 x 4 m of the subplot.

A split-plot design was chosen to gain precision in the test of Tree Species x Lime Level interaction as well as to reduce the likelihood of deep rooted tree species from encroaching on adjoining main plots. The following orthogonal comparisons were planned at the initiation of the experiment:

Tree Species Effects:

1) Tree vs No Tree - to compare the effects of alley cropping with GLM addition to not alley cropping.

2) Gliricidia (GLI) vs Other Trees - to compare the larger leafed Gliricidia planted from cuttings to the smaller leaved Paraserianthes and Calliandra planted from seed.

3) Calliandra (CAL) vs Paraserianthes (PAR) - to compare Calliandra with its high tannin content and tiny leaflets to Paraserianthes with its larger leaflets.

Lime Level Effects:

1) Lime vs No Lime - to assess the effects of lime addition.

2) Low vs High Lime - to compare liming at a low rate which provided calcium as a nutrient to liming at a high rate to eliminate Al toxicity for the Al tolerant upland rice and cowpea crops.

In addition to these general comparisons of main effects, specific comparisons were planned at each lime rate between No Tree treatments and each tree species. These comparisons were planned to determine the value of alley cropping with the three tree species at three levels of soil aluminum saturation and calcium availability. Fisher's protected LSD at the 0.05 level of probability was chosen as the test statistic due to its power in detecting significant differences in paired comparisons (Chew, 1976). The danger of increased experiment-wise error rates was of less concern than the risk of making Type II errors. Since this was preliminary research on a site with high soil variability (which inflates experimental error) more conservative multiple comparison tests were not used.

3.2.3 Experiment and Crop Management

The experiment was initiated in December 1984. A description of the establishment of the tree hedges can be found in Chapter 2. During establishment of hedges, upland rice and then cowpea were planted to assess soil variability. Establishing trees with intercropped food crops is realistic from the farmer's viewpoint since they would probably not forego growing food crops while establishing hedges.

Initial lime rates (375 kg ha^{-1} for the low lime and 2 tons ha^{-1} for the high lime treatments) were broadcast over subplots on 22 December 1984. The high rate of lime was calculated on the basis of a modified Cochrane equation (Cochrane et al., 1980), described by Wade et al. (1988) as follows:

$$LR = 1.5\ [(Al+H)-(RAS \times ECEC / 100)]$$

Where:

- LR = lime required in T Ha^{-1} of $CaCO_3$ equivalent
- Al+H = cmol Al+H L^{-1} of soil extracted with 1N KCl (ie. extractable acidity)
- RAS = maximum % Acid (Al+H) saturation tolerated by a specific crop
- ECEC = effective CEC (Al+H+Ca+Mg+K), in cmol L^{-1} soil

A blanket application of Triple superphosphate (TSP) was also applied at a rate of 40 kg P ha^{-1}. This rate of P was found to be an adequate initial application for upland rice from previous research in Sitiung (Wade et al., 1988). These low fertilizer rates are similar to rates applied by local farmers (Wade et al., 1988; Stacy Evensen, 1987, personal communication). Non-treatment fertilization rates as well as crop management practices (such as spacing, dibble planting, and pest control) were determined in consultation with local farmers to try to approximate their cropping practices whenever possible.

Soil was tilled with hoes to incorporate lime and P to about a 15 cm depth. Upland rice ("Sentani") was planted using dibbles on 12 January 1985 at a 25 x 25 cm spacing, skipping one row of rice where there was a row of trees. Furadan insecticide (3% carbofuran granules) was applied in the dibble hole at about 1.5 kg a.i. ha^{-1} to control seedling fly (Atherigona exigua). Germination was delayed by dry weather, but a good stand resulted from rains two weeks after planting. Urea was sidedressed at 25 kg N ha^{-1} at 42 days after planting. (This was the only time that N fertilizer was applied to this experiment.) However, rice blast (Pyricularia oryzae) began to appear at about this time and became so severe that almost no grain was produced. The crop was harvested for total plant weight on 13 May 1985.

A semi-determinate local variety of cowpea was planted on 17 May 1985 at 20 cm intra-row x 40 cm inter-row spacing. No rows of cowpea were skipped in subplots with trees (i.e. rows of cowpea were planted 20 cm on either side of the tree rows). No additional fertilizer was applied, so that soil microvariability could be further characterized. Sevin (85% carbamate) was applied 15 days after planting. Germination was excellent, but a prolonged drought in June and July (Figure 3.12) severely reduced pod set and yields. Plants were harvested on 12 September 1985 for total plant weights.

Trees were first pruned on 17 September 1985, nine months after planting. They were sampled to determine leaf fraction, wood fraction, and dry matter content. Prunings were spread in the alleys to dry. After four days, leaves were shaken off the branches and the branches were removed from the plots. Lime was reapplied on the high lime plots at rates of 240 to 810 kg ha^{-1} to bring acid saturation to 25 % on the basis of soil analyses for individual plots. Also, 375 kg lime ha^{-1} was applied on the low lime plots (to make a total of 750 kg lime ha^{-1} applied to these plots). TSP and Muriate of Potash (KCL) were broadcast on all plots, at rates of 50 kg ha^{-1} (i.e. 10 kg P and 25 kg K per ha). K was applied because potassium deficiency symptoms were observed in the previous cowpea crop. These fertilizers and amendments were incorporated with hoes to a depth of about 15 cm.

A local variety of upland rice, which was reportedly disease tolerant and preferred by local farmers, was planted at a spacing of 40 x 15 cm on 25 September 1985. No rows of rice were skipped because of tree hedges (i.e. rows of rice were planted 20 cm to either side of the tree hedges). Seed was placed in dibble holes along with 3 % carbofuran granules (1.3 kg a.i./ha). Germination was rapid and uniform. All tree species had resprouted well by two weeks after pruning. The trees were pruned again on 26 November 1985 to reduce shading of the rice and the prunings used as mulch between the rows of rice. Diazinon insecticide was sprayed five times during crop growth.

Blast and Helminthosporium Brown Spot (*Helminthosporium oryzae*) caused some leaf damage which looked serious in November, but the rice recovered well and produced a good crop of grain. Heavy rains in January caused some serious lodging, but stems to be included in the harvested areas were carefully sorted out. Mature panicles were harvested on February 3, 1986. Straw and late maturing panicles were harvested on February 13. The straw was returned to the plots and buried.

The trees were pruned again on 18 February 1986, the prunings placed in the alleys to dry and drop the leaves, and after four days the wood was removed. Triple Super Phosphate was broadcast at 50 kg ha^{-1} (10 kg P ha^{-1}) and leaves and fertilizer incorporated by hoe. A local variety of semi-determinate cowpea was planted at 40 x 20 cm spacing on 6 March 1986. Germination and growth was very good. On 12 April, tree hedges were pruned and prunings applied as mulch between the of cowpeas. Mature pods were harvested on 5 May and vines and remaining pods were harvested on 15 May 1986. Vines were returned to the plots. The trees were allowed to grow uncut into the dry season.

The trees were pruned again on 4 September 1986 and prunings were spread in the alleys to dry. After four days, leaves were shaken off the branches and the wood removed from the plots. Lime was reapplied on the high lime treatments to bring acid saturation to 25 %, with different amounts applied to each replication. (Rep 1 = 258 kg ha^{-1}, Rep 2 = 150 kg ha^{-1}, Rep 3 = 276 kg ha^{-1}, Rep 4 = 549 kg ha^{-1}). Also, TSP and KCl were broadcast, each at 50 kg ha^{-1} (i.e. 10 kg P and 25 kg K per ha). All these fertilizers and amendments were incorporated with hoes to a depth of 15 cm.

A local variety of upland rice (the same variety planted the previous year) was planted at a spacing of 40 x 15 cm on 13 September 1986. Seed was planted in dibble holes along with 3 % carbofuran granules (0.76 kg a.i.ha^{-1}). Germination and establishment of the rice was good. The trees were pruned again on 1 November 1986 to reduce shading of the rice and prunings were mulched. Rice leaf samples (fully expanded new leaves) were collected from all plots at approximately 50 % panicle initiation, starting 3 December 1986.

In mid-December, much rice leaf yellowing occurred as well as an unknown leaf spot disease (possibly Helminthosporium Brown Spot in combination with Rice Blast). Leaf yellowing was worst in the No Tree and Gliricidia plots and least severe in the Paraserianthes plots. The growth of Calliandra hedges was so vigorous that by late December, the rows of rice closest to the hedges were completely shaded. Shading was not as much of a problem in the Paraserianthes plots and Gliricidia hardly shaded the rice at all. The Calliandra hedges probably should have been pruned again in late December to reduce shading, but were not since it was considered best to manage all the tree species uniformly.

Leaf spot disease was rated on 13 January and found to be less severe at the zero and low lime rates. Leaf area affected by leaf spots ranged from about 3 % at the zero lime rate up to 10 % at the high lime rate. However, the growth stage of the zero lime plots (flowering) was also earlier than the high lime plots (grain fill) and the disease seemed to advance with age of the crop. Leaf spot was slightly less severe on the No Tree plots as well, but this was similarly related to delayed maturity.

On 14 January 1987, one rice plant per row in each plot was measured for height, number of fertile tillers and total number of tillers to determine competition effects with the hedges. Mature rice panicles were also harvested row by row in the plots to determine competition effects. The first harvest of panicles from each plot was on 17 or 27 January 1987. (The two harvest dates were for early and late maturing plots, respectively.) The second harvest of panicles and straw was on 31 January or 5 February 1987. Straw was returned to the plots and incorporated.

The trees were pruned again on 7 February 1987, prunings placed in the alleys to dry and drop leaves, and after four days, the wood was removed. TSP and KCl were broadcast, both at 50 kg ha^{-1}. Leaves, fertilizer and rice straw were incorporated by hoe. A local variety of cowpea (the same variety used the previous year) was planted at 40 x 25 cm spacing on 15 February 1987. The germination of seed was very poor and the stand remained spotty even after replanting gaps on 28

February. Some plots had only about 50 % stands. The poor germination was due to diseased seed and dry weather at planting.

Poor establishment of cowpeas was also related to treatment effects, with the poorest stands of cowpea occurring in the plots without lime and without trees. The tree hedges were pruned on 29 March 1987 and prunings applied as mulch between rows of cowpeas. Mature pods were harvested on 25 April and vines and remaining pods harvested on 5 May 1987. The trees were allowed to grow uncut into the dry season.

Data was collected during the 1987/88 season by Dr. Ronald Guyton (Agronomist, TropSoils Indonesia Project) and Suwandi (Technician, Indonesian Center for Soil Research). The 1987 dry season was quite severe and delayed normal pruning and crop management practices. Hedges were pruned on 5 October 1987 in preparation for planting of upland rice. Samples were taken to determine leaf and wood production and dry matter content. Prunings were spread in the alleys and allowed to dry for 1 week, at which point the wood was removed.

However, lack of rain delayed rice planting. After several days of heavy rain, TSP and KCL were broadcast on all plots on 16 November, at rates of 50 kg ha^{-1} (i.e. 10 kg P and 25 kg K per ha) and Urea at a rate of 53.4 kg ha^{-1} (25 kg N ha^{-1}). No lime was applied. A local variety of upland rice (different from that used in the previous seasons) was planted on 17 November at a spacing of 20 x 40 cm. Continued dry weather caused an uneven stand, so bare spots were replanted on 10 December. The trees were pruned and sampled on 21 December 1987 and again on 22 February 1988 to reduce shading of the rice. Prunings were mulched at both of these times. The rice crop grew very poorly due to infrequent rains and a heavy infestation of rice blast. Rice was harvested on 10 May 1988.

The trees were pruned and sampled again on 29 May 1988. Prunings were spread in the alleys to dry and the wood was removed. TSP was broadcast at a rate of 50 kg ha^{-1} and then incorporated. A local variety of cowpea was planted at 20 x 40 cm spacing in early June. Growth was very poor. Cowpeas were harvested on 20 August 1988.

3.2.4 Soil and Plant Analysis Procedures

Soil was sampled on 19 December 1984, prior to initiating the experiment. Composite samples were collected from main plots at depths of 0-15, 15-30, and 30-60 cm. Soil samples were subsequently taken at a depth of 0-15 cm from individual subplots prior to the second lime application (9 September 1985), during the growth of the second cowpea crop (4 April 1986), and during the growth of the third cowpea crop (28 February 1987).

Samples were air-dried and ground to pass a 2-mm sieve. Determinations of exchangeable Al+H were made by extraction in 1 N KCl and titration with NaOH to the phenolphthalein endpoint. Separate determinations of Al were not made since Al+H levels were found to be highly correlated with Al in previous studies in Sitiung (Wade et al., 1986). Exchangeable Ca and Mg were extracted with 1 N KCl, while K and P were extracted with Mehlich 1 (double acid) extractant (Knudsen et al., 1982). Ca, Mg, and K were measured using an Atomic Absorption Spectrophotometer while P was measured using a colorimetric procedure

(Murphy and Riley, 1962). Effective cation exchange capacity (ECEC) was calculated as: (exchangeable Ca + Mg + K + extractable Al + H). Percent acid saturation was calculated as: (((extractable Al + H)/ECEC) x 100). At the February 1987 sampling, organic carbon was analyzed using acid dichromate digestion, total nitrogen using a semimicro Kjeldahl procedure, and pH using a 1:2.5 soil to water or 1 N KCl suspension (Soil Conservation Service, 1972).

Rice leaf tissue collected on 3 December 1986 was first sun dried and later oven dried at 60 ^{o}C. Samples were ground to pass a 1-mm mesh in a Wiley mill. Total elemental analysis was done at the University of Hawaii Agricultural Diagnostic Service Center using an ICP Spectrometer. The elemental analysis of green leaf manure tissue from hedge prunings is presented in Chapter 2.

Crop grain and straw samples were taken at each harvest to determine moisture content. Grain moisture content was measured with an electronic moisture tester and yields were calculated at 14% moisture for upland rice and 12% for cowpea. Straw samples were sun-dried to constant weight. Five or six randomly selected straw samples per harvest were oven dried at 60 ^{o}C to calculate oven dry weights.

3.2.5 Farmer Managed Alley Cropping

A farmer managed follow-up study of alley cropping was initiated in November 1986 to assess farmer reactions to alley cropping and to obtain farmer's recommendations for improvement of the system. The tree species *Paraserianthes falcataria* and *Calliandra calothyrsus* were selected for study, due to promising growth in the main alley cropping experiment. Suwandi, an agricultural technician (with the Indonesian Center for Soil Research), who lived in the village of Sitiung Vc, asked various farmers in the village if they were interested in trying alley cropping. Suwandi explained to the farmers that they would only receive seed of the two tree species and instructions on planting and management of the hedges. Additional inputs were requested by the farmers for growing their food crops, but were not provided since this might have influenced their retention of the alley cropping system.

Four farmers indicated that they would like to participate. Two of the farmers were of the Sundanese (West Javanese) ethnic group and two were Javanese (East Javanese). Scarified seed were given to the farmers in sufficient quantities to plant two 25 m long hedges of each species. Suwandi assisted the farmers to plant the seed on 24 - 27 November 1986. The seeds were planted at a spacing of 3 seed every 10 cm in a hedgerow and 3 to 6 m between hedgerows. The farmers were instructed that the trees could be used as fertilizer and might help to prevent erosion. Cropping practices were determined entirely by the farmer, so that they were free to adapt the system to their own requirements.

3.3 RESULTS AND DISCUSSION

3.3.1 Tree Establishment Period

Upland rice and cowpea crops grown during tree establishment were both planted much later than usual times for local farmers. Usual planting times are at the beginning of the rains (in September/October) for upland rice and after rice harvest

(February/March) for a pulse crop. The upland rice crop suffered a serious rice blast infestation which was probably caused by high inoculum levels due to late planting. The cowpea crop withered due to insufficient moisture since it was grown through the dry season. Neither crop produced harvestable grain yields, so straw was harvested to characterize treatment responses (Table 3.2).

Upland rice straw yields and plant heights and cowpea straw yields showed highly significant responses to the first increment of lime, but no significant differences between low and high rates of lime (Table 3.3). Intercropping with the different tree species did not significantly affect rice growth. This was expected because the trees were too small during the first several months of growth to compete with the rice and had not yet been pruned for green leaf manure. However, tree species had a highly significant effect on cowpea yields. The Paraserianthes hedges significantly decreased cowpea straw yields, probably through shading since the Paraserianthes trees averaged 3-4 m in height by the cowpea harvest. The other trees did not significantly differ from the treeless control in effects on the cowpea crop. Calliandra and Gliricidia hedges were not as vigorous at this time as Paraserianthes (Chapter 2).

Within two weeks of cowpea germination, plots without lime had extensive leaf chlorosis and necrosis and seedling mortality. This probably indicates that Al toxicity and/or Ca deficiency was severe, affecting even an acid tolerant crop like cowpea (Pandey and Ngarm, 1985). At both low and high lime rates, plants were fairly healthy, although in all plots many plants exhibited leaf bronzing and purplish-brown mottling along the veins. Since exchangeable K was also very low, (section 3.3.4) a K deficiency was suspected and KCl fertilizer was applied to subsequent crops. A moderate rate of K (25 kg ha^{-1} $crop^{-1}$) and returning of crop residues was suggested by previous research in Sitiung (Gill, 1988).

3.3.2 Upland Rice and Cowpea Test Crop Yields

The yields of grain and stover for both rice and cowpea crops in the 1985/86 season increased significantly with increasing lime rates (Figure 3.1). Rice grain yields increased with both increments of lime, but were not significantly different in response to application of green leaf manures from the different tree species (Table 3.4). However, there was a tendency for rice yield to decrease in conjunction with more vigorous growth of the tree hedges (Figure 3.1a). The tree hedges were observed to shade the closest rows of rice, although this did not cause a significant rice yield decrease. Timely pruning of the tree hedges to minimize this competition seems to be important.

Table 3.4 shows that cowpea grain yield, unlike rice, increased significantly with only the first increment of lime. The application of Paraserianthes GLM caused significantly greater cowpea grain and straw yields than the other green leaf manure species or the No tree treatments (Figure 3.1b).

The interaction of green leaf manure species x lime caused significant differences only of rice grain yields (Table 3.4). This indicates that only rice grain yield response to green leaf manure application differed at different lime rates. It can be seen in

Figure 3.1a that there was a tendency (although not significant at a 0.05 level) for grain yields at the zero lime rate to increase where Paraserianthes and Calliandra were grown. At the low or high lime rates, Paraserianthes alley cropping was associated with the lowest rice grain yields, probably due to greater competition with the upland rice than in the case of the other tree species. Cowpea grain yields were higher with Paraserianthes alley cropping than without trees at all liming levels (Figure 3.1b). Coefficients of variation (Table 3.4) were high for both crops.

The yields of upland rice and cowpea for the 1986/87 season are shown in Figure 3.2. The yields of grain and straw for both rice and cowpea crops increased significantly with the application of the low rate of lime (Table 3.5), however, yields at low and high lime rates did not differ significantly. Although Calliandra hedges produced more GLM, rice grain and straw yields were significantly lower than with Paraserianthes hedges. The mean rice yields of all treatments with trees did not differ significantly from the No Tree treatments (Table 3.5). The interaction of lime x tree species caused significant differences in rice yields (Table 3.5) which indicates that the rice yield responses to different tree species varied at different levels of lime application. This is also shown in Figure 3.2a in which rice yields were highest at the low rate of lime for Paraserianthes, Gliricidia, and the No Tree plots while rice yields were lowest for Calliandra at the low rate of lime.

Although cowpea yields were quite low due to a poor stand and drought at planting, there were significant differences in response to

GLM application from the different tree species (Table 3.5). However, there was no significant interaction between lime rate x tree species. Figure 3.2b shows that cowpea yield response to Paraserianthes was significantly higher than to the Gliricidia or No tree treatments. The coefficients of variation for both upland rice and the cowpea crops are shown in Table 3.5. They were especially high for the cowpea crop, probably due to non-uniform stand.

Yields of upland rice and cowpea for the 1987/88 season are shown in Figure 3.3. Yields were very low due to a combination of irregular rainfall and heavy disease infestations. However, crop response to Paraserianthes relative to the other species was much higher than in previous seasons. Significantly lower crop yields were produced with Calliandra than with Paraserianthes (Table 3.6), despite the higher GLM production of the Calliandra hedges (Chapter 2). As in previous seasons, crops responded to only the low rate of lime. However, the tree species x lime interaction for both the upland rice and cowpea crops was significant (Table 3.6). Yields of the Paraserianthes treatments were maximum at the low lime rate while yield responses for the other species increased up to the high lime rate (Figure 3.3). (Treatment means and analyses of variance for crop yields are presented in Appendix III.A).

3.3.3 Green Leaf Manure Nutrient Additions

The amounts of N, P, K, Ca, and Mg contained in the green leaf manure produced by each species was calculated for the 1985/86 and 1986/87 seasons. Yields and nutrient analyses of the GLM at each pruning are presented in Chapter 2. GLM from the 1987/88 season were not analyzed for nutrient concentrations.

The levels of nutrients contained in GLM from four prunings during the 1985/86 season are shown in Table 3.7. Paraserianthes GLM contained the greatest amounts of all nutrients except Ca, which was not significantly higher than in Calliandra GLM. Calliandra GLM contained significantly more N, P, Ca and Mg than Gliricidia GLM. Paraserianthes clearly provided an important fertilizer supplement which may have been partly responsible for the cowpea yield response to Paraserianthes alley cropping. Lime rates did not have a significant effect on nutrient yields except for Ca, which increased with increasing lime application (Table 3.8). Nutrient yields from the different tree species did not differ at the different lime rates.

Nutrient yields from four prunings during the 1986/87 season are shown in Table 3.9. Calliandra GLM contained the greatest amounts of N, P and Ca due to high yields of prunings. However, nutrient yields of K and Mg did not differ significantly between Paraserianthes and Calliandra (Table 3.10) due to the high K and Mg contents of the Paraserianthes GLM (Chapter 2). Gliricidia nutrient yields were much lower due to low yields of prunings. Nutrient yields in Calliandra and Gliricidia GLM were significantly higher at the higher lime rates while Paraserianthes nutrient yields were not significantly affected by lime rates (Table 3.9).

These findings show that substantial nutrient accumulation occurred with both the Paraserianthes and Calliandra hedges. In the 1985/86 season, K in GLM represented 75 % (Paraserianthes) to 30 %

(Calliandra) of the annual KCl application and the P in GLM represented 23 % (Paraserianthes) to 16 % (Calliandra) of the annual TSP application. In the 1986/87 season, K in GLM represented about 40 % of the annual KCl application and the P in GLM represented 16 % (Paraserianthes) to 24 % (Calliandra) of the annual TSP application. Recycling of bases such as Ca, Mg, and K, which are prone to loss by leaching, may be an important benefit of alley cropping. Paraserianthes maintained high nutrient yields at all lime rates while nutrient yield of Calliandra and Gliricidia increased with lime application.

Yields of nutrients varied greatly at the different pruning times. Figure 3.4 shows nutrients contained in GLM at each pruning in the 1985/86 and 1986/87 seasons. The highest yields of all nutrients occurred in the first pruning of each season (in September) due to the long hedge regrowth interval. Paraserianthes nutrient yields were greater than or equal to Calliandra at this September pruning. However, Calliandra had higher yields of N, P, and Ca than Paraserianthes at the November, February, and April prunings due to more vigorous regrowth at these shorter pruning intervals.

The September pruning may be the most important in terms of nutrient application, since large amounts of nutrients mineralized at that time would be taken up by the rapidly growing rice plants. Mineralization of nutrients from prunings in November and April might not coincide as well with plant requirements, because by the time that nutrients would have mineralized, nutrient uptake by the crops would have decreased. Also the N use efficiency for GLM incorporated after the September and February prunings should be higher than the GLM mulched after November and April prunings (Terman,1979; Evensen, 1984). Therefore, the larger proportion of Paraserianthes GLM applied in September and February prunings may have provided a more timely release of nutrients to meet crop requirements than with Calliandra or Gliricidia GLM.

3.3.4 Soil Analyses

In Table 3.11, soil analyses are shown for samples taken before and during the study period. Exchangeable bases and extractable P decreased with increasing soil depths in samples taken before the start of the experiment. Acid saturation was high (87 - 90 %) throughout the profile, while extractable P was extremely low. This data is very similar to that presented in Table 3.1 for soil layers deeper than 4 cm. The surface 4 cm in the nearby undisturbed forest site had a high organic carbon content layer (Table 3.1) which was probably eroded from the alley cropping site.

Analysis of samples to 15 cm depth taken on 10 September 1985 (before the second lime application) and on 12 April 1986 (after the second lime application) show that the lime treatments had produced acid saturations approximating the desired levels. The acid saturation of soil from the high lime rates sampled on 28 February 1987 was higher than the desired level of 25 %, but still well below the critical values reported by Wade et al. (1988) for upland rice (70%) and cowpea (55%). Wade et al. (1988) also reported critical levels for upland rice of 0.20 and 0.21 $cmol_c$ L^{-1} for K and Mg, respectively.

This indicates that soil K levels were probably adequate in the 1985/86 and 1986/87 seasons, but that Mg was probably deficient.

Treatments with trees did not cause significant differences in any of the soil chemical properties measured, except that the Paraserianthes treatments had significantly higher exchangeable Mg than the other species in April 1986 and February 1987. (Detailed soil analyses are presented in Appendix III.B). Lime application caused significantly higher exchangeable Ca and Mg levels as well as lower Al+H and acid saturation levels (Table 3.11). The increase in exchangeable Mg at the first lime increment may be due to increased Mg uptake by more vigorous root systems and better retention on the exchange complex. Lower Mg levels at the high lime rate may be due to leaching losses after replacement on the exchange complex. Exchangeable K and available P were not significantly affected by either tree species or lime rates.

The response of upland rice to soil acid saturation are shown in Figure 3.5 for the No tree and Paraserianthes treatments. Critical acid saturations were estimated to be about 70 % for No tree and 81 % for Paraserianthes treatments in the 1985/86 season (Figure 3.5a). These estimates were made using a Quasi-Newton, nonlinear least squares estimation procedure (NONLIN) in the SYSTAT statistical analysis package (Wilkinson, 1988). The following equation was fitted using this procedure:

$$\text{GRAIN YIELD} = B0 + B1 * (ASAT - X0) * (ASAT > X0),$$

where:
- B0 = linear plateau yields
- B1 = regression coefficient of linear response
- X0 = critical acid saturation (intersection point)
- ASAT = percent acid (Al+H) saturation of the soil

Starting estimates for the linear plateau (B0) and regression coefficient (B1) as well as the critical acid saturation (X0) were made from scatter diagrams of the data. The model was fit and was then tested by varying estimated critical acid saturation values up and down 5 %. The model fitting was finalized when parameter estimates did not change and graphs of residuals showed no systematic deviation from the model.

During the 1985/86 season, GLM applications had just started and rice yields from the Paraserianthes treatments were lower than the treeless control, probably due to competition with hedges. (See section 3.3.5.) However, during the 1986/87 season (Figure 3.5a), rice yields were highest and no critical acid saturation level was observed for Paraserianthes alley cropping. This indicates that Paraserianthes GLM is especially beneficial to crops at high acid saturations and suggests that Al toxicity was ameliorated by GLM application. Approximately the same critical acid saturation level was estimated for the No tree treatments (67 %) as was estimated in the previous season (70 %). Yield response of Calliandra treatments was similar to Paraserianthes treatments while yield response of Gliricidia treatments was similar to No tree treatments.

The grain yield response of cowpea to soil acid saturation is shown in Figure 3.6. Yields were highest for Paraserianthes treatments in the 1985/86 season and critical acid saturation values of 62 % were estimated for the No tree treatments and 65 % for the Paraserianthes treatments (Figure 3.6a). Yield variability was high in the 1986/87 season so no regressions models were developed, however, there is no suggestion of a critical acid saturation level for the Paraserianthes treatments (Figure 3.6b). As with the rice crops, response to Calliandra was similar to Paraserianthes while response to Gliricidia was similar to No tree treatments.

Hue et al. (1986) have shown that certain organic acids (including oxalic, citric, and tartaric) can complex Al and reduce its toxicity to plants. In a greenhouse study, Hoyt and Turner (1975) also showed that adding alfalfa meal to a very acid Canadian soil, reduced exchangeable Al and increased pH and crop yield. They attributed this to complexing of Al by the organic material. Similar mechanisms may be involved in the lack of crop response to lime for several seasons following forest clearing, which has been reported by several researchers (Wade et al., 1988; Friesen et al., 1982). In this alley cropping study, it is hypothesized that organic breakdown products complexed Al rendering it non-toxic to plants, even though it was still extractable with 1 N KCl. Formation of non-soluble Al-organic matter complexes may also account for reduced Al toxicity.

3.3.5 Rice Leaf Tissue Analysis

Nutrient concentrations in rice leaf tissue sampled at 50 % panicle initiation during the 1986/87 season are shown in Table 3.12 while the analysis of variance of these tissue concentrations are shown in Table 3.13. Nitrogen concentrations in rice leaves from the No tree and Gliricidia treatments were not significantly different, but both were significantly higher than Paraserianthes and Calliandra treatments at the zero lime rate (Figure 3.7a). This suggests that the added N from the Paraserianthes and Calliandra GLM did not significantly increase yields. Since no nitrogen was applied to the No tree treatments and Gliricidia GLM did not contribute much N (Table 3.9), the higher rice leaf nitrogen levels in these treatments suggests that lack of N did not limit upland rice yields. Rice leaf N concentrations were significantly higher at the zero lime rate (Table 3.12) which can be explained by a dilution effect, since crop growth was much greater when lime was applied.

Jarrell and Beverly (1981) reviewed literature describing nutrient dilution and concentration effects in agricultural crops. They indicated that analysis of dilution effects may be particularly helpful in differentiating the effects of particular nutrients on the response of crops to "complex (multielement) materials". They also suggest that nutrient concentrations be considered along with yield responses to properly interpret dilution effects. If crop uptake of an element proceeds more slowly than dry matter accumulation, the concentration will decrease. A "C-shaped yield-nutrient concentration" curve will result (Jarrell and Beverly, 1981; Bates, 1971), in which tissue concentrations decrease with increasing yields and then increase again as dry matter accumulation slows. Dilution effects may therefore explain the higher concentrations of N, P, and K at zero lime rates shown in Table 3.12.

Phosphorus concentration of rice leaves was significantly higher in No tree treatments than in treatments with trees (Table 3.13). This could indicate some P depletion by trees and may indicate that slightly higher P fertilization rates are required for alley cropping systems than for food crops without trees. The zero lime treatments were associated with significantly higher P levels in rice leaves. Similarly, this is likely to be a dilution effect, since soil P availability was not reduced by lime application (Table 3.11). There was a significant species x lime rate interaction (Figure 3.7b) which indicates that where there were no trees, P concentrations in rice leaves were higher at zero and at high lime rates than at intermediate lime rate. However, the interpretation of this interaction is uncertain.

Concentrations of K and Mg were not significantly different in rice leaves from different tree species or treeless treatments (Table 3.13) as might be expected if the trees were actively recycling K or Mg from deeper soil layers to the surface. Long term data is needed from this trial to determine whether there is, in fact, increased recycling and availability of bases under this alley cropping system. K concentrations in rice leaves were significantly higher in the zero lime treatments than when lime was applied, indicating that calcium may have interfered with potassium availability or uptake. Magnesium levels in rice were significantly lower in the zero lime treatments than when lime was applied (Tables 3.12 and 3.13). Since magnesium was not applied to this experiment and Mg is not very mobile in the soil, more vigorous root systems in the limed plots may account for the higher Mg concentrations.

There was a strong increase in Ca concentration in rice leaf tissue with increasing lime rates (Figure 3.7). Calcium levels in rice leaves were also higher in the No tree treatments than in treatments with trees (Table 3.13), which is possibly due to calcium uptake by the trees. An indication of relative uptake of Ca by the trees is shown in Tables 3.7 and 3.9, although this shows only the Ca contained in GLM. Total uptake by the trees is higher, including Ca contained in the wood (which was not measured). Aluminum concentration decreased in rice leaves with increasing lime rates but there were no significant differences among tree species or the No tree treatments. Ca and Al levels in rice leaves were inversely related.

Manganese concentration in rice leaves was not significantly influenced by tree species (Table 3.13); however, there was a trend for higher Mn concentrations with Paraserianthes and Calliandra alley cropping (Table 3.12). Mn levels were also significantly higher at the low lime rate than at the zero or high lime rates. This soil may be quite deficient in manganese. On a similar soil in Sitiung, Makarim (1985) found that Mn deficiency symptoms in upland rice were eliminated by foliar application of Mn or application of 12.5 T ha^{-1} of fresh green manure (Calopogonium mucunoides). In Makarim's study, Mn contents in rice tissue increased from 50 to 205 mg kg^{-1} with application of the green manure, while extractable soil Mn increased from about 1.1 to 3.4 mg L^{-1}. However, Makarim imported the green manure from a more fertile site while in alley cropping, green manure is produced on site. Thus, an increase in Mn availability in the alley cropping study could only occur due to the recycling of Mn by the trees. It is not clear whether alley cropping improved Mn availability. Yoshida (1975) questioned whether Mn deficiency can even occur in rice.

Table 3.14 contains critical values and sufficiency ranges for nutrient concentrations in rice leaves as reported in literature, mainly for irrigated rice. Chang (1978) indicated that plant nutrient concentrations in diagnostic tissue, especially N and P, vary considerably due to environmental, cultural, and varietal factors. Critical values, therefore, are only approximations but can help to indicate likely deficiencies. Sufficiency ranges are the nutrient concentrations associated with optimal growth under a variety of conditions.

N, K, and Ca values presented in Table 3.12 were low but within reported sufficiency ranges indicating that these nutrients were not the main factors limiting rice yield. P was probably deficient while Mg and Mn were well below reported sufficiency ranges, indicating that they probably did limit yields. Increasing P fertilization rates may be advisable but Mg or Mn fertilizers are not currently available to farmers in West Sumatra.

3.3.6 Crop-Tree Competition

During the 1986/87 season a special study was conducted on the effects of competition between tree hedges and the upland rice crop. This study was undertaken because growth and yield of rice was observed to decrease close to the hedges. This presented an opportunity to study factors affecting competition between the rice crop and the hedges of trees.

Crop growth and yield parameters were measured on individual rows (of 3 m length each) in the harvest area of each subplot. Figure 3.8

is a diagram of the harvest area of a typical subplot with a central hedge and 10 rows of rice. Five row positions were characterized in each plot by averaging measurements of two rows at each of five distances from the hedges. In the No tree plots, all 10 rows in the harvest areas were measured. Grain yields and several components of yield were taken to better characterize this competition.

Yields of rice grain at each row position are shown in Figure 3.9a. Yields of tree species treatments at the five row positions were averaged over lime rates since neither the lime rate x row position nor tree species x lime rate x row position interactions were significant (Table 3.15). Yields of rows of rice closest to hedges were reduced due to competition with the trees. This yield reduction was most severe near Calliandra hedges, due to strong shading of the widely spreading Calliandra canopy. At harvest time, Calliandra hedges had extended out to the second row of rice, 60 cm from the hedge. Paraserianthes and the Gliricidia hedges covered only up to the first row of rice (20 cm from the hedges) and reduced yields of this inner row much less.

Among the three tree species, Calliandra was observed to regrow most vigorously after pruning. While this is an advantage in maintaining vigorous hedges, it does increase shading of food crops. Competition for light is probably the main cause of rice yield reduction since plots were cultivated twice a year. This cultivation destroyed tree roots in the surface 15 cm of soil and should have lessened root competition.

The effects of distance of rice rows from hedges on plant heights is shown in Figure 3.9b. The height of rice plants in the Paraserianthes treatments increased adjacent to the hedges suggesting that there was moderate competition for light with the trees. Plants often respond to moderate shading by increasing in height (Eriksen, 1978). If root competition had been significant, plants would probably have been stunted. Calliandra, on the other hand, reduced the height of rice plants close to the hedge due to severe shading. The row adjacent to the hedge was completely covered at harvest. Figure 3.9b shows that rice height at 20 cm was significantly lower and height at 60 cm was significantly higher than at 100, 140, or 180 cm row distances. This indicates that the first row (20 cm) was severely stunted while the second row (60 cm) was only moderately shaded.

The effects of distance of rice rows from hedges on numbers of fertile and total tillers per hill are shown in Figure 3.9c 3.9d, respectively. The number of fertile tillers and number of total tillers provide evidence as to when competition effects between trees and rice were most severe. Dedatta (1981) indicated that for medium and long maturity rice varieties (greater than 120 days), maximum tiller number is produced before panicle initiation. Competitive stress occurring during periods when these characters are determined is likely to reduce their expression.

Figure 3.9c shows that number of fertile tillers per hill increased significantly with increasing distances from the hedge for both Paraserianthes and Calliandra treatments. This suggests that a strong competitive stress occurred during panicle initiation. Panicle initiation occurred during the first two weeks of December in this rice crop. Since hedges were pruned on 1 November, competition with hedges would have been greatest in late October and again from mid-December to rice maturity. Thus, competition with the Paraserianthes and Calliandra hedges reduced fertile tillers for rows adjacent to hedges, especially with Calliandra. Fertile tillers in the Gliricidia treatments were not affected by distance from tree hedges, which would be expected from its meager growth.

Figure 3.9d shows that total number of tillers were significantly reduced only in the row adjacent to the Calliandra hedge. This indicates that competition was less severe when this trait was being expressed, which probably occurred in mid-November. This was just after hedge pruning so shading of the rice was minimal. This supports the earlier contention that competition for light was more important than root competition, since the roots would have been actively growing during this time. If there had been strong competition from tree roots, a greater reduction in total tillers might have been expected in the rows closest to the hedges.

An analysis of variance of the effects of row position (RP) on rice growth and yields per row is presented in Table 3.15. There was a highly significant Tree species x Lime rate interaction for fertile tillers, but not for total tillers. This was related to fewer fertile tillers at the zero lime rate than when lime was applied for the No tree treatments. In the treatments with trees, the number of fertile tillers per hill did not vary with lime rates. There was also a highly significant Species x Row Position interaction (Table 3.15) for fertile tillers and a lack of a significant interaction for total tillers which is further indication of more severe competition at the time of panicle initiation. Plant height is expressed throughout vegetative growth of a crop and therefore does not help to determine periods of maximum competitive stress.

These data suggest that an additional pruning in early December (about the time of panicle initiation) might have increased fertile tillers and yield. The potential for rice yield increase if competition were minimized can be calculated by dividing the yield of rows furthest from the hedges by the average yield of all rows. According to this calculation, a yield increase of 32 % for Calliandra, 13 % for Paraserianthes, and 7 % for Gliricidia is possible of competition were eliminated. Pruning hedges more frequently would reduce competition and probably raise yields. More frequent pruning would be most beneficial with Calliandra, however the added yield must be balanced against increased labor costs. Also, lower pruning heights of Calliandra hedges might increase crop yields by reducing shading.

3.3.7 Trends in Crop Yields

Growth and yields of upland rice and cowpea varied over the four cropping seasons from 1985 to 1988. As discussed in section 3.3.1, growth of upland rice and cowpea during the tree establishment period (from January to September 1985) was very poor due to late planting. Disease and pest infestations were more severe than usual. GLM was not applied during this time, so the only effect of the trees on crops was yield reduction due to shading by the vigorous Paraserianthes hedges.

Beginning in September 1985, hedges were pruned 4 times per year. Alley cropping did not increase upland rice yields in the 1985/86 season, but as shown in Table 3.5 and in Figure 3.10a, yields from Paraserianthes treatments were significantly higher than the other species in the next two seasons. This suggests that there was a cumulative effect of Paraserianthes GLM application which improved relative yields over time. Liming consistently produced higher yields in all three seasons, relative to control plots, but only to the first increment of 750 kg lime ha^{-1} (Figure 3.10b). Cowpea yields were highest in Paraserianthes treatments in all three seasons (Figure 3.11a) and responded up to the first increment of lime (Figure 3.11b).

There is an obvious trend of yields decreasing over the three seasons. This should not necessarily be attributed to a lack of sustainability of alley cropping per se, since the yields of all treatments, including the No tree controls, declined over this period. Determining the sustainability of overall upland crop production in Sitiung, while extremely important for development planning purposes, was not an objective of this study. However, since Sitiung farmers generally report either stable or increasing yields when adequate fertilizers are applied (Stacy Evensen, personal communication), other possible explanations for the yield decreases observed in subsequent years of this experiment should be considered.

The decreasing yields may be explained partly by unfavorable rainfall distribution in the latter years. Monthly rainfall distributions up to April 1987 are shown in Figure 3.12. Total rainfall as well as number of day with greater than 5 mm of rainfall were greater during the 1985/86 season than during the 1986/87 season. Differences in rainfall distribution between these seasons is also shown in Figure 3.13. The frequency and duration of rainless periods were greater in the 1986/87 season for both rice and cowpea crops.

Rainfall data for the 1987/88 season in Sitiung V are not available, but Dr. Ronald Guyton reported a severe drought up until mid-October 1987 and poorly distributed rainfall during growth of the rice and cowpea crops. Rainfall during the 1987/88 season which was recorded at a weather station about 10 km from the experimental site was about 60 % of that during the 1985/86 season. Since rainfed upland rice yields are highly correlated with high rainfall and high soil moisture availability (De Datta and Vergara, 1975), the increasing severity of moisture stress during the three seasons helps to explain the decreasing rice yields.

Cowpea is know to be fairly tolerant to drought (Purseglove, 1977) but does respond to irrigation in dry environments (Pandey and Ngarm, 1985). Poor moisture availability probably reduced cowpea yields, especially during the 1988 dry season (from June to August). Late planting probably also contributed to the higher disease and insect infestations in both the upland rice and cowpea crops in 1987/88, just as in the 1985 tree establishment period. High pest populations probably built up on neighboring farms where crops were planted earlier and infested the experimental crops at an early growth phase.

An analysis of variance of grain yields combined over the 1985/86 and 1986/87 cropping seasons is shown in Table 3.16. The 1987/88 cropping season was not included in this combined analysis since error variances were homogeneous only over the first two years as determined by procedures described by Gomez and Gomez (1984). The analysis of variance combined the split-plot experiments over the two years according to the method of McIntosh (1983).

A major concern in such an analysis is whether to consider effects of years (cropping seasons) random or fixed. If variation in weather was the main effect of years on crop yields, years should be analyzed as a random effect. As already discussed, rainfall probably influenced yields strongly. However, if the treatments, had a progressive or cumulative affect on yields, as is suspected for at least Paraserianthes alley cropping, the effects of years should be considered fixed. It seems that the effects of years were probably a combination of random and fixed components.

Fortunately, Table 3.16 shows that interpretation of the analysis of variance is simplified since the significance of most components of variance did not differ for years considered as either random or fixed effects. Years had a highly significant effect on yields of both rice and cowpea. The Tree species x Years interaction was not significant for either the upland rice or the cowpea crops indicating that the effects of Tree species on yields did not differ between the two years. The Lime x Years interaction was highly significant for both the upland rice and cowpea crops. This reflects the decreasing yields of the high lime rate relative to the low lime rate as shown in Figures 3.10b and 3.11b.

Table 3.17 shows the relative yields of treatments without lime as percentages of the No tree - low lime treatment over three years.

This provides an indication of the value of alley cropping treatments as substitutes for lime. In the 1985/86 season, crop response to the low rate of lime was greater than to alley cropping. Thereafter, crop response to Paraserianthes was greater than to lime. The increasing relative yields with Paraserianthes supports the contention that successive applications of Paraserianthes prunings had a cumulative effect to improve crop yields. Relative yields with Calliandra increased less over time, while relative yields with Gliricidia did not increase and remained well below the yields of the No tree - low lime treatment. The control treatment (No Tree - No lime) had consistently low yields which were similar to the Gliricidia - No lime treatment yields.

3.3.8 Farmer Managed Alley Cropping: Observations and Survey Results

Due to limited staff time, the on-farm alley cropping trial was not closely monitored. However, periodic observations showed that trees had germinated well and hedges had established well on all but one farm. Growth of trees was quite variable on different sites. Young seedlings were quite susceptible to erosion damage. On the farm where hedges were slow to establish, most seedlings were lost to erosion during the first 6 months after planting and other trees were destroyed by an accidental fire (Farmer 1 in Table 3.18). According to the farmer, surviving seedlings on that farm were very stunted (only 50 cm in height at 6 months) due to low soil fertility. In February 1987, one farmer was observed to have planted hedges of the short-lived woody species *Crotalaria usaramoensis* in an alley cropping system that the farmer said was faster establishing and more vigorous than the trees. (See chapter 5 for green manuring studies using this species.)

Two years after planting the hedges, a survey was conducted to assess farmers reactions to alley cropping. The survey was implemented by Suwandi and Tom Dierolf, a Graduate Student from the University of Hawaii. Results of the survey are presented in Table 3.18. Of the four farmers, only one was still alley cropping, two had removed the trees, and the fourth farmer's hedges had never established well. The main reasons given by the farmers for removing hedges were:

1) lack of time for pruning,
2) insect pests were harbored by the hedges (grasshoppers, plant hoppers, and other insects),
3) loss of crop land, and
4) shading of crops.

Both farmers who removed their hedges seemed not to value the prunings as fertilizer and did not prune the hedges regularly. This lack of pruning undoubtedly caused competition with their food crops at the time hedges were removed, although Farmer 3 indicated that an east-west hedge orientation reduced shading of his crops by the hedges. Farmer 4 also indicated that insufficient seed was given to him to plant the full length of his terraces and he felt that this would impair erosion control. This is a very good point since incomplete terraces can concentrate runoff water and cause worse erosion than no terrace (El-Swaify et al., 1982; Sheng, 1977).

The farmer who had maintained the alley cropping system (Farmer 2) was very happy with it. He had very perceptively developed management practices for his hedges. He pruned the hedges 3 time per year, just before planting a crop in August, January, and May. The prunings were mulched or if he had time, he incorporated them. Wood from the prunings was placed on the uphill side of hedges to dry and to act as a mechanical barrier to soil loss. The wood was later collected for use as fuelwood.

Farmer 2 pruned Paraserianthes to a 20 cm stump height the first time and cut it 10 - 20 cm higher at each subsequent pruning since he was afraid of it dying if too heavily pruned. He was also trying to establish a fence with Paraserianthes. However, he pruned Calliandra to a 20 cm stump height at every pruning due to its bushy, vigorous growth habit. He was afraid that it would shade his crops too much if pruned higher. These seem to be very logical management strategies for the two different species. Farmer 2 wanted to plant more hedges, but lacked seed. He was especially interested in Calliandra since it is fast growing and yielded the most green leaf manure and wood.

It is inappropriate to draw far-reaching conclusions from such a small sample size, but some generalizations can be made. The fact that only one farmer out of four was still alley cropping after two years indicates that the technology may have limited appeal to farmers in this village. However, if more interaction had occurred between researchers and farmers, perhaps early problems with the system could have been solved and more farmers would have retained alley cropping. Also, interaction between farmers could have been encouraged so that failures could have been discussed and successful management practices shared. Since one farmer failed to establish hedges due to erosion and low soil fertility, more attention should be paid to erosion control and fertilizing hedges during establishment. If this is not possible, then alley cropping should not be recommended on very steep sites with highly infertile soils.

3.4 RECOMMENDATIONS FOR FUTURE RESEARCH

This research has shown that alley cropping with Paraserianthes and possibly with Calliandra can increase crop yields on an acid and infertile soil in the humid tropics. However, there has not been an adequate assessment of the relevance and acceptability of this technology to farmers in these areas in Indonesia. The best means of introducing and adequately testing alley cropping is through on-farm research, such as described by Atta-Krah and Francis (1987) at ILCA's Humid Zone Programme in Nigeria. They conducted a series of trials of on-farm "alley farming" (i.e. including livestock production) specifically to determine alley farming's "workability and relevance to farmers". This research better defined the range of adaptability of alley farming in West Africa and provided some specific research objectives for subsequent on-station and on-farm research.

On-farm alley cropping research allows adaptation of a technology to farmer's conditions and provides researchers and extension personnel with farmer insights on management of the system under farm conditions. Also, evaluation under different environmental conditions allows determination of the range of applicability of alley cropping. This should involve assessment of the physical environment and biological response to alley cropping as well as the resources, goals, social obligations, and economic circumstances of a farm family. Situations where alley cropping is inappropriate or offers only marginal benefits must be clearly identified along with those situations where it is beneficial.

The results of the farmer-managed alley cropping trial reported here provides some guidance for conducting future research. The following recommendations could help to improve the scope and usefulness of research results from on-farm studies:

1) A sufficient number of farmers representing the important farming environments in a region should be involved, so that the potential for improved agricultural production with alley cropping can be assessed.

2) Initial interactions with farmers should be frequent. Preferably this could occur in small group meetings among neighbors, so that farmers can discuss management of the hedges with researchers and with each other.

3) Periodic follow-up should be planned with each farmer, especially in the first year after planting the hedges, so that problems can be identified and possible solutions discussed. This would also provide the researchers with an opportunity to personally assess the system.

4) Sufficient seed should be given to farmers to plant an entire hillside or small drainage area, so that good erosion control is achieved. On especially steep slopes, some mechanical barriers or grass strips may need to be established along with hedges.

5) Soil from each research site should be sampled for chemical analysis and the soil profile, topography, and vegetation (or cropping system) described. This will allow determination of the range of biophysical conditions for which alley cropping is applicable.

6) Potential interactions of alley cropping with livestock components of the farming systems should be assessed. (i.e. "alley farming")

7) Information should also be collected on labor and other costs and benefits associated with alley cropping. Farmer interviews and periodic observations by researcher could provide such information.

Studies of components of yield of the food crop may also be very useful in alley cropping research to analyze competition effects with the tree hedges. It has been shown in Section 3.3.5 how components of yield can suggest periods of greatest competitive stress for upland rice. Other components of yield could help to further determine periods of yield reduction due to competition. These include panicle number per unit area (set during vegetative growth), spikelet number per panicle (set during flowering), and filled-spikelet percentage (set during grain fill and ripening). The influence of source-sink effects on yields can also be considered with this data. Yoshida and Parao (1976) and De Datta (1981) discuss components of yield for rice.

3.5 CONCLUSIONS

The leguminous tree species, Paraserianthes falcataria and Calliandra calothyrsus, have shown potential for use in alley cropping under the soil and climatic conditions in Sitiung (i.e. acidic soils, low in bases and a warm, humid climate). Gliricidia sepium did not grow as vigorously under these conditions. During the 1985/86 growing season, upland rice did not respond significantly to green leaf manure (GLM) additions, but cowpea crop yields were increased by addition of Paraserianthes prunings. These results indicate that alley cropping provides only a marginal benefit to farmers during the first year of cropping. However, both upland rice and cowpea produced highest yields with Paraserianthes alley cropping in the 1986/87 season. Calliandra was not as productive due to shading competition with the food crops while Gliricidia did not grow well enough to influence crop yields.

Considerable amounts of nutrients were applied in Paraserianthes and Calliandra GLM. N, Ca, Mg, and K in GLM was equivalent to the amounts removed in rice and cowpea grain, as estimated from data on nutrient contents reported by Sanchez (1976). If some of this represents nutrients which would otherwise be lost through leaching, alley cropping would improve sustainability of upland crop production. Soil analyses in this study do not support nor refute the hypothetical role of trees in increasing nutrient availability in the soil surface by recycling nutrients from deeper soil layers. Evidence for such an effect, if it exists, may require a longer period of time than the two and a half years reported here.

Leguminous trees are usually used in alley cropping to provide nitrogen. In this study, however, N was probably not a major yield limiting factor because N deficiency symptoms were not observed and N concentrations in rice leaves were high in No tree and Gliricidia treatments. The major factors limiting yields were probably Al toxicity and associated deficiencies of Ca, Mg, and K.

It is likely that part of the observed crop response to Paraserianthes alley cropping was due to the amelioration of Al toxicity. If this is true, it suggests that alley cropping with Paraserianthes will be most beneficial on soils with high levels of toxic Al. If labile Al-organic matter complexes are important in reducing Al toxicity to crops, the frequent application of GLM in alley cropping would be especially beneficial. However, other factors besides Al toxicity probably influenced crop yields such as deficiencies of P, Mg, and Mn.

The highest crop yields were obtained in the Paraserianthes + Low lime rate treatment in all harvests except the initial rice crop when the effects of alley cropping were just being established. This suggests that beneficial effects of alley cropping with Paraserianthes went beyond simply substituting for lime. This synergistic effect on crop yields of alley cropping with Paraserianthes and the application of a low rate of lime can not be adequately explained with current data and requires further study.

Coefficients of variability were high throughout this experiment. Soil micro-variability on this site was high, which makes tests of significance imprecise. This is a constant problem on newly cleared forest sites (Sinclair, 1987) and in a low input trial such as this, only very strong treatment effects can be shown to be significantly different. Where all non-treatment soil fertility factors are raised to optimum levels, much of this soil micro-variability can be eliminated (Gill, 1988; Trangmar et al., 1987). However, these are not the conditions existing on limited resource farms and conclusions from such high input research may not be directly transferable to such farms.

For these reasons, a low resource approach was used in this experiment. This may have contributed to difficulties in isolating the main factors influencing yield, since many factors were confounded. Therefore soil Al toxicity, availability of Ca, Mg, K, N, and soil moisture as well as disease incidence probably all interacted to influence yields.

Alley cropping with Paraserianthes seems to provide a productive alternative to liming. Where liming is possible, economic analysis must be done to indicate whether liming, alley cropping, or their combination is more beneficial to farmers. (See chapter 4 for an economic analysis.) Where lime is not available, alley cropping with Paraserianthes has been shown in this study to more than double control plot yields after the first year of cropping. Applicability of these results under a range of environmental conditions should be tested.

Table 3.1. Soil properties of an uncleared forest site adjacent to the alley cropping experiment, Sitiung Vc, West Sumatra.

Depth	Clay	Sand	Org. C	Bulk Density	pH	Al	Ca	Mg	K	ECEC	Al Sat.
cm	%	%	%	g cm^{-1}		-------		$cmol_c$ L^{-1}		-------	%
0-4	46	42	3.81	-	3.5	3.9	0.8	0.4	0.2	5.4	72
4-34	52	37	1.06	1.28	4.5	2.2	0.1	0.1	0.1	2.5	88
34-62	61	29	0.64	1.28	4.5	1.8	tr	tr	tr	1.8	100
62-106	62	28	0.54	1.27	4.8	1.5	0.1	0.1	tr	1.7	88
106-142	64	26	0.44	1.26	5.0	1.6	tr	tr	-	1.6	100
142-180	64	23	0.32	1.24	5.0	1.7	tr	tr	-	1.7	100

(Soil pedon analyzed by the U.S Soil Conservation Service, National Soil Survey Laboratory, Lincoln, Nebraska. This data is a part of the Soil Management Support Services soil data base, classified under the soil survey number S85-FN-458-004).

Table 3.2. Upland rice and cowpea growth and yields during the tree establishment period (1985).

TREATMENT	Upland Rice Height	Upland Rice Straw Yield	Cowpea Straw Yield
	-- cm --	kg ha^{-1}	kg ha^{-1}
SPECIES MEANS:			
No Tree	42	1517	256
Paraserianthes	45	1664	49
Calliandra	42	1569	189
Gliricidia	41	1398	175
LIME RATE MEANS:			
No Lime	32	940	73
Low Lime	50	2005	213
High Lime	46	1667	216
LSD(0.05) BETWEEN:			
-Species means	ns	ns	118
-Lime rate means	9	620	92

Table 3.3. Analysis of variance for upland rice and cowpea yields during tree establishment (1985).

Source	df	Upland Rice Height MS	Upland Rice Straw Yield MS	Cowpea Straw Yield MS
Rep	3	682.7	4470244	17867
Tree Spp.	(3)	33.8	146862	89534*
Tree vs No Tree	1	3.4	6281	125481*
GLI. vs PAR.+CAL.	1	60.1	380628	25226
PAR. vs CAL.	1	38.0	53676	117894*
Error A	9	294.5	1482252	16353
Lime Rates	(2)	1469.2***	4735546**	106233**
Lime vs No lime	1	2816.7***	8556801**	212403***
Low vs High lime	1	121.7	914290	63
Lime * Tree Spp.	6	226.2	1296452	8751
Error B	24	147.7	720804	15911
CV (%) Main plot		79	40	76
CV (%) Subplot		55	28	75

*, **, *** Significant at the 0.05, 0.01, and 0.001 probability levels, respectively.

Table 3.4. Analysis of variance for upland rice and cowpea yields during the 1985/86 season.

Source	df	Upland Rice Grain MS	Upland Rice Straw MS	Cowpea Grain MS	Cowpea Straw MS
Rep	3	58478	558156	53946	118189
Tree Spp.	(3)	217301	274648	333560*	250841*
Tree vs No Tree	1	446892	78867	193893	101867
GLI. vs PAR.+CAL.	1	130305	295168	357153*	169556
PAR. vs CAL.	1	74705	449908	449634*	481100*
Error A	9	445646	474338	50970	58810
Lime Rates	(2)	7394238***	9958957***	868025***	1395855***
Lime vs No lime	1	13960600***	19595100***	1667692***	2525260***
Low vs High lime	1	827863*	322806	68358	266450**
Lime * Tree Spp.	6	443317*	759350	3776	27049
Error B	24	155329	737151	38597	28799
CV (%) Main plot		45	21	46	43
CV (%) Subplot		27	26	40	30

*, **, *** Significant at the 0.05, 0.01, and 0.001 probability levels, respectively.

Table 3.5. Analysis of variance for upland rice and cowpea yields during the 1986/87 season.

Source	df	Upland Rice Grain MS	Upland Rice Straw MS	Cowpea Grain MS	Cowpea Straw MS
Rep	3	24392	87678	31560	48260
Tree Spp.	(3)	444456	2165080	197452	289808*
Tree vs No Tree	1	79571	905352	218119	96293
GLI. vs PAR.+CAL.	1	4356	823045	249071	411688*
PAR. vs CAL.	1	1249441*	4766850*	162134	416185*
Error A	9	134342	595109	55012	62529
Lime Rates	(2)	549620**	928444*	116461**	266223**
Lime vs No lime	1	1042709***	1852040**	232344**	474390***
Low vs High lime	1	56532	4851	578	58055
Lime * Tree Spp.	6	195298*	687431*	3392	33929
Error B	24	72789	206816	19982	32703
CV (%) Main-plot		33	32	101	64
CV (%) Subplot		25	19	58	45

*, **, *** Significant at the 0.05, 0.01, and 0.001 probability levels, respectively.

Table 3.6. Analysis of variance for upland rice and cowpea yields during the 1987/88 season.

Source	df	----- Upland Rice -----		------- Cowpea --------	
		Grain MS	Straw MS	Grain MS	Straw MS
Rep	3	133	1690443	1301	3092
Tree Spp.	(3)	157669**	3866963*	92969***	90771***
Tree vs No Tree	1	112583*	2663506	66573*	38596*
GLI. vs PAR.+CAL.	1	195636**	4644695*	69391*	59501*
PAR. vs CAL.	1	164789*	4292689*	142944***	174217***
Error A	9	17309	808893	7016	6939
Lime Rates	(2)	166114**	4390688***	38631***	146175***
Lime vs No lime	1	252796***	7478596***	74070***	241803***
Low vs High lime	1	79431	1302780	3192	50546*
Lime * Tree Spp.	6	49117*	1314084*	9860*	7139
Error B	24	19272	469435	2731	7936
CV (%) Main-plot		53	61	93	48
CV (%) Subplot		56	47	58	51

*, **, *** Significant at the 0.05, 0.01, and 0.001 probability levels, respectively.

Table 3.7. Nutrients contained in green leaf manure as totals of four prunings in the 1985/86 season.

TREATMENT		N	P	K	Ca	Mg
		kg ha^{-1}				
Paraseri -anthes *	No lime	87.8	4.4	36.2	11.6	6.4
	Low lime	97.6	4.7	42.3	16.1	8.0
	High lime	91.3	4.5	35.9	20.3	6.6
Calliandra *	No lime	68.5	3.2	17.0	8.7	3.8
	Low lime	68.0	3.4	16.5	14.1	3.4
	High lime	63.4	3.0	11.1	16.0	1.9
Gliricidia *	No lime	7.4	0.5	2.9	1.4	0.3
	low lime	23.1	1.5	9.6	5.5	0.7
	High lime	31.6	2.1	11.4	9.8	1.0
SPECIES MEANS:						
Paraserianthes		92.3	4.6	38.2	16.0	7.0
Calliandra		66.6	3.2	14.9	12.9	3.0
Gliricidia		21.9	1.4	8.2	5.6	0.7
LIME RATE MEANS:						
No Lime		58.9	2.9	20.1	7.8	3.8
Low Lime		62.9	3.2	22.8	11.9	4.1
High LIme		62.1	3.3	20.2	15.9	3.4
LSD(0.05) BETWEEN:						
-Species means		23.6	1.2	7.2	4.6	1.5
-Lime rate means		ns	ns	ns	3.7	ns
-Lime means for same sp.		ns	ns	ns	6.3	ns
-Species means for same or different lime rates		35.2	1.7	13.9	6.9	2.4

Table 3.8. Analysis of variance for nutrients in green leaf manure as totals of four prunings in the 1985/86 season.

Source	df	N	P	K	Ca	Mg
		P values				
Rep	3	0.421	0.350	0.238	0.433	0.442
Tree Spp.	(2)	0.001	0.002	0.000	0.006	0.000
GLI. vs Others	1	0.001	0.001	0.001	0.003	0.000
PAR. vs CAL.	1	0.038	0.030	0.000	0.149	0.001
Error A	6					
Lime Rates	(2)	0.718	0.629	0.604	0.004	0.407
Lime vs No lime	1	0.425	0.354	0.671	0.002	0.941
Low vs High lime	1	0.929	0.879	0.383	0.088	0.189
Lime * Tree Spp.	4	0.834	0.823	0.848	0.965	0.480
Error B	17					

Table 3.9. Nutrients contained in green leaf manure as totals of four prunings in the 1986/87 season.

TREATMENT		N	P	K	Ca	Mg
		------------		kg ha^{-1}		------------
Paraseri * -anthes	No lime	73.2	3.3	20.0	7.2	5.0
	Low lime	68.5	3.0	21.3	9.0	5.8
	High lime	68.7	3.3	20.5	12.4	5.1
Calliandra *	No lime	88.2	3.8	18.8	10.7	5.5
	Low lime	119.7	5.2	24.2	23.1	5.8
	High lime	129.3	5.5	19.8	29.7	3.9
Gliricidia *	No lime	4.8	0.3	1.0	1.0	0.5
	low lime	12.1	0.8	4.9	2.9	0.3
	High lime	28.7	2.0	10.3	9.0	0.9
SPECIES MEANS:						
Paraserianthes		70.1	3.2	20.5	9.5	5.3
Calliandra		112.4	4.8	21.0	21.2	5.1
Gliricidia		16.2	1.1	5.8	4.6	0.6
LIME RATE MEANS:						
No Lime		60.0	2.6	14.3	6.8	3.9
Low Lime		66.7	3.0	16.8	11.7	4.0
High LIme		75.6	3.6	16.8	17.0	3.3
LSD(0.05) BETWEEN:						
-Species means		26.4	1.0	5.9	4.4	1.4
-Lime rate means		ns	0.6	3.2	3.4	ns
-Lime means for same sp.		28.5	1.1	5.6	6.0	1.7
-Species means for same or different lime rates		35.1	1.3	7.5	6.5	1.9

Table 3.10. Analysis of variance for nutrients in green leaf manure as totals of four prunings in the 1986/87 season.

Source	df	N	P	K	Ca	Mg
		---------------		P values		-------------
Rep	3	0.371	0.294	0.312	0.419	0.253
Tree Spp.	(2)	0.000	0.000	0.001	0.000	0.000
GLI. vs Others	1	0.000	0.000	0.000	0.000	0.000
PAR. vs CAL.	1	0.008	0.005	0.863	0.001	0.705
Error A	6					
Lime Rates	(2)	0.064	0.006	0.048	0.000	0.335
Lime vs No lime	1	0.035	0.005	0.015	0.000	0.989
Low vs High lime	1	0.274	0.073	0.983	0.004	0.145
Lime * Tree Spp.	4	0.195	0.091	0.084	0.024	0.201
Error B	17					

Table 3.11. Soil analyses for means of lime rates.

Sampling Time	Sample Type	Al+H	Ca	Mg	K	ECEC	P ppm	% Acid Sat.
		---------- ($cmol_c$	L^{-1})	----------				
19/12/84[a]	0-15cm	2.21	0.18	0.06	0.07	2.51	2.8	87
	15-30cm	1.93	0.13	0.04	0.05	2.16	0.7	89
	30-60cm	1.53	0.11	0.03	0.04	1.71	0.5	90
09/10/85[b]	Zero lime	2.21	0.38	0.06	0.09	2.73	8.1	81
	Low lime	1.89	0.75	0.11	0.08	2.83	8.8	68
	High lime	1.12	2.19	0.07	0.09	3.47	8.4	33
	LSD(0.05)	0.22	0.23	ns	ns	0.24	ns	7
04/12/86[c]	Zero lime	1.67	0.34	0.10	0.21	2.32	6.0	73
	Low lime	1.31	0.89	0.17	0.21	2.56	5.9	52
	High lime	0.76	1.62	0.12	0.21	2.71	5.8	28
	LSD(0.05)	0.21	0.25	0.04	ns	0.16	ns	9
02/28/87[d]	Zero lime	2.16	0.29	0.08	0.16	2.70	4.6	80
	Low lime	1.96	0.60	0.13	0.16	2.86	5.2	69
	High lime	1.13	1.17	0.10	0.16	2.57	4.5	46
	LSD(0.05)	0.18	0.14	0.033	ns	0.18	ns	4

[a] Sampled before the start of the experiment.
[b] Sampled before the second lime application (on September 23, 1986). All samples taken at 0-15 cm depth.
[c] Sampled after the second lime application. All samples 0-15 cm.
[d] Sampled after the third lime application. All samples 0-15 cm.

Table 3.12. Nutrient concentrations in rice leaf tissue sampled at panicle initiation during the 1986/87 season.

TREATMENT		N	P	K	Ca	Mg	Mn	Al
		----------	(g kg^{-1})		---------		(mg kg^{-1})	
No Tree *	No lime	28.9	1.65	13.8	2.1	0.65	49	54
	Low lime	23.7	1.40	14.7	4.4	1.05	75	29
	High lime	24.7	1.68	12.0	6.0	1.00	47	35
Paraseri * -anthes	No lime	25.0	1.38	15.2	2.0	0.78	66	51
	Low lime	23.3	1.25	13.0	3.8	1.08	92	38
	High lime	23.8	1.25	14.9	4.3	0.80	59	31
Calliandra *	No lime	25.9	1.43	14.9	2.0	0.78	76	43
	Low lime	24.6	1.38	12.2	3.6	0.93	85	37
	High lime	23.8	1.38	14.9	4.6	1.00	58	26
Gliricidia *	No lime	29.9	1.55	16.8	1.7	0.55	40	44
	low lime	24.9	1.40	13.9	4.4	0.88	91	30
	High lime	25.5	1.20	13.2	4.6	0.95	57	24
SPECIES MEANS:								
No Tree		25.7	1.58	13.5	4.2	0.90	57	39
Paraserianthes		24.0	1.29	14.3	3.4	0.88	72	40
Calliandra		24.8	1.39	14.0	3.4	0.90	73	35
Gliricidia		26.7	1.38	14.6	3.6	0.79	63	33
LIME RATE MEANS:								
No Lime		27.4	1.50	15.1	1.9	0.69	58	48
Low Lime		24.1	1.36	13.4	4.0	0.98	86	33
High LIme		24.4	1.38	13.8	4.9	0.94	55	29
LSD(0.05) BETWEEN:								
-Species means		1.6	0.12	ns	ns	ns	ns	ns
-Lime rate means		1.2	0.09	1.1	0.6	0.23	18	10
-Lime means for same sp.		2.4	0.18	2.3	1.1	0.47	35	20
-Species means for same or different lime rates		2.5	0.19	3.0	1.2	0.47	38	21

Table 3.13. Analysis of variance of nutrient concentrations in rice leaf tissue sampled at panicle initiation in the 1986/87 season.

Source	df	N	P	K	Ca	Mg	Mn	Al
		----------	----------	----------	P values	----------	----------	----------
Rep	3	.005	.138	.086	.092	.094	.257	.103
Tree Spp.	(3)	.018	.004	.726	.122	.760	.447	.560
Tree vs No Tree	1	.337	.001	.355	.025	.673	.211	.454
GLI. vs PAR.+CAL.	1	.004	.398	.617	.542	.349	.325	.493
PAR. vs CAL.	1	.308	.098	.737	.981	.890	.917	.337
Error A	9							
Lime Rates	(2)	.000	.005	.010	.000	.035	.002	.001
Lime vs No lime	1	.000	.001	.003	.000	.011	.095	.000
Low vs High lime	1	.618	.666	.558	.004	.704	.001	.228
Lime * Tree Spp.	6	.136	.018	.016	.285	.854	.734	.761
Error B	24							

Table 3.14. Critical values and sufficiency ranges for nutrient concentrations in rice leaves as reported in literature.

Nutrient	Critical Value or Sufficiency Range	Growth Stage[1]	Reference
	($g\ kg^{-1}$)		
	25	Til	Tanaka and Yoshida, 1970
N	26 - 32	Pan	Mikkelsen and Hunziker, 1971
	28.5 - 42.0	Pan	Ward et al., 1973
	1.0	Til	Tanaka and Yoshida, 1970
P	1.8	Pan	Angladette, 1964
	1.8 - 2.9	Pan	Ward et al., 1973
	10	Til	Tanaka and Yoshida, 1970
K	10 - 22	Pan	Mikkelsen and Hunziker, 1971
	11.7 - 25.3	Pan	Ward et al.
Ca	1.9 - 3.9	Pan	Ward et al., 1973
Mg	1.6 - 3.9	Pan	Ward et al., 1973
	($mg\ kg^{-1}$)		
Mn	252 - 792	Pan	Ward et al., 1973

[1] Til = Tillering, Pan = Panicle initiation

Table 3.15. Analysis of variance of the effects on rice grain yield per row on proximity of rice row to tree hedges.

Source	df	F-test Error	Grain Yield	Rice Height	Fertile Tillers	Total Tillers
			P Value			
Replication (Rep)	3	Ea	0.887	0.999	0.103	0.081
Tree Species (Spp)	3	Ea	0.084	0.029	0.065	0.499
Error a (Ea)	9					
Lime	2	Eb	0.002	0.005	0.098	0.155
Spp x Lime	6	Eb	0.038	0.020	0.001	0.126
Error b (Eb)	24					
Row Position (RP)	4	RepxRp	0.000	0.015	0.011	0.647
Spp x RP	12	Ec	0.000	0.003	0.000	0.059
Lime x RP	8	Ec	0.776	0.945	0.746	0.413
Spp x Lime x RP	24	Ec	0.949	0.519	0.180	0.547
Error c (Ec)	144					
Total	239					

Table 3.16. Combined analysis of variance of crop yields for two years.

Source	df	Upland Rice SF*	Upland Rice SR	Cowpea SF	Cowpea SR
		P Value			
Year	1	0.000	0.000	0.000	0.000
Reps in Season	6				
Tree Species (Spp)	3	0.623	0.790	0.001	0.006
Spp x Season	3	0.207	0.207	0.883	0.883
Pooled error a	18				
Lime	2	0.000	0.273	0.000	0.171
Lime x Year	2	0.000	0.000	0.007	0.007
Spp x Lime	6	0.002	0.091	0.993	0.450
Spp x Lime x Season	6	0.261	0.261	0.995	0.995
Pooled error b	48				
Total	95				

* S = Season, F = Fixed, R = Random

Table 3.17. Relative yields over three years of the treatments without lime as percentages of the low lime treatment without trees.

Crop	Year	Paraserianthes (zero lime levels)	Calliandra	Gliricidia	No Tree
		(%)			
Rice	1985/86	44	42	27	22
	1986/87	101	73	63	51
	1987/88	226	168	21	11
Cowpea	1985/86	89	45	29	25
	1986/87	155	98	27	29
	1987/88	306	97	25	0

Table 3.18. Responses of farmers in the on-farm alley farming trial to a survey taken in 1988, two years after hedge planting.

	-------- Sundanese -------		-------- Javanese --------	
	Farmer 1	Farmer 2	Farmer 3	Farmer 4
Date surveyed	17 Nov.	23 Sep.	23 Sep.	17 Nov.
Slope of site	Steep	Moderate	Gentle	Gentle
Alley width	3 m	4-5 m	5-6 m	5-6 m
Alleys retained	No	Yes	No	No
Large trees retained	No	Yes (2 Paraserianthes, largest is 9m tall)	No	Yes (2 Paraserianthes, largest is 5.5m tall)
Crop sequence after hedge planting * = hedge removal	peanut, peanut *	soybean, soybean, rice, (annual cycle)	soybean, soybean, peanut, rice *	soybean + peanut, soybean + peanut *
Hedges regularly pruned	No	Yes	No	No
First pruning height				
a. Paraserianthes	--	2 m	6-7 m	> 2 m
b. Calliandra	--	2.5 m	5 m	> 2 m
Uses of hedges by the farmers	--	Fuelwood, green manure, erosion control, fence.	Fuelwood, green manure (gathered senesced leaves)	Green manure (used once, when hedges removed)
Age of hedges when removed	6 months	--	1 year	8 months
Farmers reasons for discontinuing alley cropping	- Hedges destroyed by erosion and fire - Poor tree growth due to low soil fertility	--	- Lacked time to prune hedges - Hedges harbored insect pests	- Loss of crop land to hedges - Shading of crops
Overall attitude on alley cropping	Uncertain	Very Positive	Negative	Negative

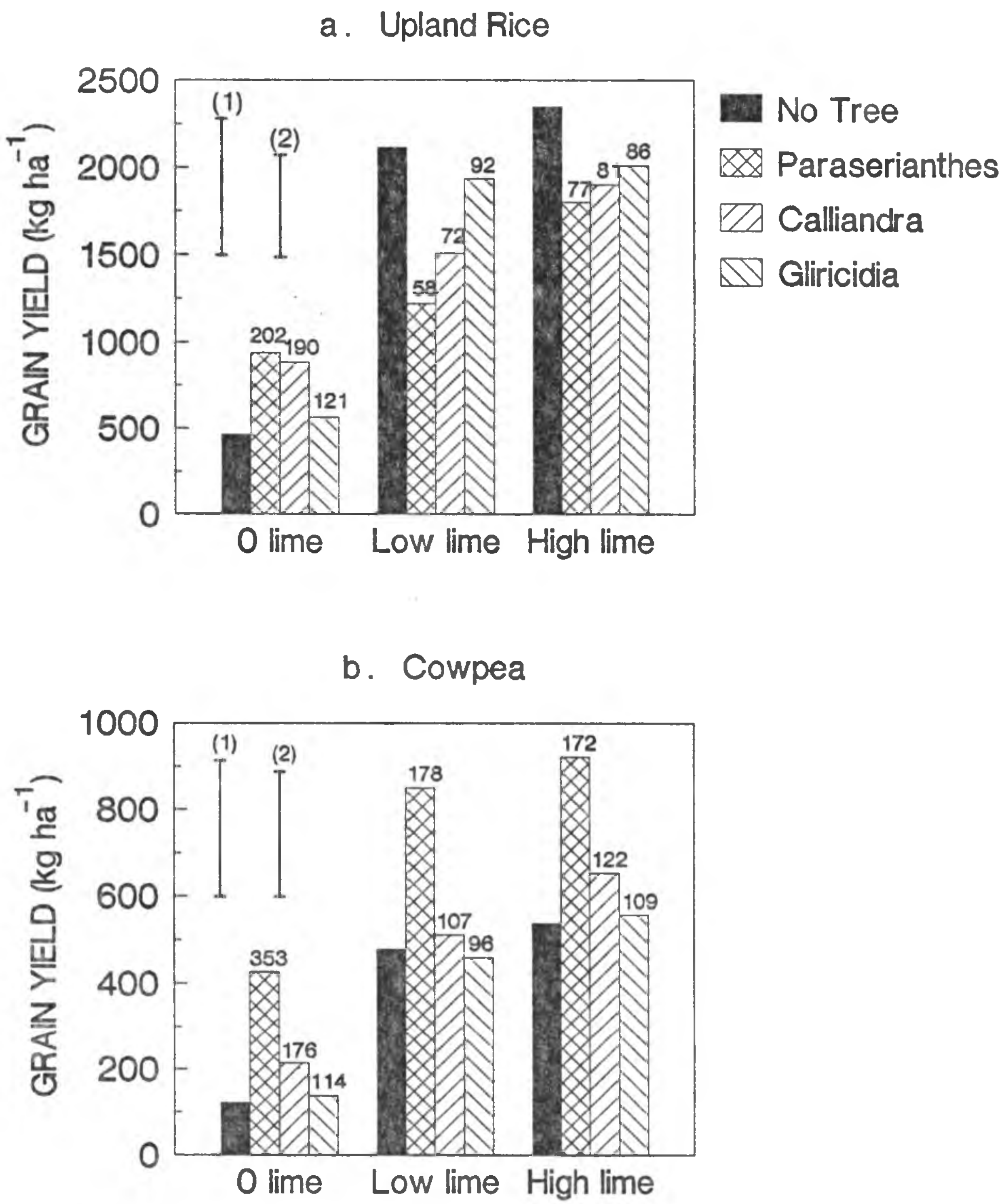


Figure 3.1 Upland rice and cowpea grain yields during the 1985/86 season. Numbers above the bars are percentage of No tree treatment yields at each lime level. Vertical lines are LSD (0.05) values, (1) to compare species means at the same or different lime rates, and (2) to compare lime means for the same species.

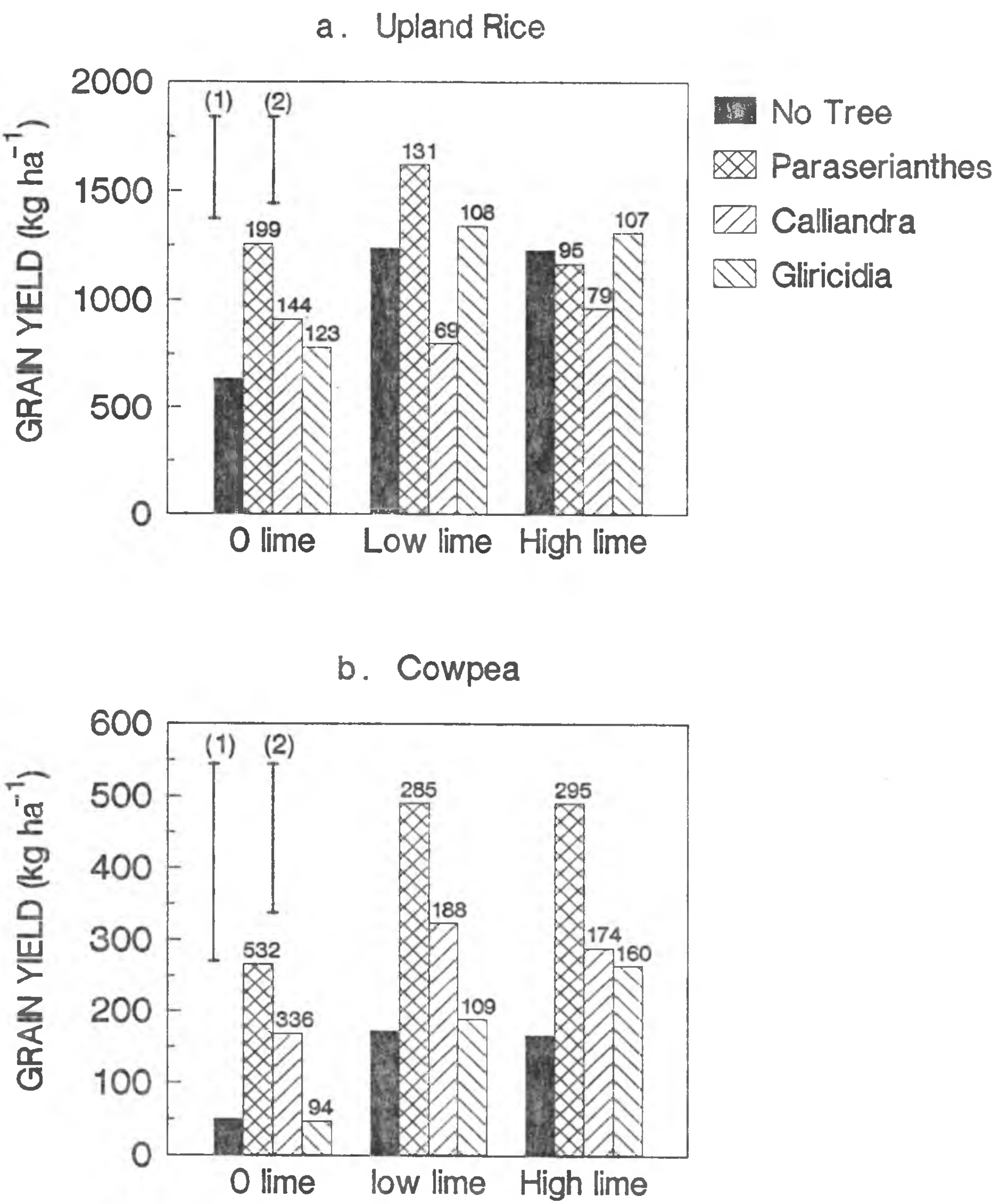


Figure 3.2 Upland rice and cowpea grain yields during the 1986/87 season. Numbers above the bars are percentage of No tree treatment yields at each lime level. Vertical lines are LSD (0.05) values, (1) to compare species means at the same or different lime rates, and (2) to compare lime means for the same species.

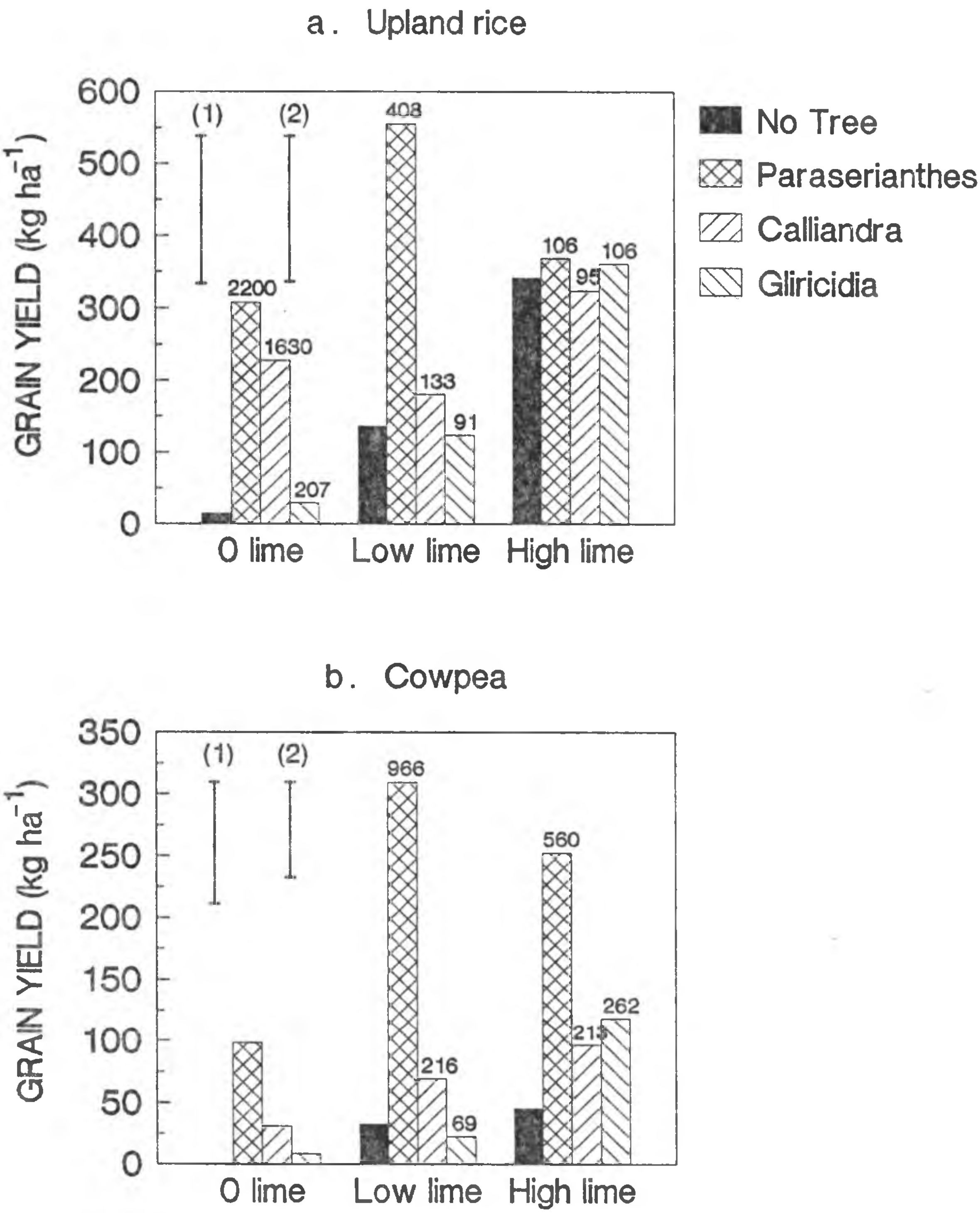


Figure 3.3 Upland rice and cowpea grain yields during the 1987/88 season. Numbers above the bars are percentage of No tree treatment yields at each lime level. Vertical lines are LSD (0.05) values, (1) to compare species means at the same or different lime rates, and (2) to compare lime means for the same species.

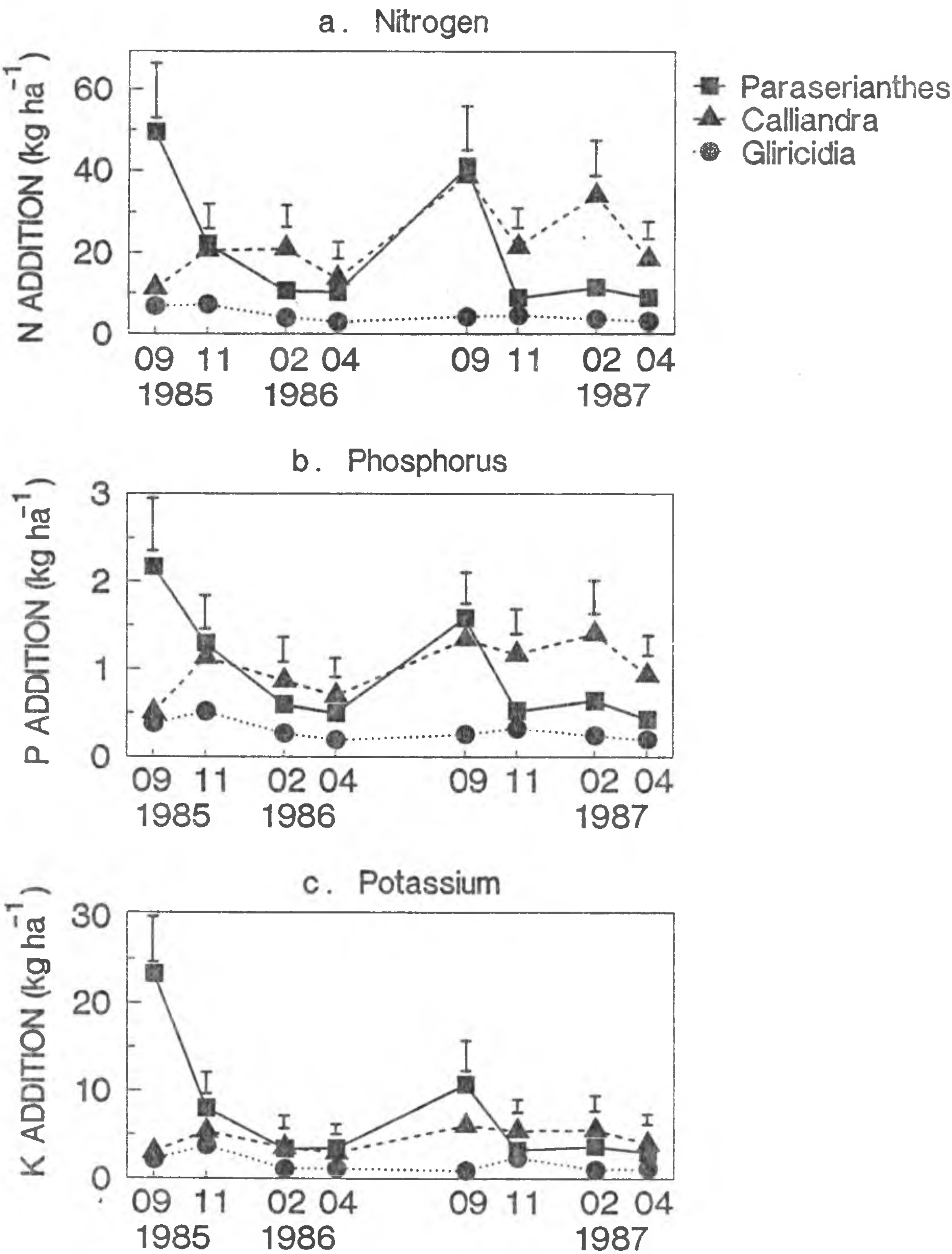


Figure 3.4 Nutrients contained in green leaf manures at each pruning in the 1985/86 and 1986/87 seasons. Vertical lines are LSD (0.05) values to compare species means at each harvest.

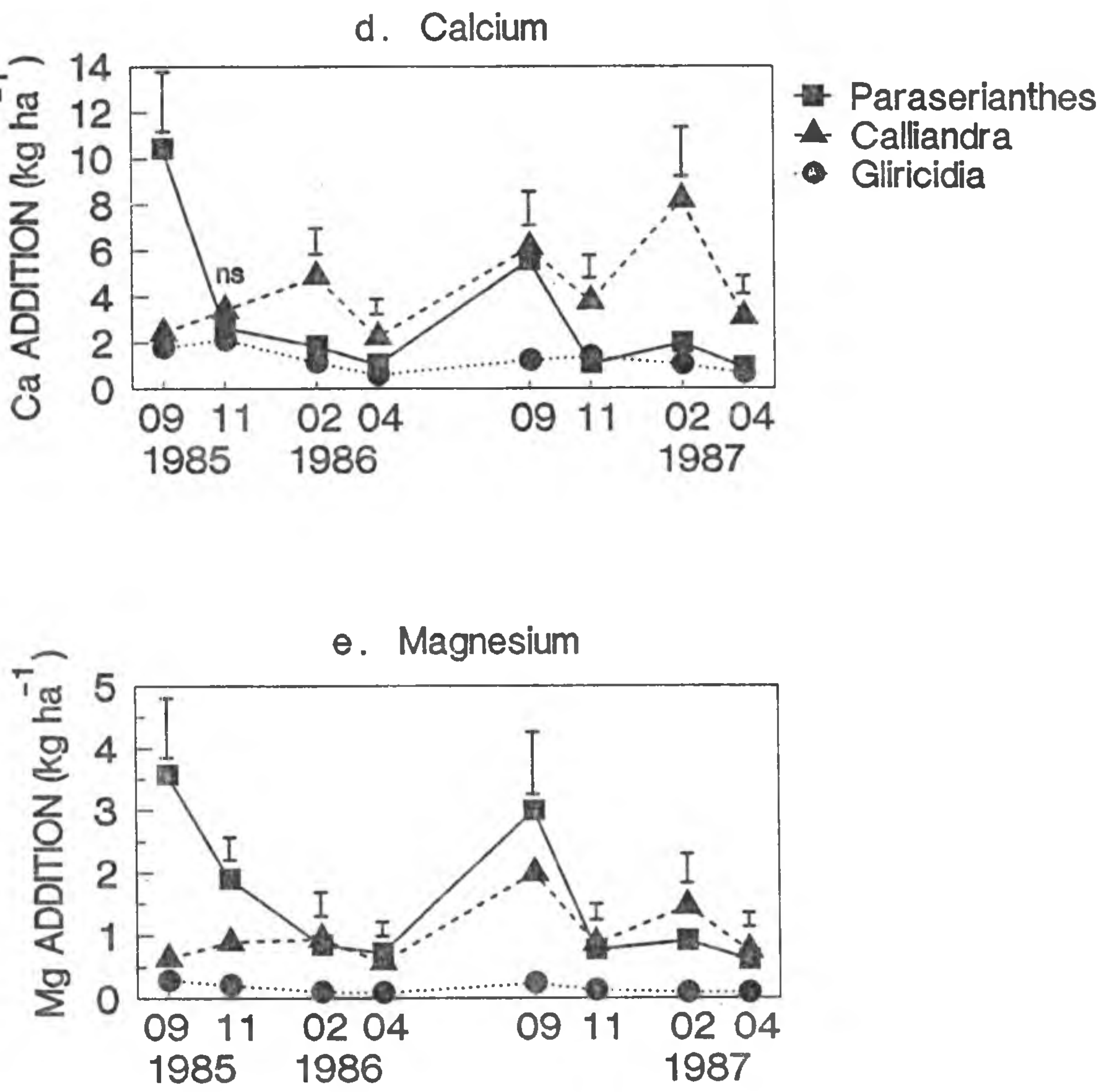


Figure 3.4 (cont.) Nutrients contained in green leaf manures at each pruning in the 1985/86 and 1986/87 seasons. Vertical lines are LSD (0.05) values to compare species means at each harvest.

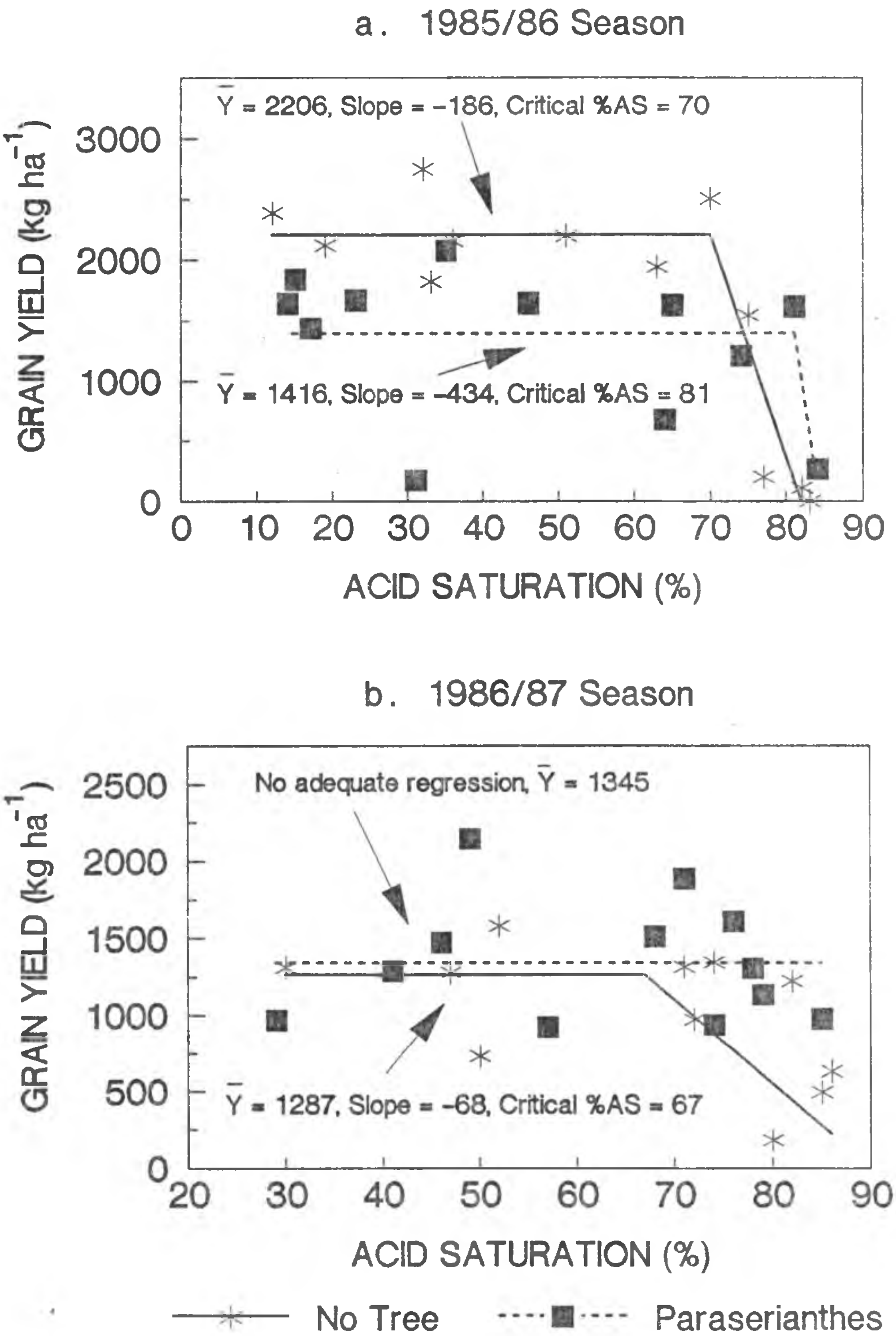


Figure 3.5 Upland rice response to percent acid (Al+H) saturation in the soil to 15 cm depth.

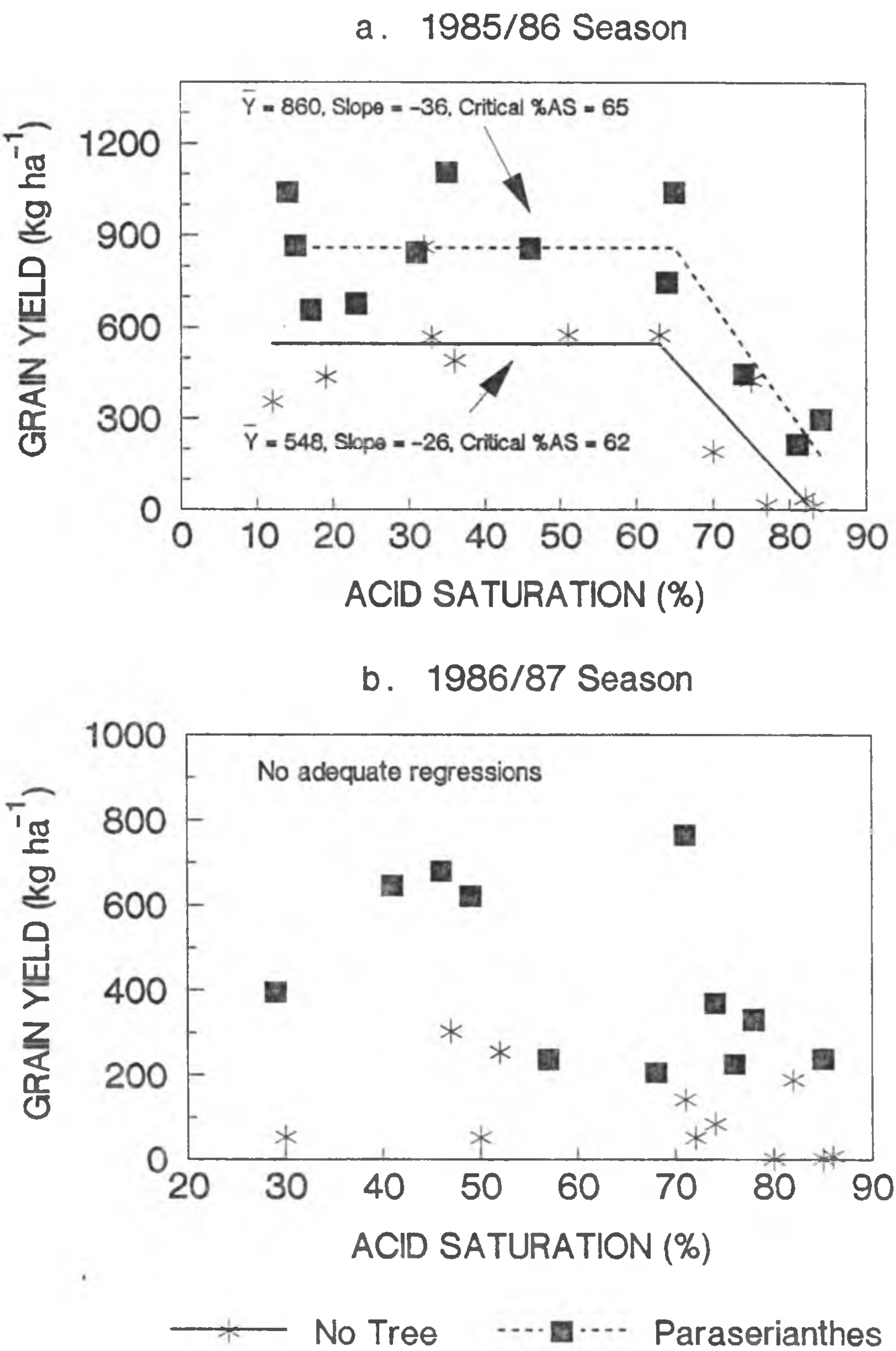


Figure 3.6 Cowpea response to percent acid (Al+H) saturation in the soil to 15 cm depth.

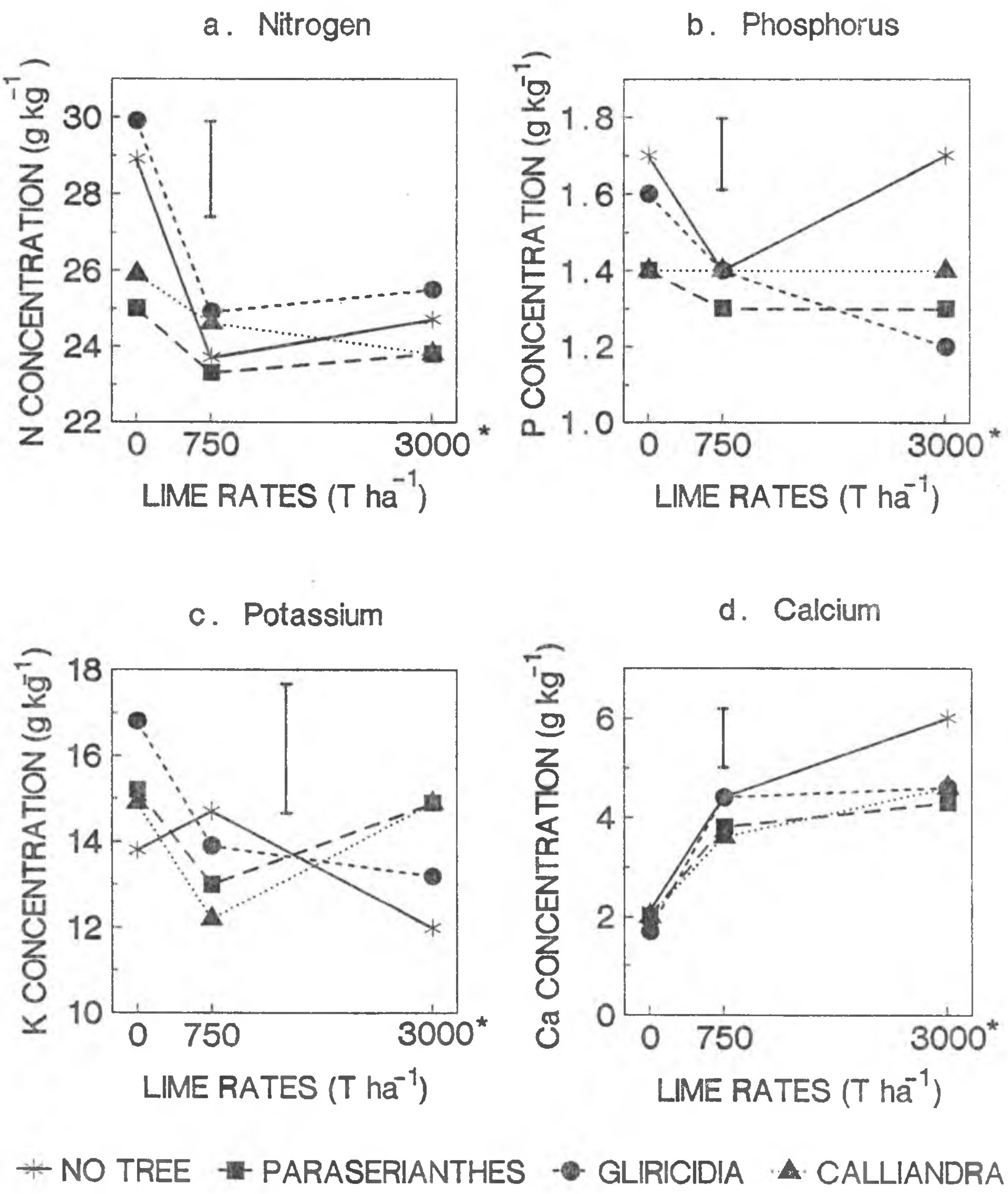


Figure 3.7 Nutrient (N,P,K, and Ca) concentrations in rice leaves sampled at panicle initiation (3 December 1986). Vertical lines are LSD (0.05) values to compare species means at the same or different lime rates.

* Actual lime application at the high rate varied in trying to achieve 25% acid saturation in individual plots.

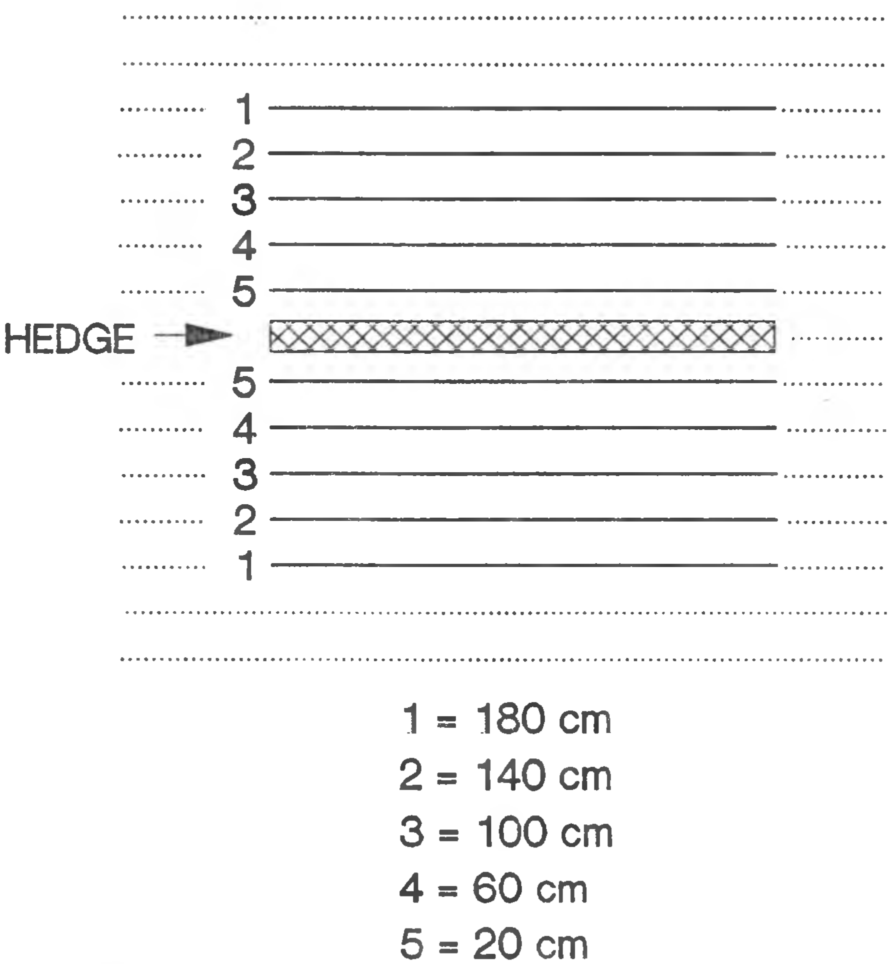


Figure 3.8 Diagram showing row positions (distance of rows from hedge) within a harvest area for the 1986/87 upland rice crop.

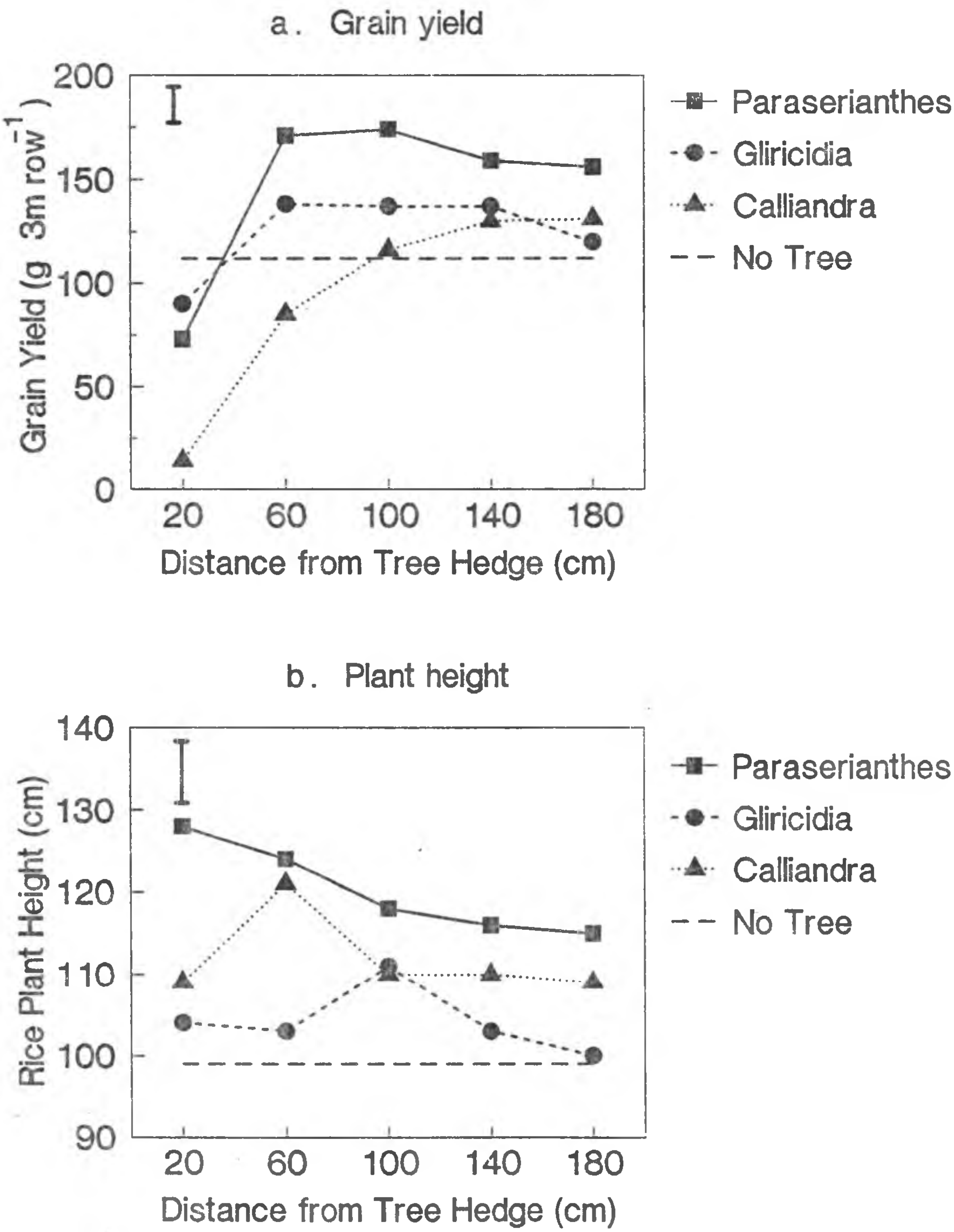
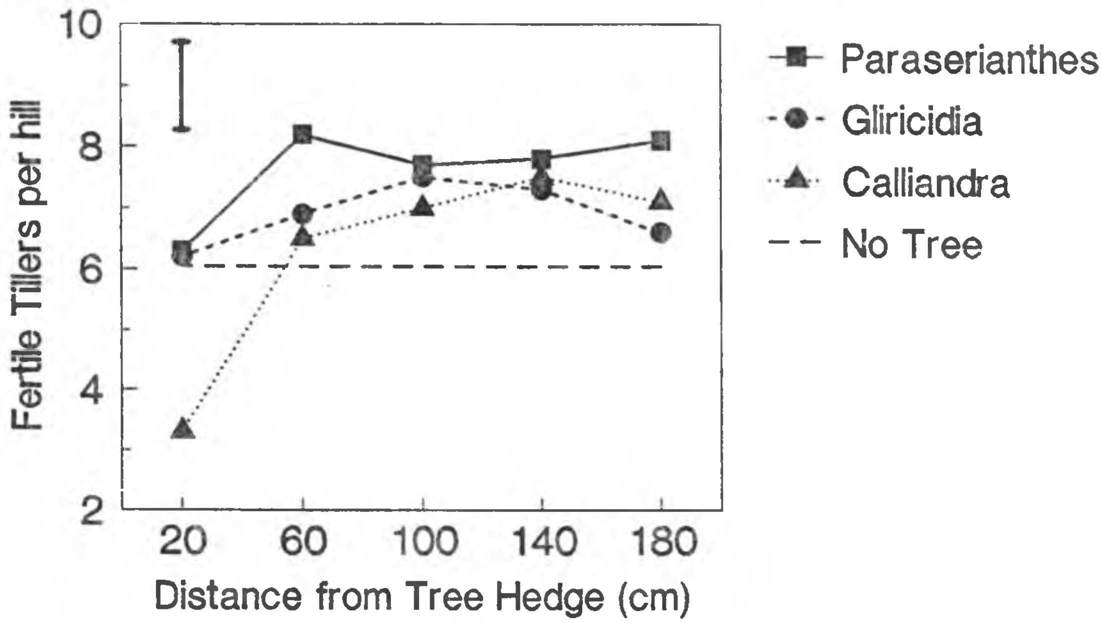


Figure 3.9 Effects of distance from tree hedges on rice growth and yield. Vertical lines are LSD (0.05) values to compare row position means for the same species (averaged over all lime rates).

a. Fertile tillers per hill



b. Total tillers per hill

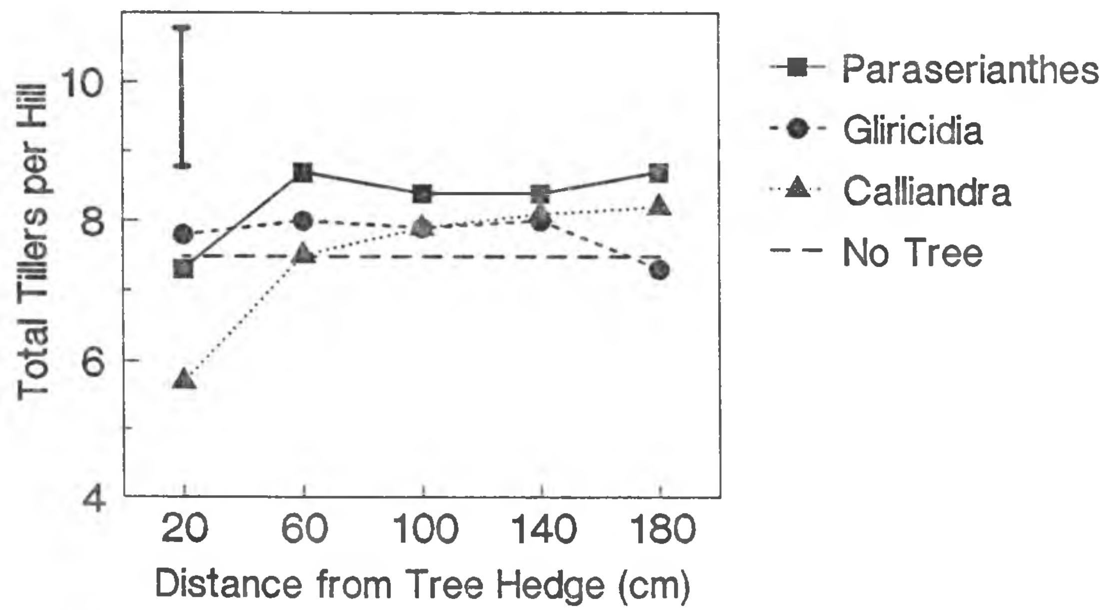


Figure 3.9 (cont.) Effects of distance from tree hedges on rice growth and yield. Vertical lines are LSD (0.05) values to compare row position means for the same species (averaged over all lime rates).

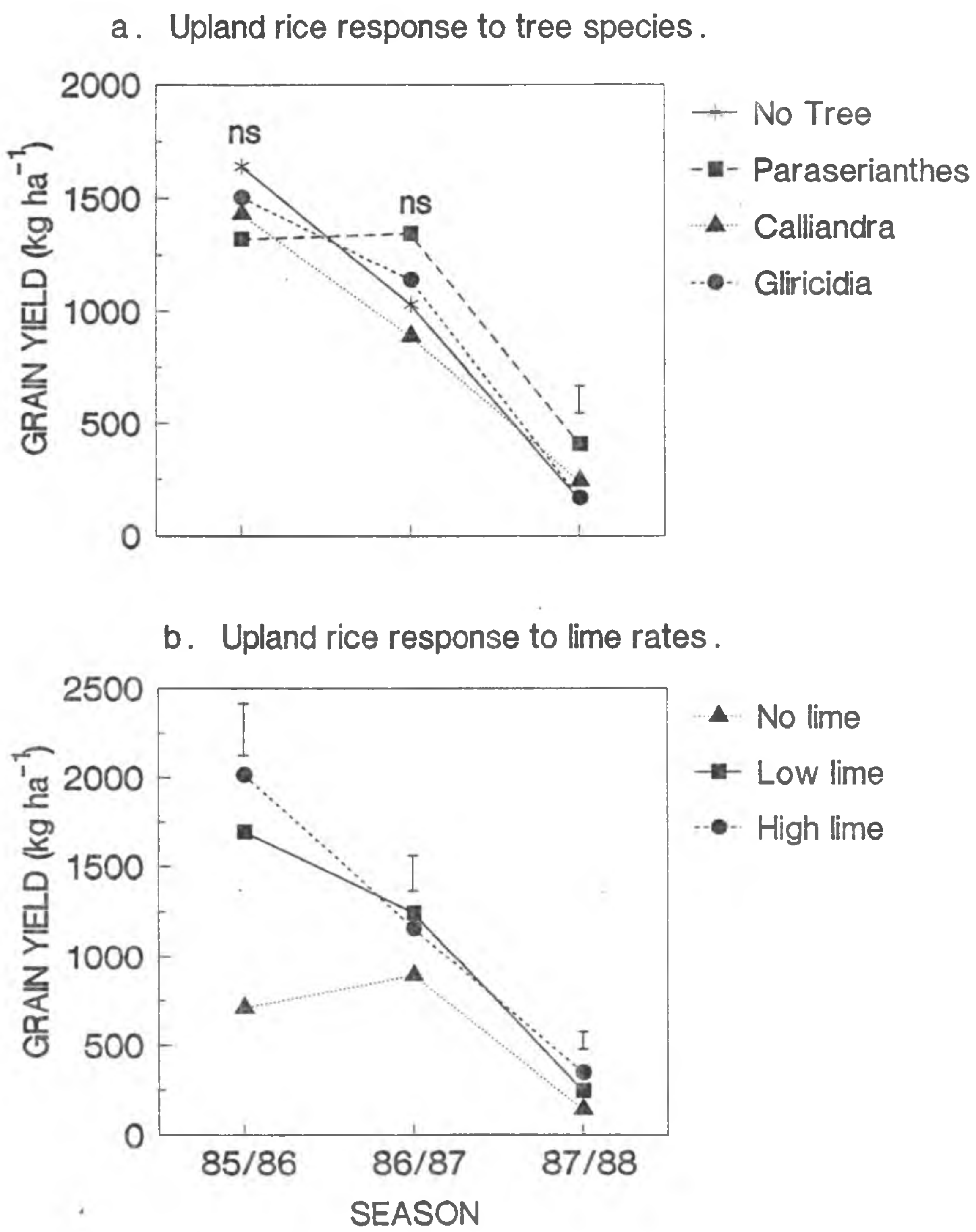


Figure 3.10 Upland rice grain response to species and lime rate main effects over three seasons. Vertical lines are LSD (0.05) values for main effects and ns indicates differences between means of main effects are not significant.

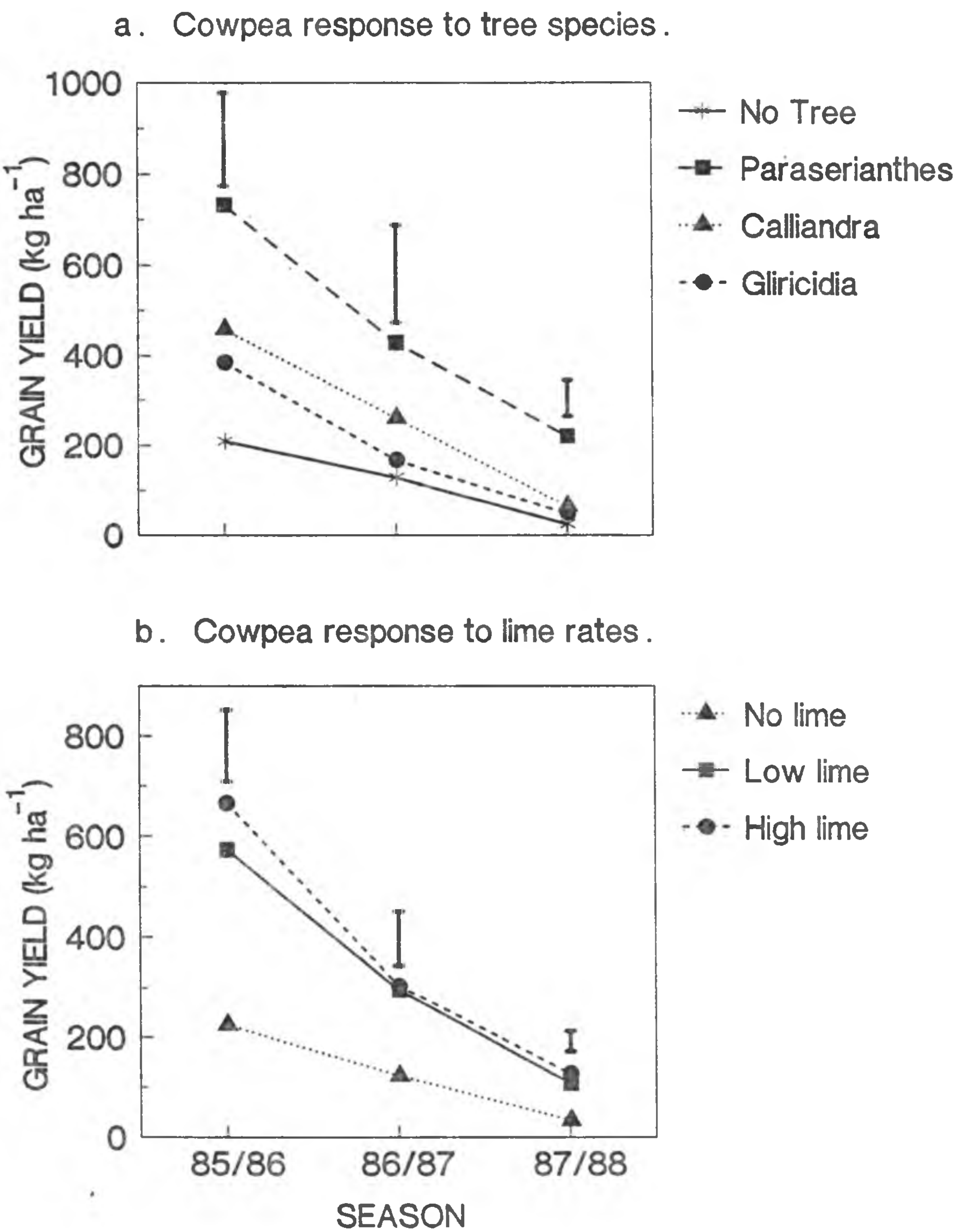


Figure 3.11 Cowpea grain response to species and lime rate main effects over three seasons. Vertical lines are LSD (0.05) values to compare main effects during each season.

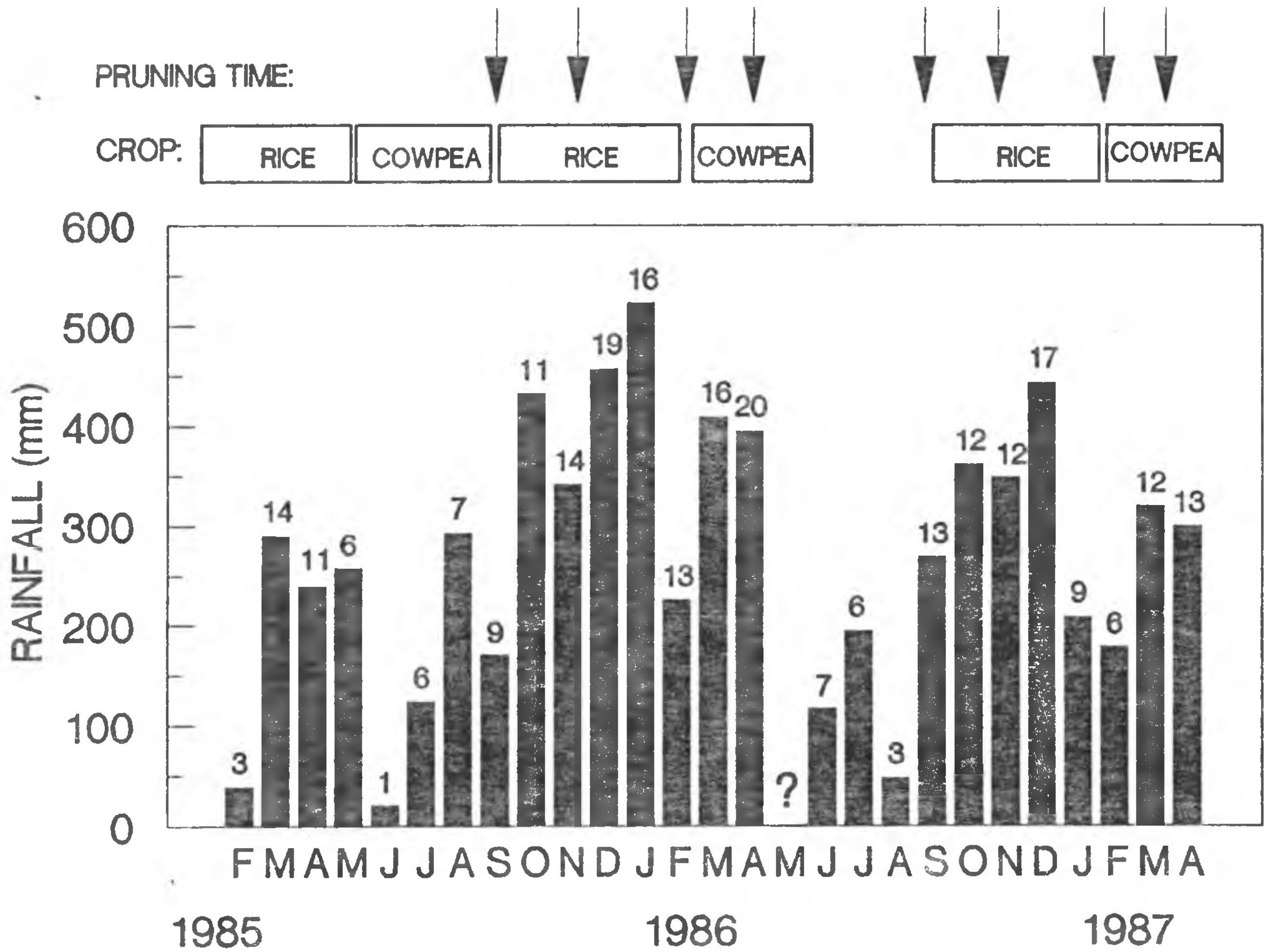


Figure 3.12 Pruning and cropping schedule and monthly rainfall from February 1985 to April 1987. Numbers above bars are days per month with 5 mm or more of rainfall.

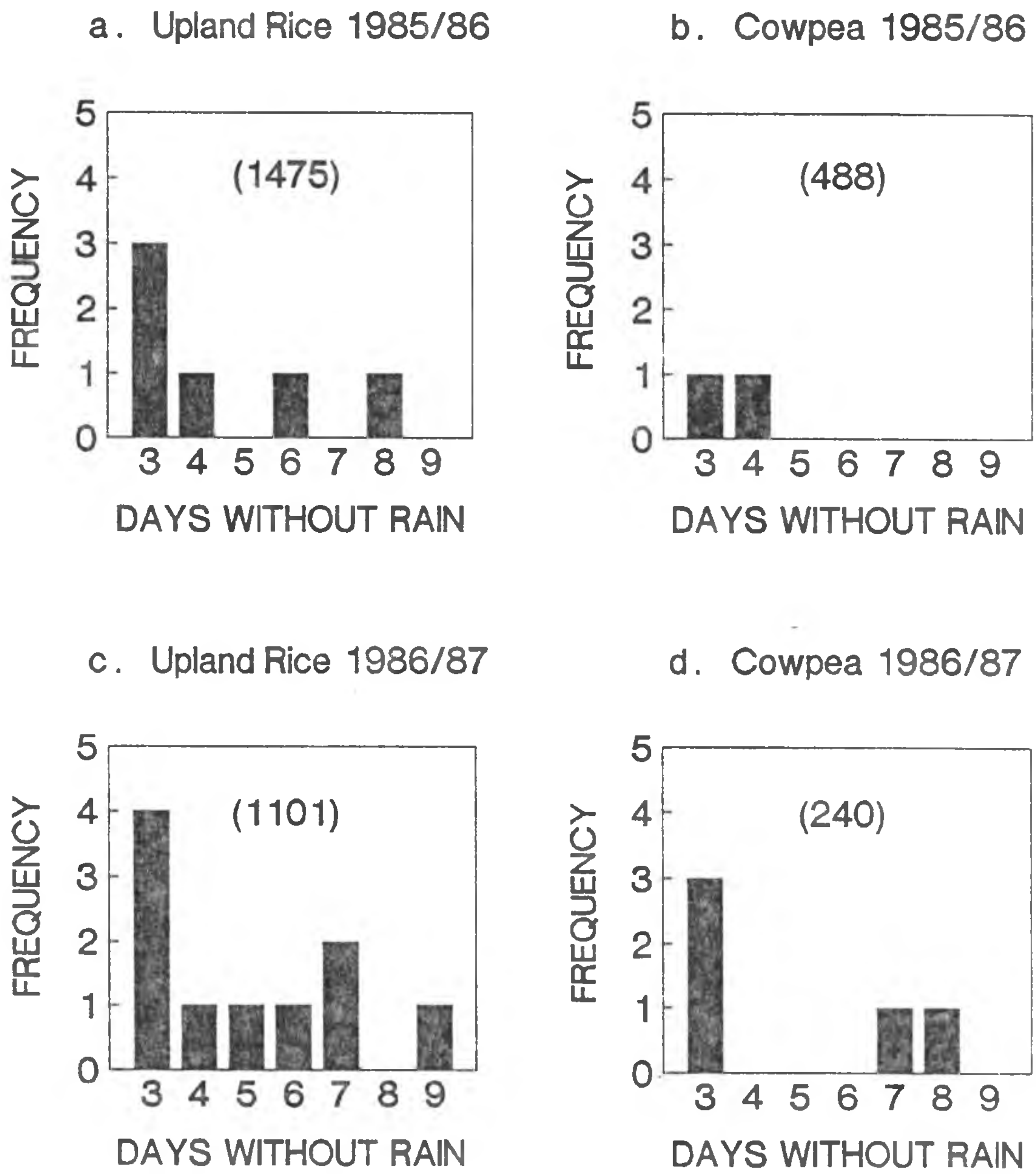


Figure 3.13 Frequency of drought periods of 3 to 9 days in duration during the upland rice and cowpea crops in the 1985/86 and 1986/87 seasons. Numbers in parentheses are average yields of all treatments in kg/ha at each harvest.

CHAPTER 4

ECONOMIC COMPARISON OF ALLEY CROPPING AND LIMING IN WEST SUMATRA

4.1 INTRODUCTION

This chapter reports economic analyses of an experiment comparing alley cropping and liming as means of improving soil productivity in the transmigration area of Sitiung, West Sumatra. The research was conducted with the TropSoils Indonesia Project over the period of December 1984 to May 1988. Agronomic and statistical analysis of this data may be found in Chapters 2 and 3 and is therefore not duplicated here. A methodology was developed for economic analysis of experimental data and comparison of potential changes in farming practices over multi-year time periods. This analysis was developed to assess the economic implications of crop yield increases observed in response to alley cropping and liming. Such analysis provides a more thorough utilization of the research results than agronomic analyses alone and allows initial farmer recommendations to be developed.

Crop production in Sitiung, as in many other upland transmigration areas in Indonesia, is severely limited by acid and infertile soil conditions. Soil acidity and the associated aluminum toxicity is probably the major limiting factor for the growth of most crops in Sitiung (Wade et al., 1988). In an attempt to provide farmers with feasible alternatives to their present low yielding practices, a factorial experiment of alley cropped tree species by liming rates was conducted on a farmer's field. Three levels of liming were used (zero, 750 kg lime ha^{-1} applied during the first two years of cropping, and about 3.0 T lime ha^{-1} applied over 3 years) as well as three tree species (Paraserianthes falcataria (syn. Albizia falcataria), Calliandra calothyrsus , and Gliricidia sepium) and treeless control plots. The trees were planted in December 1984 and were first pruned for green leaf manure (GLM) use in September 1985. The food crops grown were a rotation of upland rice and cowpeas, which are common crops in Sitiung. Three seasons of data are reported here.

Yields varied over time and were quite low during the 1987/88 cropping season due to erratic rainfall and pest infestations. However, a strong response to the low lime application was observed throughout (see Chapter 3). In the first crop of upland rice after pruning began, there was no response to alley cropping, but in the five subsequent crops there were highly significant yield increases to alley cropping. Alley cropping with the tree species Paraserianthes falcataria, hereafter called Paraserianthes, produced the highest food crop yields among the tree species. Therefore, in this economic analysis, four treatments are compared:

1) No tree + zero lime (Control);
2) Paraserianthes + zero lime (Alley);
3) No tree + low lime (Lime);
4) Paraserianthes + low lime (Alley + Lime).

In this analysis, current farmer practice is considered equivalent to the control treatment, although some farmers have received lime free from the government. The yields of rice and cowpea crops are presented in Appendix IV.A.

Scientists in Africa who have conducted economic analyses of alley cropping data, (generally with Leucaena leucocephala as the tree species) have found alley cropping to be economically superior to current farmer practices, particularly when the value of the wood produced is included as a co-product (Raintree and Turay, 1980; Hoekstra, 1983; Verinumbe et al., 1984; Reshid et al. 1987). Comparisons of costs and benefits generally indicate that alley cropping increases labor costs but can reduce capital costs while improving yields and yield stability.

Ngambeki (1985), in studies in South West Nigeria, found leucaena alley cropping in to be more labor demanding than farmer's normal practices, nitrogen fertilization, or herbicide application. However, a very labor intensive practice of stripping leaves off of prunings was used. Using this method, he estimated that after one year of fallow, 31 man-days of labor per hectare were required for initial pruning and about 30 to 40 man-days were required for three prunings in each subsequent season. In leucaena alley cropping, although labor requirements were increased by about 50 %, maize yields were increased by over 60 %. At the same time, economic benefits of nitrogen fertilizer were eliminated while benefits from herbicide application were reduced. Attractive benefit-cost ratios of 1.23 to 1.32 were obtained with maize production using leucaena. However, cowpea yields were reduced with leucaena alley cropping.

Sumberg and colleagues (1987) studied the potential for integrating crop and livestock production in "alley farming" systems in Africa. Alley farming is a system of hedgerow intercropping which includes livestock production, while alley cropping involves only crop production between the hedgerows. By comparing net present values, they found that alley cropping was superior to fallow systems. Also, alley farming in which prunings supplemented the diets of sheep or goats would only be attractive if net productivity of dams increased by 30 to 40%. They also estimated labor requirements for alley cropping to be about 18 man-days ha^{-1} $crop^{-1}$ with 2 to 3 prunings made during the growth of a maize crop.

Studies have shown various benefits from alley cropping including improved nitrogen nutrition of alley crops, production of wood for stakes and fuel, and weed suppression (Kang et al., 1984). Alley cropping may also be very beneficial for resource poor farmers in humid tropical areas as a possible substitute for liming. This present study compares the economic benefits and costs of alley cropping and liming and provides the basis for making initial farmer recommendations. Also, the methodologies and procedures developed should provide a useful framework for economic analysis of future alley cropping data.

4.2 METHODOLOGY

Partial budgeting and cash flow discounting are the primary economic analysis methodologies used in this analysis. As discussed by Perrin et al. (1976) and by Harrington (1982; 1985) partial budgeting is an appropriate analytical tool for assessing new technologies which involve incremental changes in farming practices and farm organization. It is a robust methodology which can readily handle many "real-world complications" such as transport costs, interest and management charges, value of by-products, and land-tenure effects (Harrington, 1985). Partial budgeting uses marginal analysis which shows the net increase or decrease in farm income resulting from a proposed change rather than profit or loss for the whole farm. However, partial budgeting is of limited value for assessing the profitability of more comprehensive changes in farm organization or management because interacting factors may complicate the analysis.

In partial budgeting, treatments (or technologies) can be compared by assessing the costs that vary between treatments and the benefits associated with each treatment. Fixed costs are not included. Total costs that vary (TCV) and net benefits (NB) are then compared by calculating Marginal Rates of Return (MRR = change in NB/change in TCV) between the various treatments. In interpreting partial budgets, the marginal rate of return is compared to the minimum rate of return. This represents an estimated cost of capital plus the return to management (the farmer) required to induce investment. If the MRR is higher than the minimum rate of return, the treatment is considered profitable. Harrington (1985) suggests that the minimum rate of return be estimated as the cost of borrowed capital, which can be as high as 100% per year.

Gittinger (1972) and Brown (1979) indicate that partial budgets are most useful for estimating the profitability of marginal changes in farm organization. If proposed changes are extensive, total budgeting (whole enterprise or whole farm) is more appropriate. A particularly important concept associated with long term changes is the time value of money. When implementation of a technology extends over a several year period, the times when costs and benefits occur determine how valuable they are. Often the bulk of costs are incurred in the beginning and benefits accrue later. Since present resources are generally preferred to future resources, proposed technologies must be compared in terms of their income streams over time. Discounting procedures are used to "standardize the values of cost and benefit streams extending over several years to provide a proper basis for comparison" (Brown, 1979).

Three investment criteria involving discounting are commonly applied to agricultural decision making (Gittinger, 1972), which are; 1) benefit-cost ratio, 2) net present value, and 3) internal rate of return. All use the concept of present value, with which future benefit and cost streams are reduced to their present worths, which are determined by discounting at a estimated discount interest rate. Discounting can be considered to be the opposite of compounding of interest (Gittinger, 1972; Brown, 1979). The equation normally used in cash flow discounting to account for the time value of money is the following:

$$(1)\quad \text{Present Value} = \sum_{x=1}^{n} (\text{Costs or Benefits per period}) \,/\, (1 + i)^n$$

where: n = number of discounting periods (seasons or years)
i = the discounting interest rate

This equation carries the assumptions that production can be subdivided into homogeneous periods and that a constant interest rate can be applied to all periods. These assumptions are reasonable for most agricultural enterprises.

Benefit-cost ratios are derived by dividing present values of total benefits by present values of total costs. Net present value (NPV) is the difference between the present worths of the benefits and costs which is discounted over the life of the project or enterprise under consideration. Internal rate of return is the average discount rate at which the present worth of costs equals the present worth of benefits (ie. the NPV equals zero). This gives the average interest rate at which investments are paid back over the life of the project (or enterprise). Gittinger states that internal rate of return is superior to benefit-cost ratio or net present value for comparing the profitability of projects, but that net present value can be used if costs and benefits are of the same magnitude.

Net present values can also be calculated on the change in net benefits associated with a change from one treatment to another (Hogg et al., 1976). The equation used for calculating the net present value of changing treatments is:

$$(2) \quad \text{NPV of Change} = \sum_{x=1}^{n} (\text{NB treatment } 1 - \text{NB treatment } 2\ ) \ / \ (1 + i)^{n}$$

This is analogous to the marginal analysis used in partial budgeting, except that discounted changes in net benefits are compared. Such an analysis is especially appropriate if relatively small changes in farming practices are being considered and where benefit and cost streams vary over time for the technologies being compared. In such a case, net benefits are calculated for each year (or season) for each of the technologies. Then, the change in net benefits associated with a change from the farmers practice to another technology is calculated for each year. These changes in net benefits are then discounted at an appropriate interest rate. Hogg and colleagues (1976) recommend that internal rates of return be calculated and the change in technology with the highest internal rate of return be selected. Alternatively, the change in technology with the highest net present value can be selected.

In the present analysis, benefit-cost ratios were not calculated, since this requires information on total costs, not just the costs that vary between treatments. Total costs are very difficult to estimate, especially those related to the value of land. While internal rate of return is the recommended decision criterion (Brown, 1979), as will be shown, this was impossible to calculate for this data. Therefore, the net present values of the changes in net benefits of the alley cropping and liming treatments from the control treatment are compared, as suggested by Hogg et al. (1976).

The actual yield data obtained from the alley cropping experiment were not considered representative of general conditions due to extreme year to year variation in yields. Therefore, yields were estimated for average conditions in Sitiung. The yields of liming and control treatments were estimated as averages of crop yields in the 1985/86 and 1986/87 seasons while the yields for alley cropping treatments were calculated as percentages of the average liming treatment yields. Yields in the 1987/88 season are considered unrepresentative of normal yields and were not included in the averages. (See Appendix IV.A for details of these calculations).

Partial budgets were initially calculated for each year to compare the four treatments; Control, Alley, Lime, and Alley+Lime. The life of a Paraserianthes alley cropping enterprise is assumed to be at least five years and since first year costs are higher and benefits lower than in subsequent years, discounting methods were used to compare alley cropping and liming treatments. Changes in net benefits associated with change from control to Alley, Lime, or Alley+Lime treatments were calculated for years 1 through 5 and then discounted. These changes were then compared in terms of their discounted net present values. Since labor, value of wood, and capital may not be equally scarce, sensitivity analysis was used to determine the influence of these costs on the interpretation of the economic analysis.

Due to the limited data used to derive these yield estimates (three years of data from one location) these yield estimates are quite uncertain but are the best available at present. Unless otherwise indicated, all analyses reported are for estimated yields. However, an economic analysis using the actual yield data obtained from the experiment is also presented for comparison with the analysis using estimated yields. Sensitivity analysis was also conducted for variations in crop yields.

Input data on costs and prices of inputs and outputs were required for this economic analysis. Some information, such as the market prices of grains were determined in surveys conducted by Stacy Evensen (personal communication). However, many data, particularly labor costs, were estimated by the author from observation of farmers in Sitiung. Details on costs and prices estimates and their associated calculations are presented in Appendix IV. The prices quoted in this analysis are at 1987 levels, at which time the exchange rate was US$ 1 = Rp 1640.

4.3 ANALYSIS AND DISCUSSION

4.3.1 Calculation of Annual Partial Budgets

In partial budgeting, extensive information on the prices and costs of all inputs and labor is not needed -- only those associated with costs that vary between treatments. Table 4.1 shows the partial budget for the first year of alley cropping or liming. The year would begin with tree establishment during the middle of the rainy season (planting in about January) and concurrent growth of the first cowpea crop. Since the tree hedges would grow out during the cowpea crop, there would be no benefits from green manuring and no fuelwood produced. Crop response to liming would be strong on an acid soil.

Gross field benefits are seen to derive (Table 4.1) from the field prices of grains times estimated yields and, in the case of alley cropping, from the value of fuelwood as a co-product. Costs that vary between treatments are assessed for liming and tree establishment and are used to determine net benefits associated with each treatment. Net benefits for the Liming treatment are higher during the first year than for either the Alley or Alley+Lime treatments. Details on calculations of the elements of the partial budgets are presented in Appendix IV.B.

Table 4.2 shows the partial budget for year two. This differs from the partial budget for year one in that tree establishment costs would be replaced by tree pruning costs. Crop response to alley cropping treatments would increases as would the yield of wood. Net benefits for the alley cropping treatments are higher than for the liming treatment. Table 4.3 shows the partial budget for years three through five. It is assumed that the crop response to alley cropping would stabilize and not vary in these years. As in year two, the highest net benefits and total costs that vary occur in the Alley+Lime treatment. In comparing costs incurred in the various treatments, it can be seen that alley cropping is more labor intensive while liming is more capital intensive. Due to variations in cost and income streams between years one through five, discounting analysis is clearly required.

4.3.2 Net Present Value of Changing Treatments

The discounting analysis of the costs and benefit streams of the treatments over a five year period is presented in Table 4.4. Since there is no universally appropriate value for the discounting interest rate (i), five values are used to provide a sensitivity analysis. Higher discounting interest rates indicate a greater preference for current over future income, as is likely with poor farmers.

A discounting interest rate of about 12% would probably apply to "progressive" farmers who are part of a cash economy and have access to government loans. A discounting interest rate of about 50% might apply to poorer, subsistence level farmers who require relatively high initial returns on their investment in a new technology. However, differences in discounting interest rates do not reflect differences in risk aversion, which is also important to subsistence farmers but is not considered in this analysis. Given the limited data on alley cropping, it is difficult to assess the risk involved in this technology.

Table 4.4 shows net present value calculations for the change from the Control to Alley, Liming, or Alley+Liming treatments at discounting interest rates of 0%, 12%, 25%, 50%, and 100%. The internal rates of return for each treatment can not be calculated since net benefits are positive in all years (Tables 4.1, 4.2, and 4.3). Therefore, net present values will be positive at all internal rates of return and can approach but will never equal zero. However, the profitability of changing from the Control to Alley, Lime, or Alley+Lime treatments can be compared by the magnitude of the net present value of making this change. This represents the "present day" value to the farmer of making these changes in his or her farming practices.

The change to the Alley+Lime treatment clearly results in the greatest net present values at all discounting interest rates. This indicates that alley cropping with Paraserianthes and application of lime at an annual rate of 250 kg ha^{-1} is the most profitable enterprise of the four in the Sitiung area. This suggests that there is a synergistic or additive effect of alley cropping and liming on crop yields. Apparently there are benefits from alley cropping beyond those provided by liming. The specific factors causing the yield response to alley cropping have not been determined definitely, but may involve increased nutrient availability as well as the alleviation of aluminum toxicity (see Chapter 3).

It should be understood that these values for the net present value of the change are not the actual profit that a farmer will make since fixed costs were not included in the calculations. They do, however, provide an indication of relative profitability and indicate the increase in profit which a farmer can expect above that obtained with current practices. It could be assumed that the farmer's current practices are profitable, or else they would be discontinued.

Table 4.4 also indicates that the Lime treatment is more profitable than the Alley treatment at all discount interest rates. However, the net present value of change from the Control to the Alley treatment is also positive at all five interest rates. This is an important result since there are areas in Indonesia (and elsewhere in the humid tropics) where lime is not available and where transport would be excessive and reliable delivery of lime impossible. In such areas, alley cropping with Paraserianthes would be a profitable change from farmer's current practices. Since the Alley+Lime treatment was more profitable than the Lime treatment, this also suggests that alley cropping may be profitable even in areas with less acidic soils.

If the actual crop yields obtained over 4 years in the alley cropping experiment (see Appendix IV, Tables IV.A 1 and 2) are used to calculate net present values of changing from the control treatment (Table 4.5), the Alley+Lime treatment remained most profitable at the lower discounting interest rates. Using this analysis, farmers might be indifferent to the choice between the Lime and the Alley+Lime treatments at a discounting interest rate of 50% and would favor the Lime treatment at higher rates. This analysis is unrealistically favorable for the Lime treatment since it was associated with high early yields followed by a general decline in the yields of all treatments. However, even under these very site and season specific conditions, the profitability of the Alley+Lime treatment was generally favorable.

4.3.3 Sensitivity Analysis and Break-Even Values

The costs and values of several input variables are quite site dependant in Indonesia. Lime has been provided free of charge to some farmers in Sitiung as part of a national liming for soybean production program. For other farmers and in other areas, the cost of transportation may make lime costs prohibitively high. A relatively low market cost of Rp 60 kg^{-1} of lime is common in Sitiung since there are sources of lime nearby in West Sumatra. Another variable factor related to liming is the actual lime requirement for maximum crop production. This would certainly vary with different sites depending on the soil acidity or aluminum toxicity. This current analysis applies to sites with aluminum saturation over about 60 - 70 %, where rice and cowpea crops would probably respond to liming.

In Figure 4.1, a sensitivity analysis is presented of the effects of the cost of lime on the relative profitability of the treatments. The net present values of changing from the Control to the Lime treatment decrease with increasing lime cost and increasing discount interest rates (Table 4.1a). The break-even values given are the costs of lime at which farmers would be indifferent to the choice between the Lime treatment and the Alley or Control treatments. This is calculated by finding the cost of lime at which net present values of changing from the Control are equal for the treatments compared. For the Control, the break-even value is the cost of lime at which the net present value of changing is zero. At a 12% discounting interest rate, lime cost would only have to increase to Rp 84 kg^{-1} for the Alley treatment to be as profitable. The break-even value at 25% is Rp 108 kg^{-1} and at 50% is Rp 149 kg^{-1}. Lime costs would have to increase to Rp 470 kg^{-1} for the Control to be as profitable.

The profitability of the Alley+Lime treatment is less sensitive to increases in lime cost (Figure 4.1b). The cost of lime would have to be greater than Rp 255 kg^{-1} (i=50%) for the Alley treatment to be as profitable while lime costs of over Rp 576 kg^{-1} (i=50%) would make the Control as profitable. Costs of lime of over about Rp 200 kg^{-1} are unlikely in Indonesia. The government subsidized price of Urea, KCl, and Triple Super Phosphate fertilizers in Sitiung is about Rp 125 kg^{-1} and it is unlikely that lime costs would exceed those prices.

The cost of labor also varies between different sites as well as between farmers in the same location. This depends on the value of alternative sources of income (other farm enterprises or off farm income) which can be expressed as opportunity costs. In Sitiung, an opportunity cost of Rp 2000/day is reasonable, reflecting the average daily wage for an agricultural laborer. Figure 4.2 shows the effects of labor costs on the economic outcome.

Alley cropping has much higher labor costs than does liming and this is reflected in the break-even values for the Alley as compared to the Lime treatment of Rp 1345 day^{-1} (i=12%) and Rp 629 day^{-1} (i=25%) (Figure 4.2a). Labor costs would have to rise to over about Rp 11000 day^{-1} for the Control treatment to be as profitable as the Alley treatment. The Alley+Lime treatment is quite insensitive to labor costs (Figure 4.2b). Labor costs would have to rise above about Rp 5000 day^{-1} or Rp 14000 day^{-1} for the Lime treatment or Control treatments respectively, to be as profitable. It is highly unlikely that the opportunity cost of labor would be above about Rp 3000 day^{-1} for any farmer, however, opportunity costs could be as low as Rp 500 - 1000 day^{-1} for farmers with no outside sources of income.

Similarly, fuelwood value may vary dramatically between different rural areas depending on available forest resources. For Sitiung transmigration sites, which are often surrounded by forests, a low value of Rp 5 kg^{-1} wood was estimated, based on an assumed opportunity cost of collecting the wood (see Appendix IV). In other parts of Indonesia where there are high population pressures or few trees available, fuelwood presumably commands a much higher value. Figure 4.3 shows the effect of varying wood prices on the relative profitability of Alley and Alley+Lime treatments.

As the value of wood increases, the net present values of changing to Alley or to Alley+Lime treatments increase. If wood value increases to Rp 7.0 kg^{-1} (i=12%), Rp 9.1 kg^{-1} (i=25%), or Rp 12.6 kg^{-1} (i=50%), the Alley treatment will be as profitable as the Lime treatment (Figure 4.3a). Increasing wood values will not make the Control treatment as profitable as either of the alley cropping treatments, nor can the Lime treatment be as profitable as the Alley+Lime treatment at lower wood values (Figure 4.3b).

As has been shown in this study, alley cropping with the application of lime is the most profitable treatment at all realistic discounting interest rates. However the variation in yields over the three years reported here (Appendix IV.A) indicates that the yield estimates used in this analysis are uncertain. To test the sensitivity of the Alley+Lime treatment to variations in yield, net present values of changing from the Control were calculated at increasing percent yield reductions. The calculations were made by reducing yields by the same amount in each of the five years. The results are presented in Table 4.6 along with break-even values for comparison with the Control, Alley, and Lime treatments.

Percent yield reductions (equal reductions in all five years) of about 67 % gave net present values of changing from the Control of zero. At this level of reduced yields, Control and Alley+Lime treatments are equally profitable and the results were not sensitive to changing discounting interest rates (i). Yield reductions of about 25 % would make Alley and Alley+Lime treatments equally profitable at i = 12%, 25%, or 50%. These would be fairly large reductions in relative yields, so the greater profitability of Alley+Lime over Control or Alley treatments seems likely.

The break-even values for reduced yields at which Lime and Alley+Lime treatments were equally profitable were somewhat sensitive to changes in discount interest rates. At i = 50%, Alley+Lime yields would only have to decrease by 14% for the Lime treatment to have an equal net present value of change. Yield reductions of 22% would make Lime and Alley+Lime equally profitable at i = 12%. Therefore, especially for subsistence level farmers (or others with a high preference for current income) caution must be exercised in recommending alley cropping with liming over liming alone. This decision would probably hinge on the farmer's labor availability, as illustrated in Figure 4.2.

Variation in lime and labor costs and the value of fuelwood can therefore affect the assessment of the profitability of the treatments. Likewise, since only limited data has gone into these estimates of the crop yield response to alley cropping, the superiority of the Alley+Lime over the Lime treatment should be verified by further study. However, it is likely that alley cropping with Paraserianthes and lime application at a rate of 250 kg ha^{-1} $year^{-1}$ is the most profitable treatment at realistic ranges of lime and labor costs.

4.4 CONCLUSIONS

The foregoing analyses show that alley cropping with the tree species Paraserianthes falcataria plus lime application at 250 kg ha^{-1} $year^{-1}$ is economically advantageous to farmers in Sitiung. This analysis was quite insensitive to variations in the cost of lime or labor. Lime application alone was also more profitable than alley cropping alone or the control treatment. However, lime is unavailable in some areas, such as in isolated parts of Kalimantan where lime sources are distant and transportation infrastructure is poorly developed. In such areas, alley cropping with Paraserianthes may provide a profitable alternative to current farmer practices. An expert system is currently being developed by the author and other researchers at the University of Hawaii which compiles and organizes the necessary calculations needed to make recommendations on the profitability of changing from current farming practices to alley cropping and/or liming.

In cases where capital is considered to be more scarce and is valued more highly than labor, alley cropping will be more attractive economically than liming. In comparing the liming and alley cropping treatments, if lime costs were increased or labor costs were lowered, alley cropping would become more attractive economically. Relatively speaking, liming is a capital intensive technology while alley cropping is more labor intensive. However, if lime and labor are both available, alley cropping plus lime application produced highest yields and was most profitable. This suggests that alley cropping may be beneficial even in areas where upland rice and cowpea yields are not limited by soil acidity. Betters (1988) suggested that once the best production combination has been determined, such as alley cropping plus liming in this study, linear programming analysis can then be used to indicate optimal combinations of resources by considering resource constraints and farmer's requirements.

Further research is warranted on liming and alley cropping. In particular there is need to clarify the crop yields that can generally be expected for alley cropping on acid soils. The long term effects of alley cropping on soil fertility and the effects of liming should be determined by continued experimentation, preferably in farmer-managed trials. Research is also need on other food crops such as maize, peanuts, and soybeans, which may respond differently to lime and alley cropping. Also economic surveys and monitoring of farmer practices are needed to confirm estimates of the costs of capital, inputs and labor as well as actual yields obtained by farmers.

Table 4.1. Partial budget for the first year after implementation of the treatments.

		Control	Alley	Lime	Alley + Lime
Yield (kg ha^{-1})	1) Cowpea	85	85	325	325
	2) Rice	548	737	1675	972
	3) Wood	0	2600	0	2600
Gross Field Benefit (Rp ha^{-1})					
(Rp 101 kg^{-1} x cowpea yield)		8585	8585	32825	32825
(Rp 85 kg^{-1} x rice yield)		46580	62645	142375	82620
(Rp 5 kg^{-1} x wood yield)		0	13000	0	13000
		55165	84230	175200	128445
Cost of Lime (Rp kg^{-1})					
(Labor:Rp 10 kg^{-1}x250 kg ha^{-1})		0	0	2500	2500
(Capital:Rp 60 kg^{-1}x250 kg ha^{-1})		0	0	15000	15000
		0	0	17500	17500
Cost of Tree Establishment (Rp ha^{-1})					
(Labor:3 days @ Rp 2000 day^{-1})		0	6000	0	6000
(Capital:seed cost)		0	6250	0	6250
		0	12250	0	12250
Total Costs that Vary (Rp ha^{-1})		0	12250	17500	29750
Net Benefits (Rp ha^{-1})		55165	71980	157700	98695

Table 4.2. Partial budget for the second year after implementation of the treatments.

	Control	Alley	Lime	Alley + Lime
Yield (kg ha^{-1}) 1) Cowpea	85	289	325	579
2) Rice	548	1692	1675	2194
3) Wood	0	3100	0	3100
Gross Field Benefit (Rp ha^{-1})				
(Rp 101 kg^{-1} x cowpea yield)	8585	29189	32825	58479
(Rp 85 kg^{-1} x rice yield)	46580	143820	142375	186490
(Rp 5 kg^{-1} x wood yield)	0	15500	0	15500
	55165	188509	175200	260469
Cost of Lime (Rp kg^{-1})				
(Labor:Rp 10 kg^{-1}x250 kg ha^{-1})	0	0	2500	2500
(Capital:Rp 60 kg^{-1}x250 kg ha^{-1})	0	0	15000	15000
	0	0	17500	17500
Cost of Pruning (Rp ha^{-1})				
(Labor:13 days @ Rp 2000 day^{-1})	0	26000	0	26000
Total Costs that Vary (Rp ha^{-1})	0	26000	17500	43500
Net Benefits (Rp ha^{-1})	55165	162509	157700	216969

Table 4.3. Annual partial budget for the third through the fifth years after implementation of the treatments.

	Control	Alley	Lime	Alley + Lime
Yield (kg ha^{-1}) 1) Cowpea	85	504	325	926
2) Rice	548	1692	1675	2194
3) Wood	0	3100	0	3100
Gross Field Benefit (Rp ha^{-1})				
(Rp 101 kg^{-1} x cowpea yield)	8585	50904	32825	93526
(Rp 85 kg^{-1} x rice yield)	46580	143820	142375	186490
(Rp 5 kg^{-1} x wood yield)	0	15500	0	15500
	55165	210224	175200	295516
Cost of Lime (Rp kg^{-1})				
(Labor:Rp 10 kg^{-1}x250 kg ha^{-1})	0	0	2500	2500
(Capital:Rp 60 kg^{-1}x250 kg ha^{-1})	0	0	15000	15000
	0	0	17500	17500
Cost of Pruning (Rp ha^{-1})				
(Labor:13 days @ Rp 2000 day^{-1})	0	26000	0	26000
Total Costs that Vary (Rp ha^{-1})	0	26000	17500	43500
Net Benefits (Rp ha^{-1})	55165	184224	157700	252016

Table 4.4. Net present value over a five year period of changing from the Control to Alley, Lime, or Alley+Lime treatments at various discounting interest rates.

Treatment Changed to	Discounting Interest Rate (%) 0	12	25	50	100
	(Rp ha^{-1})				
Alley	511336	347700	243383	139647	63475
Lime	512675	369616	275745	178065	99331
Alley+Lime	795887	544771	384301	224066	105277

Table 4.5. Net present value over four years of actual yield data of changing from the Control to Alley, Lime, or Alley+Lime treatments at various discounting interest rates.

Treatment Changed to	Discounting Interest Rate (%) 0	12	25	50	100
	(Rp ha^{-1})				
Alley	151246	107731	77801	45529	19534
Lime	183672	141420	109716	71839	36480
Alley+Lime	237503	168712	121273	70007	28701

Table 4.6. Sensitivity analysis for effects of percent yield reductions in Alley+Lime treatments on net present values of changing from the Control to the Alley+Lime treatment. (Percent yield reductions were calculated by reducing estimated yields by the same amount in each of the five years.)

Percent Yield Reduction	Discounting Interest Rate (%) 12	25	50
	(Rp ha^{-1})		
10	469559	330495	191889
30	303614	212757	122466
50	142456	98143	54606
70	-16470	-14472	-11587
Break-even Values*			
Control	68	67	66
Alley	25	25	25
Lime	22	19	14

* Values reported are percent yield reductions in the Alley+Lime treatment required to give equivalent net present values of change (or for the Control treatment, a net present value of change of zero).

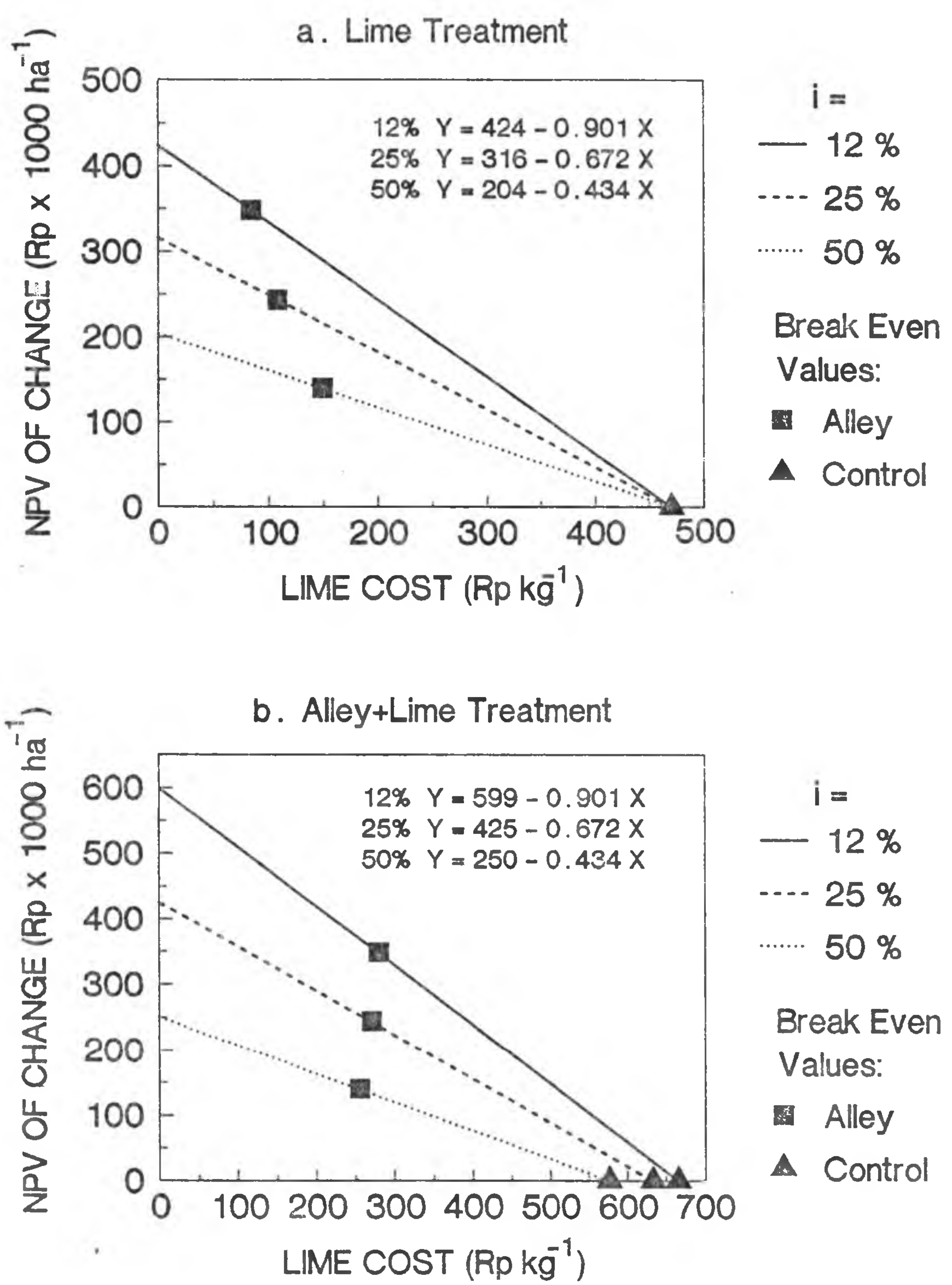


Figure 4.1 Sensitivity analysis for effects of cost of lime on net present value of changing from the control treatment to the Lime or Alley+Lime treatments at three discounting interest rates (i).

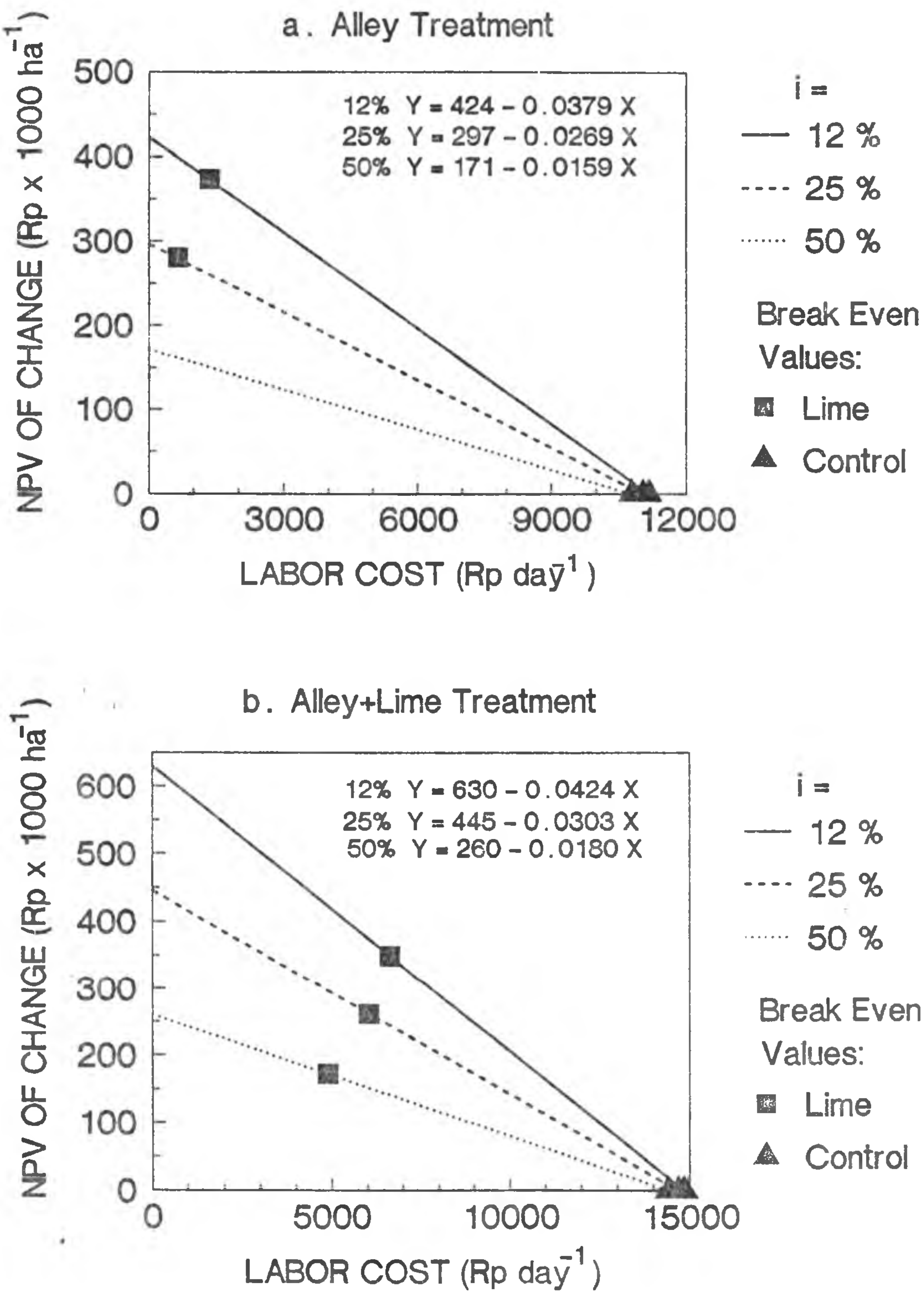
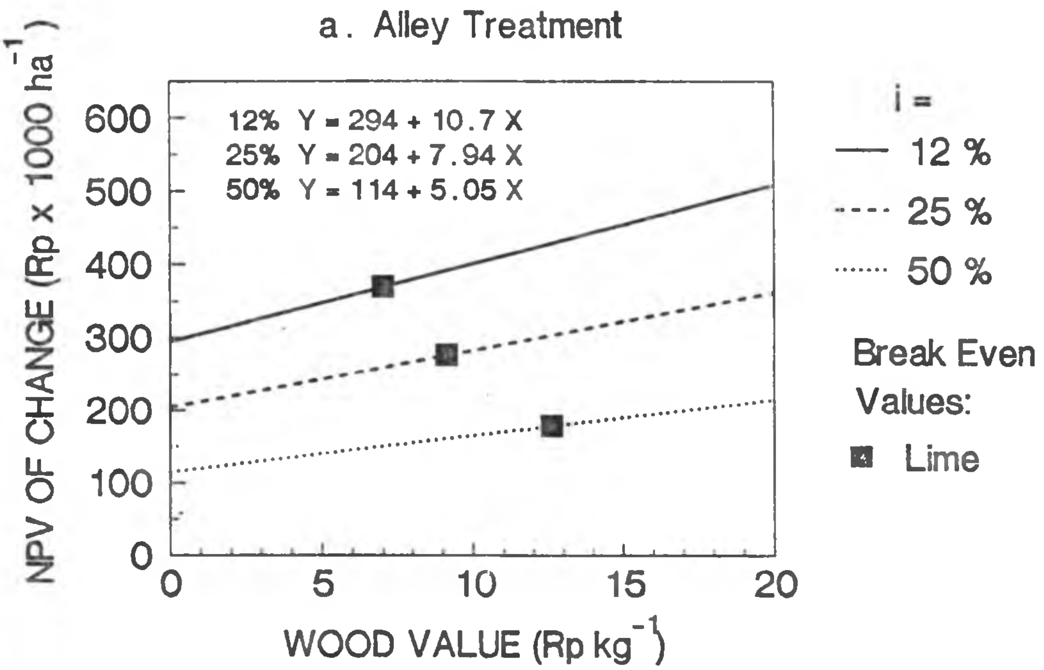


Figure 4.2 Sensitivity analysis for effects of cost of labor on net present value of changing from the control treatment to the Alley or Alley+Lime treatments at three discounting interest rates (i).



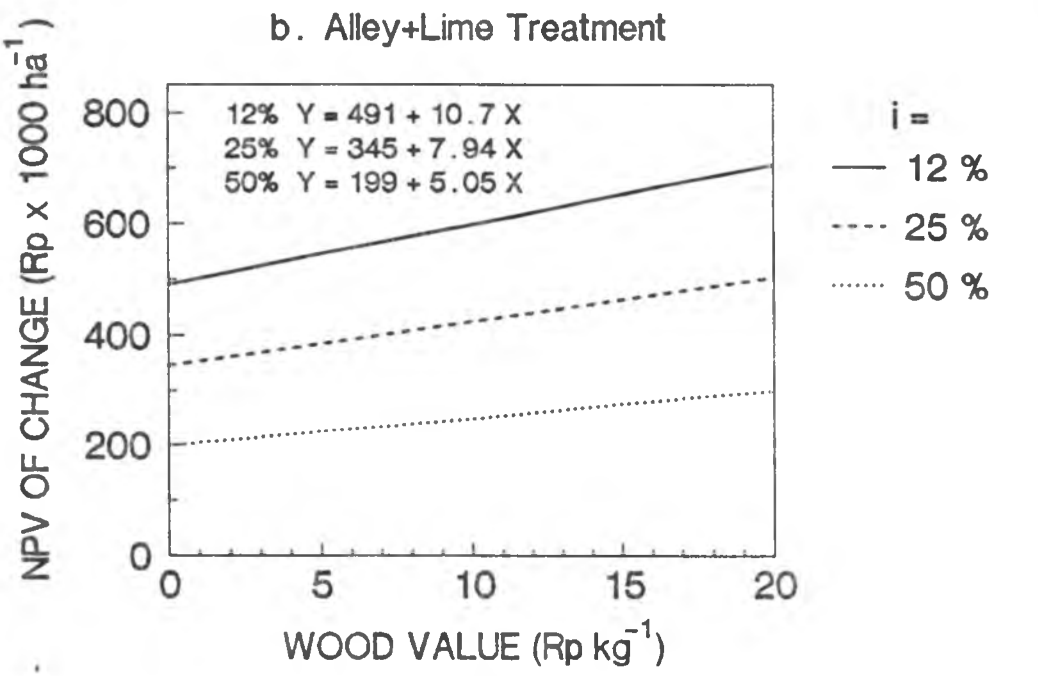


Figure 4.3 Sensitivity analysis for effects of value of wood on net present value of changing from the control treatment to the Alley or Alley+Lime treatments at three discounting interest rates (i).

CHAPTER 5

GREEN MANURE MANAGEMENT FOR THE AMELIORATION OF SOIL ACIDITY IN THE HUMID TROPICS OF WEST SUMATRA

5.1 INTRODUCTION

Green manuring is the agricultural practice of growing and incorporating a crop into the soil while it is still green for the purpose of improving the productivity of subsequent crops. It has been practiced around the world since ancient times and traditionally was an important component of cropping systems, particularly in Asia (Allison, 1973). Due to increasing intensification of crop production systems and widespread availability of inorganic fertilizers, green manuring is less commonly used today (Yost and Evans, 1988). However, in recent years there has been renewed interest in green manuring in the tropics due to increasing fertilizer costs, concern for improving the sustainability of agricultural production, and the need to find alternatives to systems of shifting cultivation (Young, 1979; Sanchez and Salinas, 1981; von Uexkull, 1984; Yost and Evans, 1988). This chapter describes an experiment in which the management of herbaceous green manures was studied on an acid and infertile soil in a humid tropical area of West Sumatra.

Increases in crop yield and other benefits associated with green manuring can be impressive, especially on low fertility soils. Wade and Sanchez (1983) found that with five consecutive food crops grown in an experiment in Yurimaguas, Peru, incorporation of _Pueraria phaseoloides_ produced an average of 90% of the yields obtained with completely fertilized plots without green manure. Crop yields with green manures were double the yields of unfertilized and unamended plots. The decomposing Pueraria provided large amounts of plant nutrients, reduced crop moisture stress, decreased soil Al saturation and lowered soil bulk density.

Redshaw (1982) described an improved cropping system using Pueraria which was developed for the "red-yellow podsolic" soils (mostly Oxisols and Ultisols) in recently cleared forest lands on the outer islands of Indonesia. These soils are of very low fertility, easily damaged by erosion, and if unfertilized, produce very low crop yields. Leguminous cover crops, such as Pueraria phaseoloides, were cut and used as mulch in strips of 5 - 8 m width. Food crops such as maize and cassava were grown in these mulched strips for one year, after which an adjacent strip was cleared and Pueraria was allowed to re-establish in the previously cropped strip. Moderate crop yields were produced for several years using this system experimentally, but it was not known if farmers would accept such a system in which a large part of their land was not producing crops.

Despite these benefits associated with green manure use, there are various problems, especially in subsistence agricultural systems where the benefits are most needed. Agboola (1974) indicated that Nigerian farmers were reluctant to use green manures because they occupy crop land without providing an immediate return and because planting a sole green manure crop does not fit into their mixed cropping systems. The incorporation of the fibrous vines of common tropical green manure crops, such as Calopogonium mucunoides, Pueraria phaseoloides, and Stizolobium aterrimum, is difficult with hand tools. Sanchez and

Salinas (1981) reported that the added labor required for producing and applying green manures limits their use in South America. These disadvantages as well as lack of planting material, occasional harboring of pests and diseases, and lack of information on best management practices were reported in a recent survey on the current use of green manures in the tropics (Yost and Evans, 1988).

Webster and Wilson (1980) summarized these main objections to the use of green manures as follows:

> "[Farmers] are naturally averse to growing a crop which occupies the land for the whole, or the greater part, of the rainy season without giving any direct return, and which demands labour for planting and for digging in at times which coincide with the busy periods of planting and harvesting food crops. Green manures are most likely to be used where they can be grown as short-term crops, occupying the land for only part of the rainy season, either before of after the main crop."(p.211)

In using green manures and cover crops on acid and infertile soils, obviously it is important to select species which are well adapted and productive. Such crops should also be quickly and easily established, be resistent to pests and diseases, should fix nitrogen, and should be drought resistant (Purseglove, 1977). Many species of tropical legumes have these characteristics and are commonly used as green manures. Among the species of legumes which are best adapted to high rainfall areas with acidic soils are Calopogonium mucunoides, Centrosema pubescens, Desmodium ovalifolium, Pueraria phaseoloides, and Stylosanthes guianensis (Burt et al., 1983; Hutton, 1970; Kretschmer, 1978). Sanchez and Salinas (1981) showed that various tropical legumes differ greatly in their tolerance or susceptibility to high levels of extractable aluminum and/or manganese. Legumes also differ in their tolerance to low P, Ca, Mg, K, and Mo levels (Kanehiro et al., 1983).

Clearly, a green manure species must be carefully selected for adaptation to the particular environment in which it is to be grown.

The most widely recognized benefit of green manuring is in nitrogen fertilization. Leguminous green manures supply significant amounts of N to crops and can substitute for inorganic fertilizers (Bouldin et al., 1979; Stickler et al., 1959; Weeraratna, 1979). However, the effects of organic matter additions on amelioration of soil acidity has been suggested by some research in the tropics (Wade and Sanchez, 1983; Wahab and Lugo-Lopez, 1980), but is not well understood. Previous research done in West Sumatra (Wade et al., 1988) indicated that green manuring temporarily alleviated Al toxicity, enhanced P availability and supplied other nutrients such as K and Mn. The research described here was initiated to compare green manuring and liming for upland crop production on an acid soil in West Sumatra.

The objectives of this study were: 1) to compare three legume green manure crops for ameliorating effects on soil acidity and potential reduction of lime requirements for upland crops; 2) to compare three methods of production and application of green manures; and 3) to determine the response relationships of upland crops to lime and to inorganic and green manure N application.

5.2 MATERIALS AND METHODS

5.2.1 Site Characteristics

The experiment was conducted in the transmigration village of Sitiung Vc (Aur Jaya) in West Sumatra. The site was located about 0.5 km from the alley cropping experiment which is described in Chapters 2, 3, and 4. The soil, climate and initial forest clearing practices are very similar for these two sites, so a description of site characteristics is not repeated here. Since forest clearing in 1982 the site of this green manure management experiment had been cultivated occasionally with scattered plantings of cassava, maize, and banana but had not been fertilized.

5.2.2 Experimental Design and Statistical Analysis

The experiment was conducted using a randomized complete block design with three replications. The test crops grown were a rotation of a grain crop (upland rice or maize) followed by peanut during two seasons of cropping. The plot dimensions were 4m x 6m. The experimental factors studied were the following:

EXPERIMENTAL FACTORS

Species:
1) *Calopogonium mucunoides* (CAL)
1) *Crotalaria usaramoensis* (CRO)
3) *Centrosema pubescens* (CEN)

Methods of Green Manure Application:
1) In situ incorporation (INC)
2) Cut and carry (CUT)
3) Root residue and stubble from plots that were used to produce the cut and carry material (RES)

Levels of Lime:
1) L0 = no lime
2) L1 = 375 kg lime/ha
3) L2 = liming to 40% Acid (Al+H) saturation
4) L3 = liming to 20% Acid saturation

Level of Nitrogen:

	1985/86	1986/87	
1) N0 =	0	0	
2) N1 =	30	60	kg N ha^{-1} (split application)
3) N2 =	60	120	kg N ha^{-1} "
4) N3 =	120	180	kg N ha^{-1} "

These experimental factors were combined to produce 20 experimental treatments in four groupings of related treatments. The treatments used were the following:

EXPERIMENTAL TREATMENTS

Trt no.	Green Manure species	Application Method	(Nitrogen,Lime)	(Code)
Group 1:	(GM species and application methods)			
1)	CAL	INC	(N0,L2)	(02I/CAL)
2)	CRO	INC	(N0,L2)	(02I/CRO)
3)	CAL	CUT	(N0,L2)	(02C/CAL)
4)	CRO	CUT	(N0,L2)	(02C/CRO)
5)	CAL	RES	(N0,L2)	(02R/CAL)
6)	CRO	RES	(N0,L2)	(02R/CRO)
7)	check (no GM)	-	(N0,L2)	(02)
8)	CEN	INC	(N0,L2)	(02I/CEN)
Group 2:	(Lime response with GM also applied)			
9)	CRO	INC	(N0,L0)	(00I/CRO)
10)	CRO	INC	(N0,L1)	(01I/CRO)
11)	CRO	INC	(N0,L2)	(02I/CRO)
12)	CRO	INC	(N0,L3)	(03I/CRO)
Group 3:	(Lime response with no GM applied)			
13)	check (no GM)	-	(N0,L0)*	(00 or 20)
14)	check (no GM)	-	(N0,L1)*	(01 or 21)
15)	check (no GM)	-	(N0,L2)*	(02 or 22)
16)	check (no GM)	-	(N0,L3)*	(03 or 23)
Group 4:	(Inorganic nitrogen response)			
17)	check (no GM)	-	(N0,L2)	(02)
18)	check (no GM)	-	(N1,L2)	(12)
19)	check (no GM)	-	(N2,L2)	(22)
20)	check (no GM)	-	(N3,L2)	(32)

* Nitrogen was applied at the N2 level in the Group 3 treatments in the 1986/87 season.

The treatments in group 1 (except for treatment 8) were designed to be compared using single df orthogonal contrasts as follows:

Trt 7 vs. Others (contrast GM vs. No GM)
Trts 1+3+5 vs. 2+4+6 (contrast of CAL vs. CRO)
Trts 5 vs. 1+3 (contrast CAL, RES vs. INC+CUT)
Trts 6 vs. 2+4 (contrast CRO, RES vs. INC+CUT)
Trts 1 vs. 3 (contrast CAL, INC vs.CUT)
Trts 2 vs. 4 (contrast CRO, INC vs.CUT)

Yield data from groups 2, 3, and 4 were analyzed using regression methods to determine the response relationships of yield regressed on lime with GM (group 2), lime without GM (group 3), and inorganic nitrogen (group 4). The yield responses to lime both with and without GM were also compared to determine the potential for reducing lime requirements with green manure applications. Fisher's protected LSD was calculated for comparison of the treatments, although this used sparingly due to increased experiment-wise error rates in comparing all 20 treatments (Chew, 1976).

5.2.3 Experimental and Crop Management

The experiment was initiated on 4 March 1985 with planting of a local variety of cowpea. Cowpeas were planted as a uniformity trial to characterize soil variability before imposition of the treatments. Although 60 plots were needed to accommodate the 20 treatments, 75 were planted so that the extremely variable plots could be discarded. Only Triple super phosphate (TSP) fertilizer was applied on all plots at a rate of 40 kg P ha^{-1}. Germination was delayed for over a week by dry weather and was uneven. Gaps in the stand of cowpeas were replanted on 27 March 1985. Due to non-uniform growth, harvesting of pods was staggered over several weeks, with two harvests on 22 May and 8 June 1985.

Cowpea yields and soil analyses from each plot were used to determine between-plot variability while within-plot variability was visually rated on the basis of growth uniformity and plant vigor. Both between-plot and within-plot variability were used to select "uniform" plots to be included in each block of the subsequent experiment. Plots were selected to minimize variability within replications and plots with the highest within-plot variability were discarded.

In the following two cropping seasons, green manure (GM) crops were grown during the dry season (June to August) and then a grain crop followed by a peanut crop were grown during the rainy season (September to May). After harvest of the uniformity trial, lime was applied on 13 June 1985 according to the treatment plan. However, lime was applied at different rates in each replication to create the desired acid saturations due to differing mean acid saturations and extractable acidities in each replication (Table 5.2). Liming rates were calculated using the equation of Cochrane et al. (1980) to try to produce the desired acid (Al+H) saturations.

Green manure crops (see Experimental Factors above) were planted on 14 June 1985 at a spacing of 40 cm between rows and densely within the rows (for Crotalaria about 50 seeds m^{-1} and for Calopogonium and Centrosema about 25 seeds m^{-1}). Calopogonium seeds were scarified for 12 minutes and Centrosema seeds for 8 minutes in concentrated sulfuric acid. Crotalaria seed did not require scarification. Growth was very slow at first due to a drought and gaps in the stand were replanted on

18 July. Several days of rain followed and the germination and subsequent growth of the GM crops was quite vigorous.

The GM crops were harvested on 19 September 1985 with a harvest area of 4 m x 2.4 m and incorporated with hoes according to the treatment plan as given above. Litter on the soil surface and root residue produced by the green manures were also estimated since this is what was left in the green manure residue treatments. Two strips, each 40 cm wide and 4 m long, were harvested in each of the green manure residue plots (treatment numbers 5 and 6). Surface litter and stubble was collected and roots dug to 30 cm depth and shaken free of soil. These samples were dried and then sieved to remove remaining soil. This simple procedure did not result in complete recovery of fine or deep roots and was only a rough estimate. Triple super phosphate (TSP) and Muriate of Potash (KCL) were also incorporated on all plots at rates of 10 kg P and 25 kg K ha^{-1} at the same time that the green manures were applied.

A local variety of upland rice (disease tolerant and preferred by local farmers) was planted at a spacing of 25 cm x 25 cm on 24 September 1985. The seed was planted in dibble holes along with 3 % carbofuran granules (625g a.i. ha^{-1}). Germination was fairly good, but there were a few gaps in the stand which were replanted after the first weeding on 8 October. Half of the required nitrogen was applied as urea in the N treatments on 23 October (15, 30, and 60 kg N ha^{-1}) and the same amounts were applied on 27 November. Following the second application, the field was weeded again. Insect control was achieved with regular spraying of diazinon, Azodrin (monokrotophos), and Sevin (carbaryl), as is common practice among local farmers.

Rice Blast (Pyricularia oryzae) and Helminthosporium Brown Spot (Helminthosporium oryzae) caused severe leaf damage in November, with many older leaves completely dying, but surprisingly, by December the rice had produced new leaves and recovered well. This tolerance to diseases is the reason a local variety was grown. On 22 November, recently fully expanded leaves (40 leaves per plot) were collected for nutrient analysis. Grain set was very heavy and uniform, with treatment effects not evident. However, very heavy winds and rain in mid-January caused serious lodging throughout the experiment. Due to this lodging, harvest areas were reduced to portions of plots that were still intact for the first harvest of mature panicles on 21 January as well as the final harvest of panicles and straw on 1 February 1986. Harvest areas ranged from 3.3 m^2 to 10.5 m^2, with most (45 plots) measuring 8 m^2. Rice straw was returned to the plots and buried by hoe along with TSP at 10 kg P ha^{-1}.

A local variety of red peanut (Valencia type) was planted at 25 cm x 25 cm on 16 February 1986. The crop was sprayed once with Sevin (carbaryl). Peanut growth was quite good but rat damage began to occur in mid-April. This was relatively minor (less than about 5 %) and was corrected by slightly reducing harvest areas to exclude damaged hills. Peanuts were harvested on 13 May 1986 with most harvest areas being 8 m^2.

After peanut harvest, green manure crops were again planted on 21 May 1986 in rows 50 cm apart. Dry weather reduced germination and gaps in the rows of green manures were replanted on 6 June 1986, after which uniform stands were obtained. One weeding in early July was required to establish the green manure crops. They grew well after that, making good use of the sporadic rainfall.

The green manure crops were harvested on 8 September 1986 using 2 m x 4 m harvest areas and were incorporated according the treatment plan. Estimates of litter and root residue were made as in the previous season. TSP and KCl were applied to all plots at rates of 10 kg P and 25 kg K ha^{-1}. Lime was reapplied only on the highest lime level treatment to try to reestablish 20 % acid saturation (Table 5.2). Soil samples taken to 15 cm depth on 14 April 1986, indicated that the target acid saturation of 40% was achieved for the third lime rate, but that the highest lime rate averaged 27% acid saturation (Table 5.15).

Maize (Cargill C-1 Hybrid) was planted at a spacing of 80 cm x 20 cm on 6 October 1986. Two seeds were placed in each dibble hole along with 3 % carbofuran granules (1 kg a.i. ha^{-1}). Maize was planted this season instead of upland rice since maize is known to be more responsive to lime on soils with high acid saturations (Wade et al., 1988). Since maize is often highly responsive to nitrogen application (Fox et al., 1974; Grove, 1979), rates of urea applied to the inorganic N treatments were increased to 60, 120, and 180 kg ha^{-1}. Urea was also applied at a rate of 120 kg ha^{-1} to the liming treatments without GM (treatments 13, 14, 15, and 16) so as not to confound lime response of the crop with a possible N deficiency. Half of the urea was applied at planting and half applied on November 8 (about 5 weeks after planting) and was incorporated to about 2 cm depth to reduce possible N volatilization losses (Gould et al., 1986). The maize was thinned to one plant per hill on 30 October 1986.

The maize germinated and established well. Two weedings were done at about 3 and 5 weeks after planting; the second weeding followed the second urea application. During the first two weeks of December, 15 ear leaves were collected in each plot when 50% of the plants showed silk extrusion. The maize was sprayed several times with diazinon for insect control. Some minor damage by wild pigs occurred in six plots in early January, even though the field had been guarded by night watchmen starting in late December. Pig damage was corrected for by slightly reducing harvest areas to exclude damaged plants. Maize was harvested on 11 January 1987 (99 days from planting) with most harvest areas of 2.4 m x 4 m. Maize stover was removed from the plots (as is usual farmer practice in Sitiung) and TSP and KCL were incorporated on all plots at rates of 10 kg P and 25 kg K ha^{-1}.

Peanuts were planted (the same variety as in the previous year) on 19 January 1987 at a spacing of 25 cm x 25 cm with one to two seeds per planting hole. Peanuts established well and required no replanting. After several weeks, all of the zero and low lime plots had high rates of seedling death and leaf necrosis, but other plots had excellent growth. To determine the effects of N application on peanut yields, urea was applied on 10 February to the inorganic N treatments (18, 19, and 20) at rates of 15, 30, and 60 kg ha^{-1}. Peanut plants were sprayed twice with Sevin (carbaryl) and once with Thiodan to control caterpillar and leaf hopper infestations. The peanuts were harvested on 28 April 1987 using a 2 m x 4 m harvest area.

Soil samples were collected at 0-15 cm depths on 19 February 1985 (before planting the uniformity trial), on 14 April 1986 (during the growth of the peanut crop), and on 13 January 1987 (before planting the peanut crop). Samples were air-dried and ground to pass a 2-mm sieve. Test results were expressed on per soil volume basis (which is almost equivalent to a per weight basis since bulk density of the soil was close to 1).

Determinations of exchangeable Al+H were made by extraction in 1 N KCl and titrated with NaOH to the phenolphthalein endpoint. Separate determinations of Al were not made since Al+H levels were found to be highly correlated with Al in previous studies in Sitiung (Wade et al., 1986). Exchangeable Ca and Mg were extracted with 1 N KCl, while K and P were extracted with Mehlich 1 (double acid) extractant (Knudsen et al., 1982). Ca, Mg, and K were measured using an Atomic Absorption Spectrophotometer while P was measured using a colorimetric procedure (Murphy and Riley, 1962). Effective cation exchange capacity (ECEC) was calculated as: (exchangeable Ca + Mg + K + extractable Al + H). Percent acid saturation was calculated as: (((extractable Al + H)/ECEC) x 100). Organic carbon was analyzed using acid dichromate digestion, total nitrogen using a semimicro Kjeldahl procedure, and pH using a 1:2.5 soil to water suspension (Soil Conservation Service, 1972).

Rice leaf tissue (collected on 22 November 1985), green manure samples (collected on 8 September 1986) and maize ear leaves (collected in December 1986) were sun dried and later oven dried at 60 ^{o}C. Samples were ground in a Wiley mill to pass a 1-mm mesh. Total elemental analysis was done at the University of Hawaii Agricultural Diagnostic Service Center using an X-ray fluorescence quantometer (rice leaves) and an ICP Spectrometer (green manure samples and maize leaves). Nitrogen in all samples was analyzed using a semi-automated indophenol blue colorimetric method (Suehisa, 1980).

Crop grain and straw samples were taken at each harvest to determine moisture content. Grain moisture content was measured with an electronic moisture tester and yields were calculated at 14% moisture for upland rice, 15% moisture for maize, and 12% for cowpea and peanut. Straw samples were sun-dried to constant weight. Five or six randomly selected straw samples per harvest were oven dried at 60 ^{o}C to calculate oven dry weights.

5.3 RESULTS AND DISCUSSION

5.3.1 Initial Uniformity Trial

Crop yields from the uniformity trial and soil analysis data collected before and after plot selection are shown in Table 5.1. The range and variation of most of these variables were reduced slightly by discarding 15 plots. The selected plots were still quite variable as measured by soil properties and cowpea yields; however, much of this variability was stratified into between-block variation. The soil was generally quite infertile and high in extractable acidity (Al+H).

To test the effectiveness of plot selection and blocking, treatments were randomly assigned to the three blocks of "uniform" plots and an analysis of variance was calculated using cowpea yields from the uniformity trial as the dependant variable. Because the treatments had not been imposed, a significant treatment effect could only have been due to inherent soil variability. However, "treatment" effects in this analysis of variance were non-significant (with probability values of 0.18, 0.25, and 0.15 for cowpea grain, pod and vine yields, respectively). Block effects were highly significant, suggesting that plot selection and blocking had been appropriate.

5.3.2 Green Manure Yields and Nutrient Analyses

Yields of green manure crops grown in 1985 and in 1986 are shown in Table 5.3 and Table 5.4, respectively. Above ground dry matter yields of Crotalaria increased with increasing liming rates and was higher than yields of Calopogonium and Centrosema at the equivalent lime rate (lime 2) in both seasons. Crotalaria residues (surface litter and roots) were only about 25% as large as above ground biomass, while Calopogonium residues were about 50% as large as above ground biomass. However, all green manure crops grew well and produced large amounts of dry matter, considering the dryness of the growing seasons. Apparently, all three green manure crops are suitable for growth during the dry season in Sitiung.

The months of June, July, and August are generally quite dry in Sitiung, averaging 100 mm of rainfall per month, as opposed to 250 to 400 mm during the rainy season (Soil Research Institute, 1979). (See Figure 3.12 in Chapter 3 for the monthly rainfall distribution during the experimental period.) During these dry months, crop production is quite tentative and farmers often leave their fields fallow. These GM crops were planted during this normally fallow period to make green manuring more attractive to farmers since food crops would not be replaced.

Nutrient contents in green manures harvested on 8 September 1986 are presented in Table 5.5. N, P, K, Mg, and Zn concentrations did not differ significantly between the six green manure treatments (Crotalaria at 4 lime rates, Calopogonium, and Centrosema). Ca concentration was highest for Calopogonium GM and increased with increasing lime rates in Crotalaria GM. Nutrient yields per hectare are shown in Table 5.5b. The nutrient contributions of the green manures were fairly low as compared to nutrient yields from trees in a related alley cropping study (Tables 3.7 and 3.9). However, the green manure crops provided important amounts of at least N and K for low input cropping systems.

5.3.3 Crop Growth and Yields

The growth of upland rice in the 1985/86 season was very uniform and yields quite high, averaging 3150 kg ha^{-1} (with a range of 1880 to 4330 kg ha^{-1}). There were no significant treatment effects on grain yields (Tables 5.6, 5.8 and 5.10). Coefficients of variability were 14% for rice grain and 18% for rice straw (Table 5.6), suggesting that this lack of treatment effect is probably not due to unexplained variability. Table 5.8 shows that there were no significant differences between methods of green manure application. Also, liming (Table 5.10) and nitrogen rates did not significantly affect yield. It seems that at the moderately high liming rates (to about 40 % acid saturation), upland rice did not respond to either green manure or nitrogen application. For this reason, maize was used as the test crop in the following season, since it is more responsive to liming.

The peanut crops in both the 1985/86 and 1986/87 seasons responded strongly to increasing liming rates (Tables 5.6 and 5.7), with higher rates producing larger, greener tops and better filling of pods. Excellent nodulation was observed on most plots during harvest. However, the average effects of both Crotalaria and Calopogonium green manures applied in September did not have a significant influence on yields, as shown in an analysis of variance (Table 5.8). Crotalaria GM did cause significantly higher yields than Calopogonium GM, which was probably associated with the larger amounts of Crotalaria green manure grown in situ.

Liming significantly increased peanut yields in a linear fashion in both seasons (Tables 5.10 and 5.11), while quadratic and cubic effects were not significant. In both seasons, Crotalaria green manure applied before the previous grain crop significantly increased peanut yields over the lime treatments without green manure. The lime by GM versus No GM interaction was significant for only nut yields in the 1986/87 season, indicating that at that time, peanut yield response to lime was significantly greater when GM was added than when no GM was added.

Maize growth increased with increasing lime levels from the first few weeks of growth, but not with the addition of urea or GM. There were no significant differences in maize yields due to the different methods of green manure application (in situ incorporation, cut and carry, or root residues). However, green manure application significantly increased maize yields compared to no green manure (Table 5.9). The response of maize to lime was strongly linear and there was a significant lime x GM vs. No Gm interaction (Table 5.11) This interaction indicates that maize yield response was significantly greater when green manure was applied.

Linear, quadratic, and cubic effects of grain or straw yields regressed on nitrogen rates were not significant for any of the four test crops. There was, however, a significant maize grain yield response to the first level of inorganic nitrogen (Table 5.7) which is mirrored by a large increase (almost doubling) in ear leaf N content Table 5.13). Response to this modest addition of 60 kg N ha^{-1} is similar to the findings of Fox and colleagues (1974) who determined that on Oxisols and Ultisols in Puerto Rico, maximum maize grain yields were obtained with 67 kg of urea N ha^{-1}. However, response to N fertilizers is clearly related to the N supplying ability of the soil, which was not studied. It is also interesting to note that the urea N application to the second peanut crop (at rates of 15, 30, and 60 kg N ha^{-1} in treatments 18, 19, and 20 in Table 5.7) caused a significant decrease in nut yields and a trend (non-significant) of increasing straw yields. N fertilization of peanuts does not appear to be warranted, because of this yield decrease.

The coefficients of variability were relatively low in both seasons (Tables 5.6 and 5.7) for a site with such high variability. Coupled with the significant replication effects for most of the crops, this indicates that the preliminary uniformity trial and special efforts of stratifying plot variability to replications helped to reduce experimental error due to soil variability. This may prove to be a useful technique in field experimentation on soils with high micro-variability, such as on newly cleared land.

5.3.4. Crop Tissue and Soil Analyses

The adequacy of nutrients for good plant growth is often assessed with reference to published critical values or sufficiency ranges of nutrients in diagnostic plant tissue (Munson and Nelson, 1973). For upland rice the most commonly used diagnostic tissue is the most recent fully expanded leaf at 50% panicle initiation (Ward et al., 1973) while for maize, it is the ear leaf at 50% tasseling or silking (Melsted et al. 1969; Jones, 1967; Cornforth and Steele, 1981). Study of nutrient concentrations in diagnostic tissue can be especially valuable to determine the effects of fertility treatments on non-treatment nutrient concentrations.

The effects of treatments on nutrient concentrations in rice leaf diagnostic tissue are shown in Table 5.12. There were no significant differences in tissue concentrations of N, P, S, or Mn and few differences in other nutrients, except for increasing Ca concentrations with increasing lime rates. What is quite remarkable about this data are the high levels of all nutrients as compared to published critical values and sufficiency ranges for rice leaf tissue. (See Table 3.13 in Chapter 3 for these published values.) All nutrients for all treatments are well within the sufficiency ranges, except for Mg which was slightly low at the low lime treatments. N levels were extremely high and indicate that the N supplying ability of the soil was quite high during the growth of this first test crop. Also, Mn levels were quite high, unlike rice leaf tissue from the alley cropping experiment (Chapter 3) where Mn deficiencies were suspected.

The effects of treatments on nutrient concentrations in maize ear leaf diagnostic tissue are shown in Table 5.13. All the nutrient concentrations presented were significantly affected by treatments. The adequacy of the nutrients can be assessed with reference to published critical values and sufficiency ranges (Table 5.14). N, P, K, and especially Mg levels were low for all treatments as compared to the published values. Micronutrients (Mn, Cu, and Zn) were all well within sufficiency ranges for all treatments.

The lack of a strong response to nitrogen fertilizer was especially surprising for the maize crop, which had nitrogen contents in ear leaves which were lower than published critical levels (Tables 5.13 and 5.14). Possibly, low availability of other nutrients such as K and Mg limited maize response to N. Ear leaf concentrations of both K and Mg decreased significantly with increasing N application (Table 5.13), which suggests dilution effects occurred for these nutrients (Jarrell and Beverly, 1981). However, comparison of K and Mg concentrations of the liming rate treatments (9 to 16), show that green manure application may have improved K and Mg availability at the low lime levels.

Soil analyses for samples taken during the two cropping seasons are shown in Tables 5.15 and 5.16. The unamended soils can be seen to be quite acidic, with high acid (Al+H) saturation. Application of lime at the two highest rates achieved close to the target acid saturations of 40% and 20% in both seasons. There was also an apparent increase in exchangeable Mg with increasing lime rates. This increase in Mg coincided with increasing ECECs and might be explained by better Mg retention on the soil exchange complex.

A comparison of linear regression equations for crop response to acid saturation with or without Crotalaria green manure application is presented in Table 5.17. The regression equations with and without GM differed significantly for only the maize crop as determined by comparing confidence limits of slopes and Y-intercepts. Confidence limits were calculated according to the procedures described by Draper and Smith (1981). Since lime rates were calculated to achieve specific percent acid saturations, this was used as the independant variable in the regressions rather than lime rates.

Linear regressions of crop yields versus soil acid saturation are presented for the two seasons in Figures 5.1 and 5.2 for liming treatments with and without green manure. The linear responses for all the crops within the range of 25% to 80% acid saturations, supports the critical acid saturations of 28% and 29% estimated for peanut and maize by Wade et al. (1988) in Sitiung. Wade and colleagues also estimated the critical acid saturation of upland rice to be 70%, which would explain the lack of a stronger response by rice in this study (Figure 5.1a). The fit of the regression for upland rice was quite low, which is understandable since the unamended soil seemed to provide adequate fertility for this crop as shown by the high nutrient concentrations in leaf tissue (Table 5.12).

To better identify the soil chemical factors associated with crop yield responses, correlations were calculated between grain (or nut) yield and a number of soil test variables in both seasons (Table 5.18). As might be expected, upland rice yields were weakly related to all soil test parameters. However, maize and peanut crop yields were very strongly related to soil exchangeable Ca and Mg and to acid saturation levels. There was little or no relationship indicated for crop yields with soil P or K, which were applied as blanket fertilizer applications.

Using this information, predictive models were developed relating crop grain or nut yields to soil test parameters. A stepwise regression procedure was used (Draper and Smith, 1981) with "best" regression equations selected based on increases in R^2, reduction of residual sum of squares, and partial F-values of predictor variables with probability values of less than the 0.10 level. Quadratic and cubic variables were included in the analysis procedure on the basis of curvilinear trends indicated in scatter diagrams of each soil test parameter versus crop yields.

For upland rice, the selected regression equation included Mg, Mg^2, and (Acid Saturation)^2 terms, but accounted for only about 41% of the variability in yields. The selected models for the peanut crops included (Acid Saturation), Mg, Ca and Ca^3 terms. The maize grain yields were best fit with linear, quadratic and cubic Ca terms. This finding is in agreement with Njoku and colleagues (1987), who found that maize growth on an acid soil in eastern Nigeria was limited more by Ca deficiency than by Al toxicity. Clearly, these factors of exchangeable Ca, Mg, and acid saturation accounted for most of the variability in crop yields for the liming treatments in this experiment.

5.4 CONCLUSIONS

The legume species Crotalaria usaramoensis, Calopogonium mucunoides, and Centrosema pubescens can be successfully grown as green manures during the dry season in Sitiung. Growth of a green manure crop at this time does not displace food crops since most fields are fallow during the dry season in Sitiung. However, upland crop responses to these green manures were quite limited in this study. Of the three green manure crops, the most consistent crop responses were observed with Crotalaria, which also produced the largest amounts of green manure biomass. Crotalaria usaramoensis becomes somewhat woody if it is grown longer than about 3 months, which makes it difficult to incorporate with hand tools. However, it can persist for at least 2 years of growth and resprouts well after repeated prunings (author's personal observations) so it could also be considered as a candidate green leaf manure species for hedgerow intercropping systems of short duration.

Unlike other green manuring studies in Sitiung by TropSoils project personnel (Wade et al., 1988), the green manures in this study were grown in place and not transported to the site from outside areas. It is more realistic to farmer's capabilities to study green manures grown in place since this avoids the costs of transportion of the green manure. Also, green manures grown on a fertile site, such as on well fertilized rubber plantations, can add large amounts of nutrients (Gill and Adiningsih, 1986) which would not be supplied by green manures grown in place.

Crotalaria grown in this study responded strongly to lime application, with biomass and nutrient yields more than doubling with increasing lime rates. Different methods of green manure application (grown in place, cut and carried within the field, and residue remaining after cutting) did not cause significant differences in crop yields.

The first test crop of upland rice did not respond to either liming or green manure application, probably because of adequate soil fertility for this acid tolerant crop. However, the unusually well distributed rainfall during the growth of the rice crop may in part explain the lack of response to treatments. Unusually good upland rice growth and lack of response to liming was also noticed by other researchers in Sitiung during this season (Wade et al., 1986). Due to the lack of response to the experimental treatments, maize was substituted for upland rice in the crop rotation in the second season.

Maize and peanut crops both responded strongly to liming and less strongly to Crotalaria green manuring. The strong relationships between maize and peanut yields and soil exchangeable Ca suggest that yield increases were mainly related to improved Ca nutrition. Maize ear leaf concentrations of K and Mg also increased with lime as well as with Crotalaria green manure application. Improved K and Mg nutrition may have been related to increased uptake by more vigorous root systems and possibly to increased cation exchange capacity and reduced leaching losses of K and Mg.

There was little or no response of upland crops to inorganic nitrogen during the two cropping seasons reported. Apparently, adequate amounts of N were available in the soil for moderate crop growth. Therefore, the response of crops to N contained in the green manures was probably limited and the modest maize and peanut crop responses to Crotalaria green manure was probably related to increase availability of nutrient bases. It is also possibly that green manure additions reduced aluminum toxicity through such mechanisms as Al complexation with organic breakdown products (Hoyt and Turner, 1975; Hue et al., 1986). However, continued cropping on this soil without green manure or N fertilizer additions would probably result in N deficiencies in crops.

On the basis of these studies, the advisability of growing herbaceous green manure crops in Sitiung farming systems is somewhat questionable. Crop responses to green manuring were slight and the increased labor costs of this activity may make green manuring unattractive to farmers. However, the long term sustainability of farming systems may be improved by planting green manure crops for soil protection during fallow periods, particularly if the farmer is forced to fallow his of her field through the rainy season, when erosion hazards and nutrient leaching losses are greatest. The possibility of combining green manure production with livestock grazing may also make green manuring more attractive to local farmers.

Table 5.1. Cowpea growth and soil test analyses summarized from the uniformity trial before and after plot selection.

	Cowpea Yields			Soil Analyses		
	Grain	Pod	Vine	Al+H	Ca+Mg	Acid Sat.
	------- ($kg\ ha^{-1}$) ------			-- ($cmol_c kg^{-1}$) --		(%)
75 Original Plots:						
Mean :	653	1170	665	2.27	0.69	74
Standard Deviation :	269	488	390	0.39	0.23	6.0
Minimum :	78	126	119	1.40	0.30	57
Maximum :	1397	2568	2005	3.40	1.50	84
60 Selected Plots:						
Mean :	654	1173	652	2.25	0.70	74
Standard Deviation :	236	425	350	0.33	0.23	5.8
Minimum :	185	330	169	1.50	0.30	57
Maximum :	1116	1891	1415	3.00	1.50	83

Table 5.2. Rates of lime applied to each replication on 13 June 1985 and (for the 20 % acid saturation level only) on 11 September 1986.

Rep.	Lime 1	40% Acid Sat.	------- 20% Acid Sat. --------		
			13/06/85	11/09/86	Total
I	375	1000	1604	354	1958
II	375	1396	2083	396	2476
III	375	1208	1900	278	2174

Table 5.3. Green manure biomass yields in 1985 (for the growth period of 14 June to 19 September 1985 -- 97 days).

Green Manure Species	Lime[1] Rate	Above Ground Dry Matter Yield	Soil Surface Litter	Root Residue
		---------------- kg ha^{-1}	----------------	
Crotalaria	Lime 0	1923	--	--
	Lime 1	2806	--	--
	Lime 2	3408	75	690
	Lime 3	3710	--	--
Calopogonium	Lime 2	2198	400	640
Centrosema	Lime 2	2303	--	--
LSD (0.05)		949		

1 Lime rates: 0, 1 = 375 kg ha^{-1}, 2 = liming to 40% acid saturation, 3 = liming to 20% acid saturation.

Table 5.4. Green manure biomass yields in 1986 (for the growth period of 21 May to 8 September 1986 -- 110 days).

Green Manure Species	Lime[1] Rate	Above Ground Dry Matter Yield	Soil Surface Litter	Root Residue
		---------------- kg ha^{-1}	----------------	
Crotalaria	Lime 0	1782	--	--
	Lime 1	2806	--	--
	Lime 2	3477	346	494
	Lime 3	3651	--	--
Calopogonium	Lime 2	1590	475	347
Centrosema	Lime 2	2405	--	--
LSD (0.05)		1264		

1 Lime rates: 0, 1 = 375 kg ha^{-1}, 2 = liming to 40% acid saturation, 3 = liming to 20% acid saturation.

Table 5.5. Nutrients contained in green manures (GM) harvested in September 1986.

a. Nutrient concentrations in GM tissue.

Green Manure Species	Lime[1] Rate	N	P	K	Ca	Mg	Mn	Cu	Zn	B
		---------	($g\ kg^{-1}$)			---------	---	($mg\ kg^{-1}$)		---
Crotalaria	Lime 0	17.0	0.63	11.5	4.1	0.77	83	11	34	13
	Lime 1	17.7	0.63	9.8	5.4	1.33	93	10	40	15
	Lime 2	17.1	0.68	8.8	6.4	1.10	57	8	31	15
	Lime 3	12.7	0.47	8.6	4.8	1.37	37	8	26	11
Calopogonium	Lime 2	19.3	1.10	9.9	10.7	1.55	58	11	32	21
Centrosema	Lime 2	23.1	0.80	16.4	9.1	1.33	79	16	33	20
LSD (0.05)		ns	ns	ns	0.3	ns	19	4	ns	6

b. Nutrient yields per hectare

Green Manure Species	Lime[1] Rate	N	P	K	Ca	Mg	Mn	Cu	Zn	B
		-------	($kg\ ha^{-1}$)			----------	----	($g\ ha^{-1}$)		----
Crotalaria	Lime 0	29	1.0	21	7.4	1.4	161	19	57	23
	Lime 1	46	1.8	27	15.8	4.0	270	28	112	42
	Lime 2	59	2.2	29	21.6	3.8	196	27	105	50
	Lime 3	46	1.7	32	17.3	5.0	133	29	93	41
Calopogonium	Lime 2	31	1.8	16	17.2	2.5	89	17	51	34
Centrosema	Lime 2	57	1.8	38	21.9	3.2	187	38	80	47
LSD (0.05)		25	ns	ns	10.3	ns	109	13	45	ns

[1] Lime rates: 0, 1 = 375 $kg\ ha^{-1}$, 2 = liming to 40% acid saturation, 3 = liming to 20% acid saturation.

Table 5.6. Yield response of upland rice and peanut to treatments in the 1985/86 season.

Treatment (Code)	Upland Rice Grain	Upland Rice Straw	Peanut Nut	Peanut Straw
	($kg\ ha^{-1}$)			
(GM application methods)				
1) (02I/CAL)	3345	3760	943	2150
2) (02I/CRO)	3091	3606	1231	2722
3) (02C/CAL)	3174	3553	885	2158
4) (02C/CRO)	3531	4057	1009	2190
5) (02R/CAL)	3139	3306	983	2023
6) (02R/CRO)	3273	4232	1060	1961
7) (02)	3447	3944	1130	2493
8) (02I/CEN)	3571	3792	1132	2628
(Lime rates with GM)				
9) (00I/CRO)	2601	2992	451	1826
10) (01I/CRO)	2910	4105	787	2060
11) (02I/CRO)	2988	2639	1341	2692
12) (03I/CRO)	2992	3519	1457	3048
(Lime rates without GM)				
13) (00)	2509	2137	267	1439
14) (01)	2945	3671	591	1407
15) (02)	3020	3423	866	2093
16) (03)	3446	4239	1035	2323
(Inorganic N rates)				
17) (02)	3176	3460	1219	2310
18) (12)	3404	4211	974	2364
19) (22)	3402	3874	1234	2762
20) (32)	3094	3672	1042	2310
LSD (0.05)	ns	1086	407	723
CV (%)	14	18	25	20

Code Key: First number codes for N level; second number codes for lime level.

N LEVEL	LIME LEVEL	GM SPECIES
0 = No N	0 = No lime	CAL = Calopogonium
1 = 30 $kg\ ha^{-1}$	1 = 375 $kg\ ha^{-1}$	CRO = Crotalaria
2 = 60 $kg\ ha^{-1}$	2 = 40% Acid Sat.	CEN = Centrosema
3 = 120 $kg\ ha^{-1}$	3 = 20% Acid Sat.	

Table 5.7. Yield response of maize and peanut to treatments in the 1986/87 season.

Treatment	(Code)	Maize Grain	Maize Straw	Peanut Nut	Peanut Straw
		(kg ha^{-1})			
(GM application methods)					
1)	(02I/CAL)	2392	3216	754	1449
2)	(02I/CRO)	2530	3525	1058	1611
3)	(02C/CAL)	2071	2870	874	1433
4)	(02C/CRO)	2277	3362	845	1956
5)	(02R/CAL)	2205	3010	713	1408
6)	(02R/CRO)	1918	2821	882	1615
7)	(02)	1361	2228	862	1541
8)	(02I/CEN)	2520	3537	958	1622
(Lime rates with GM)					
9)	(00I/CRO)	314	743	58	1133
10)	(01I/CRO)	1845	2213	720	1648
11)	(02I/CRO)	2111	2813	955	1637
12)	(03I/CRO)	2900	3756	1268	1668
(Lime rates without GM)					
13)	(20)	90	587	20	486
14)	(21)	1246	1769	188	2042
15)	(22)	2616	3054	658	1604
16)	(23)	3906	4585	957	1700
(Inorganic N rates)					
17)	(02)	1881	2808	692	1589
18)	(12)	3100	3722	1005	1799
19)	(22)	2712	2973	801	1902
20)	(32)	3072	3619	514	2247
LSD (0.05)		985	1031	418	691
CV (%)		28	22	34	26

Code Key: First number codes for N level; second number codes for lime level.

N LEVEL	LIME LEVEL	GM SPECIES
0 = No N	0 = No lime	CAL = Calopogonium
1 = 60 kg ha^{-1}	1 = 375 kg ha^{-1}	CRO = Crotalaria
2 = 120 kg ha^{-1}	2 = 40% Acid Sat.	CEN = Centrosema
3 = 180 kg ha^{-1}	3 = 20% Acid Sat.	

Table 5.8. Analysis of variance for the effects of methods of green manure application on upland rice and peanut yields in the 1985/86 season.

Source	df	Upland Rice Grain MS	Upland Rice Straw MS	Peanut Nut MS	Peanut Straw MS
REPLICATION	2	519923*	3363061**	203637**	84971
GM TREATMENTS	(6)	81043	307723	41069	219205*
GM vs. no GM	1	91358	94360	31895	219860
CAL vs. CRO	1	28338	815833	119088*	146322
CAL,RES vs.INC+CUT	1	2908	320720	7212	490017**
CRO,RES vs.INC+CUT	1	28920	245373	9471	34217
CAL,INC vs.CUT	1	290752	305788	73638	424696*
CRO,INC vs.CUT	1	43981	64274	5110	116
ERROR	12	109360	395018	19920	67190

Table 5.9. Analysis of variance for the effects of methods of green manure application on maize and peanut yields in the 1986/87 season.

Source	df	Maize Grain MS	Maize Straw MS	Peanut Nut MS	Peanut Straw MS
REPLICATION	2	807182*	588522	226467*	183280
GM TREATMENTS	(6)	445750	549347	36310	106366
GM vs. no GM	1	1950692**	2112974*	160	3728
CAL vs. CRO	1	1659	187333	98213	396822
CAL,RES vs.INC+CUT	1	470288	774888	9763	56740
CRO,RES vs.INC+CUT	1	1401	2113	20510	2145
CAL,INC vs.CUT	1	96089	39544	67756	178400
CRO,INC vs.CUT	1	154369	179228	21456	363
ERROR	12	199320	309956	27615	87059

Code Key: CAL = Calopogonium
CRO = Crotalaria
RES = Root Residue
INC = *In situ* incorporation
CUT = Cut and Carry

Table 5.10. Analysis of variance for the effects of lime application with and without green manure on upland rice and peanut yields in the 1985/86 season.

Source	df	Upland Rice		Peanut	
		Grain MS	Straw MS	Nut MS	Straw MS
REPLICATION	2	38538	2432074*	77358	306939
GM vs. No GM	1	68469	17168	611683**	2095922*
LIME RATES	(3)	458609	2576634**	976534***	1560237*
Lime linear	1	1282222	2858655*	2838748***	4369702**
Lime quadratic	1	37139	339745	52295	54970
Lime cubic	1	56468	4531504*	38560	256040
± GM x LIME	3	85321	1019504	34137	31938
ERROR	12	353480	555047	69479	303659

Table 5.11. Analysis of variance for the effects of lime application with and without green manure application on maize and peanut yields in the 1986/87 season.

Source	df	Maize		Peanut	
		Grain MS	Straw MS	Nut MS	Straw MS
REPLICATION	2	124174	222559	40266	118799
GM vs. No GM	1	177797	82791	520087***	24143
LIME RATES	(3)	10962500***	13182700***	1282359***	1287584*
Lime linear	1	32580900***	39397900***	3829256***	1725889*
Lime quadratic	1	139492	11935	17734	1416982*
Lime cubic	1	167097	138190	86	719882
± GM x LIME	3	777698*	456085**	60873*	279963
ERROR	12	225055	70739	14778	265815

Table 5.12. Effect of treatments on nutrient concentrations in rice leaf tissue (at 50% panicle initiation) in 1985.

Treatment	(Code)	N	P	K	Ca	Mg	S	Mn
		------------	--- ($g\ kg^{-1}$)	-----------				($mg\ kg^{-1}$)
(GM application methods)								
1)	(02I/CAL)	36.8	1.80	18.9	5.07	2.10	2.50	276
2)	(02I/CRO)	38.9	1.80	20.2	5.10	2.20	2.57	283
3)	(02C/CAL)	37.9	1.73	21.8	5.37	1.87	2.60	324
4)	(02C/CRO)	37.8	1.80	20.5	5.33	2.00	2.47	339
5)	(02R/CAL)	38.2	1.77	17.5	5.40	2.00	2.60	330
6)	(02R/CRO)	38.5	1.83	16.9	4.67	2.10	2.60	258
7)	(02)	37.9	1.73	18.7	5.30	1.87	2.50	265
8)	(02I/CEN)	37.3	1.80	20.4	5.17	2.13	2.50	282
(Lime rates with GM)								
9)	(00I/CRO)	37.5	1.70	21.8	3.47	1.30	2.60	309
10)	(01I/CRO)	38.9	1.83	21.0	4.47	1.73	2.53	340
11)	(02I/CRO)	37.7	1.73	19.9	5.23	1.90	2.50	303
12)	(03I/CRO)	38.6	1.97	20.5	5.50	2.60	2.53	225
(Lime rates without GM)								
13)	(00)	39.6	1.67	19.9	3.60	1.43	2.63	382
14)	(01)	36.5	1.57	20.1	3.70	1.20	2.43	213
15)	(02)	38.0	1.80	20.2	4.53	1.87	2.47	352
16)	(03)	36.7	1.43	16.1	4.97	2.10	2.40	161
(Inorganic N rates)								
17)	(02)	37.5	1.63	19.0	4.60	1.70	2.43	255
18)	(12)	39.7	1.90	17.4	4.90	2.47	2.60	341
19)	(22)	38.5	1.73	20.3	4.80	2.10	2.53	292
20)	(32)	38.2	1.77	18.9	5.17	1.83	2.73	209
LSD (0.05)		ns	ns	3.0	0.93	0.58	ns	ns
CV (%)		3	9	9	12	18	5	303

Code Key: First number codes for N level; second number codes for lime level.

N LEVEL	LIME LEVEL	GM SPECIES
0 = No N	0 = No lime	CAL = Calopogonium
1 = 30 $kg\ ha^{-1}$	1 = 375 $kg\ ha^{-1}$	CRO = Crotalaria
2 = 60 $kg\ ha^{-1}$	2 = 40% Acid Sat.	CEN = Centrosema
3 = 120 $kg\ ha^{-1}$	3 = 20% Acid Sat.	

Table 5.13. Effect of treatments on nutrient concentrations in maize ear leaves (at 50% silking) in 1986.

Treatment (Code)	N	P	K	Ca	Mg	Mn	Cu	Zn
	--------(g kg^{-1}) ---------					-- (mg kg^{-1}) --		
(GM application methods)								
1) (02I/CAL)	15.2	1.73	16.6	2.97	0.87	35	8.7	16
2) (02I/CRO)	14.9	1.50	15.0	2.57	0.80	41	7.7	14
3) (02C/CAL)	16.0	1.60	16.8	2.57	0.77	38	8.7	15
4) (02C/CRO)	15.9	1.63	17.2	2.70	0.80	39	8.3	15
5) (02R/CAL)	15.4	1.63	14.6	3.20	0.80	39	9.0	16
6) (02R/CRO)	16.8	1.43	14.0	3.03	0.73	32	9.3	15
7) (02)	13.9	1.87	16.2	3.13	0.83	35	8.0	15
8) (02I/CEN)	15.9	1.70	16.4	2.77	0.77	36	8.3	15
(Lime rates with GM)								
9) (00I/CRO)	15.7	3.17	12.4	1.90	0.73	23	12.3	14
10) (01I/CRO)	18.1	2.10	15.9	2.30	0.73	32	10.3	15
11) (02I/CRO)	15.8	1.87	15.6	3.30	0.90	42	9.3	16
12) (03I/CRO)	15.0	1.57	16.8	2.80	0.97	33	10.0	16
(Lime rates without GM)								
13) (20)	16.9	2.83	6.8	1.63	0.37	35	24.3	14
14) (21)	19.9	2.70	11.6	2.90	0.63	32	21.7	17
15) (22)	25.8	2.07	13.3	4.20	0.80	49	21.0	20
16) (23)	22.6	1.77	12.9	4.70	1.37	41	15.0	19
(Inorganic N rates)								
17) (02)	13.9	1.90	16.7	3.20	0.90	35	9.3	15
18) (12)	22.8	2.23	14.8	3.70	0.83	53	15.7	19
19) (22)	24.5	2.03	15.4	3.47	0.80	52	16.7	19
20) (32)	25.0	2.27	12.1	4.27	0.67	50	24.7	20
LSD (0.05)	2.7	0.46	2.8	0.59	0.22	11	3.3	3
CV (%)	9	14	12	12	12	16	17	11

Code Key: First number codes for N level; second number codes for lime level.

N LEVEL	LIME LEVEL	GM SPECIES
0 = No N	0 = No lime	CAL = Calopogonium
1 = 60 kg ha^{-1}	1 = 375 kg ha^{-1}	CRO = Crotalaria
2 = 120 kg ha^{-1}	2 = 40% Acid Sat.	CEN = Centrosema
3 = 180 kg ha^{-1}	3 = 20% Acid Sat.	

Table 5.14. Critical values and sufficiency ranges for nutrient concentrations in maize ear leaves as reported in literature.

Nutrient	Melsted et al. (1969) at silk	Jones (1967) at silk	Cornforth and Steele (1981) at tassel
		$g\ kg^{-1}$	
N	30.0	27.6 - 35.0	22.5 - 33.0
P	2.5	2.5 - 4.0	1.8 - 3.2
K	19.0	17.1 - 25.0	17.0 - 30.0
Ca	4.0	2.1 - 10.0	4.0 - 8.0
Mg	2.5	2.1 - 6.0	1.3 - 2.5
		$mg\ kg^{-1}$	
Mn	15	20 - 150	18 - 140
Cu	5	6 - 20	8 - 20
Zn	15	20 - 70	22 - 85

Table 5.15. Analyses of soil samples (0-15cm) taken during the growth of the peanut crop on 14 April 1986.

Lime Rate	Al+H[1]	Ca[1]	Mg[1]	K^2	ECEC	P^2	Acid Sat.
	------------	$cmol_c\ kg^{-1}$			------------	ppm	%
0	1.84	0.31	0.12	0.23	2.51	6	73
375 kg ha^{-1}	1.57	0.63	0.19	0.28	2.69	4	58
40% Acid Sat.	1.12	1.22	0.21	0.24	2.82	5	40
20% Acid Sat.	0.86	1.70	0.30	0.27	3.13	4	27

[1] Extracted with 1 N KCl. [2] Extracted with Mehlich I extractant.

Table 5.16. Analyses of soil samples (0-15cm) taken before planting the peanut crop on 13 January 1987.

Lime Rate	pH	Al+H[1]	Ca[1]	Mg[1]	K^2	ECEC	P^2	Acid Sat.	Org. C	Total N
		--------	$cmol_c\ kg^{-1}$			--------	ppm	-----	(%)	-----
0	4.67	1.00	0.24	0.08	0.16	1.47	4.37	67	2.16	0.18
375 kg ha^{-1}	4.67	0.96	0.41	0.10	0.16	1.63	4.79	58	1.91	0.16
40% Acid Sat.	4.80	0.80	0.69	0.12	0.16	1.76	4.00	45	2.00	0.17
20% Acid Sat.	5.03	0.48	0.96	0.18	0.17	1.79	3.97	27	2.11	0.19

[1] Extracted with 1 N KCl. [2] Extracted with Mehlich I extractant.

Table 5.17. Comparison of linear regression equations for crop grain yield response to percent soil acid saturation, with and without Crotalaria green manure (GM).

a. Upland rice crop in 1985/86 season

Soil Amendment	95 % Confidence Limits for Slope	95 % Confidence Limits for Y-intercept
Lime with GM	-6.9 ± 10.4	3211 ± 544
Lime without GM	-20.5 ± 23.6	4025 ± 1273

b. Peanut crop in 1985/86 season

Soil Amendment	95 % Confidence Limits for Slope	95 % Confidence Limits for Y-intercept
Lime with GM	-20.8 ± 10.3	2024 ± 537
Lime without GM	-15.4 ± 9.0	1474 ± 487

c. Maize crop in 1986/87 season

Soil Amendment	95 % Confidence Limits for Slope	95 % Confidence Limits for Y-intercept
Lime with GM	-54.0 ± 20.8	4313 ± 1024
Lime without GM	-82.4 ± 23.6	6327 ± 1312

d. Peanut crop in 1986/87 season

Soil Amendment	95 % Confidence Limits for Slope	95 % Confidence Limits for Y-intercept
Lime with GM	-20.5 ± 6.6	1541 ± 369
Lime without GM	-25.1 ± 10.5	1922 ± 517

Table 5.18. Correlation coefficients for crop yields regressed on various soil test parameters in two cropping seasons.

a. 1985/86 Season[1]

Soil Test Parameter	Ranges in Soil Test Values	Correlation Coefficients (r) Upland Rice GM	Upland Rice No GM	Upland Rice Total	Peanut GM	Peanut No GM	Peanut Total
Al+H[2]	0.66 - 2.35	.389	.540	.403	.772**	.732*	.687***
Ca[2]	0.22 - 2.00	.392	.503	.443*	.879***	.735**	.758***
Mg[2]	0.10 - 0.37	.300	.518	.436*	.677*	.560	.580**
K[3]	0.16 - 0.40	.156	.456	.279	.125	.345	.044
P[3]	0 - 11	.074	.272	.133	.386	.413	.350
ASAT[4]	23 - 78	.425	.521	.441*	.819***	.767**	.762***

b. 1986/87 Season[1]

Soil Test Parameter	Range in Soil Test Values	Correlation Coefficients (r) Maize GM	Maize No GM	Maize Total	Peanut GM	Peanut No GM	Peanut Total
Al+H[2]	0.77 - 2.58	.684*	.821***	.728***	.654*	.746**	.704***
Ca[2]	0.18 - 1.71	.929***	.935***	.903***	.941***	.965***	.925***
Mg[2]	0.03 - 0.40	.785**	.825***	.799***	.746**	.852***	.756***
K[3]	0.09 - 0.27	.281	.116	.150	.167	.103	.224
P[3]	2.37 - 8.63	.070	.023	.046	.125	.024	.067
ASAT[4]	29 - 86	.878***	.926***	.863***	.860***	.909***	.874***
pH[5]	4.13 - 4.83	.505	.647*	.580**	.501	.497	.494*
OC[6]	1.26 - 2.27	.543	.225	.008	.455	.249	.061
TOTN[7]	0.11 - 0.23	.263	.345	.150	.212	.360	.160

*, **, *** Significant at the 0.05, 0.01, and 0.001 levels, respectively.

1 Soil analyses are for samples taken on 12 April 1986 for the 1985/86 season and on 28 February 1987 for the 1986/87 season.
2 Extracted with 1 N KCl. Units of test values are $cmol_c L^{-1}$.
3 Extracted with Mehlich I (double acid) extractant. Units of K test values are $cmol_c L^{-1}$ and units of P test values are $mg\ kg^{-1}$.
4 Percent acid saturation: calculated as ((Al+H)/(Al+H+Ca+Mg+K))x100.
5 Measured in a 1:2.5 soil to water suspension.
6 Percent organic carbon: measured as Walkley-Black organic carbon.
7 Percent micro-Kjeldahl N.

Table 5.19. "Best" regression equations[1] relating crop yields (Y) to soil test parameters in two seasons for lime treatment both with green manure and without green manure.

Crop	Equation	R^2	P value of regression
<u>1985/86 Season</u>			
Rice	$Y = 5776 - 23698(Mg) + 52744(Mg)^2 - 0.175(ASAT)^2$	0.407	0.014
Peanut	$Y = 3082 - 31.0(ASAT) - 3287(Mg)$	0.638	0.000
<u>1986/87 Season</u>			
Maize	$Y = -4644 + 31184(Ca) - 48116(Ca)^2 + 25271(Ca)^3$	0.893	0.000
Peanut	$Y = -513 + 2453(Ca) - 849(Ca)^3$	0.897	0.000

[1] The criteria for the selection of "best" regression equations were increases in R^2, reduction of residual sum of squares, and partial F-values of predictor variables with probability values of less than the 0.10 level.

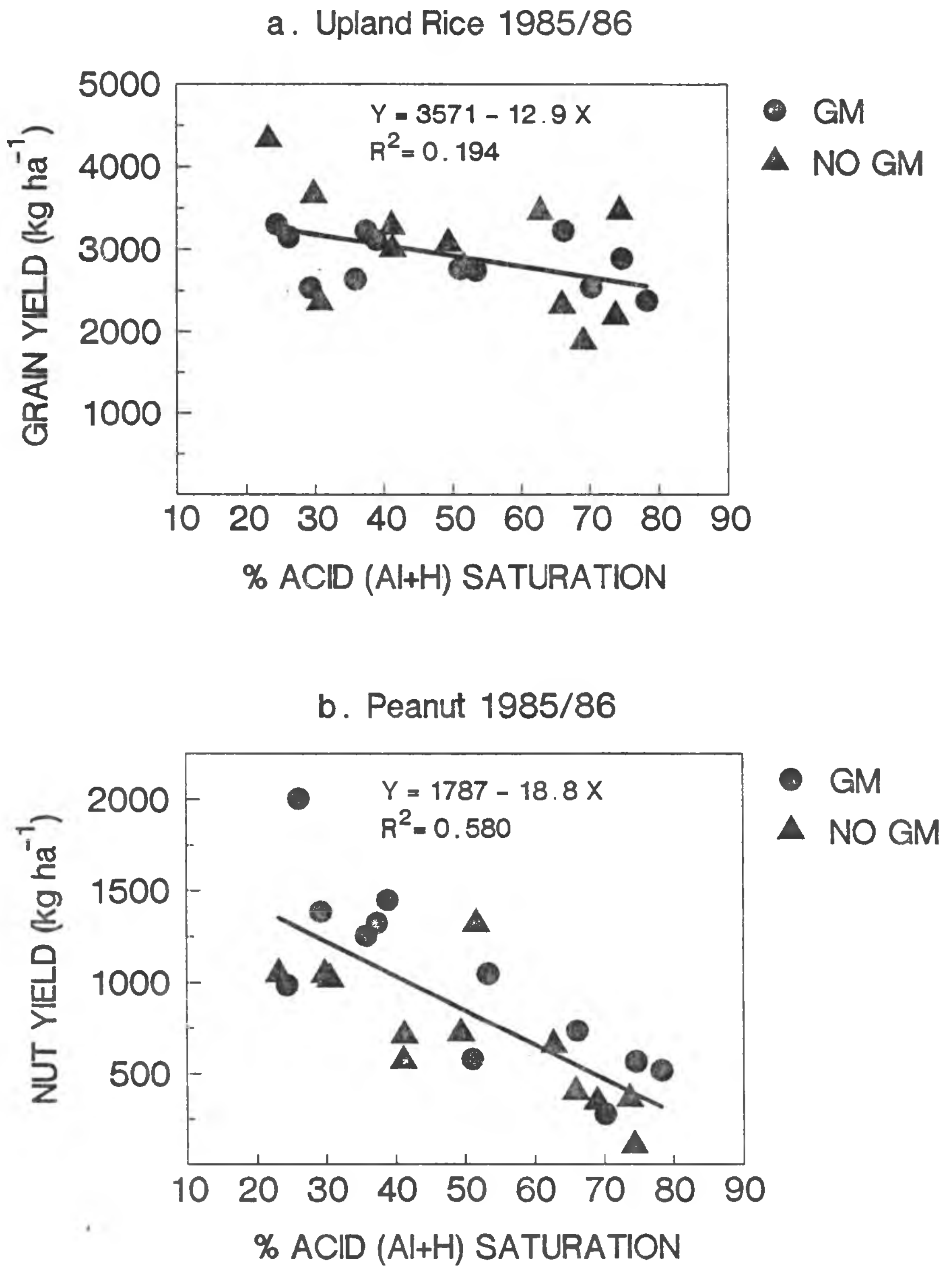


Figure 5.1 Crop response to percent acid saturation (Al+H/ECEC) in the 1985/86 season.

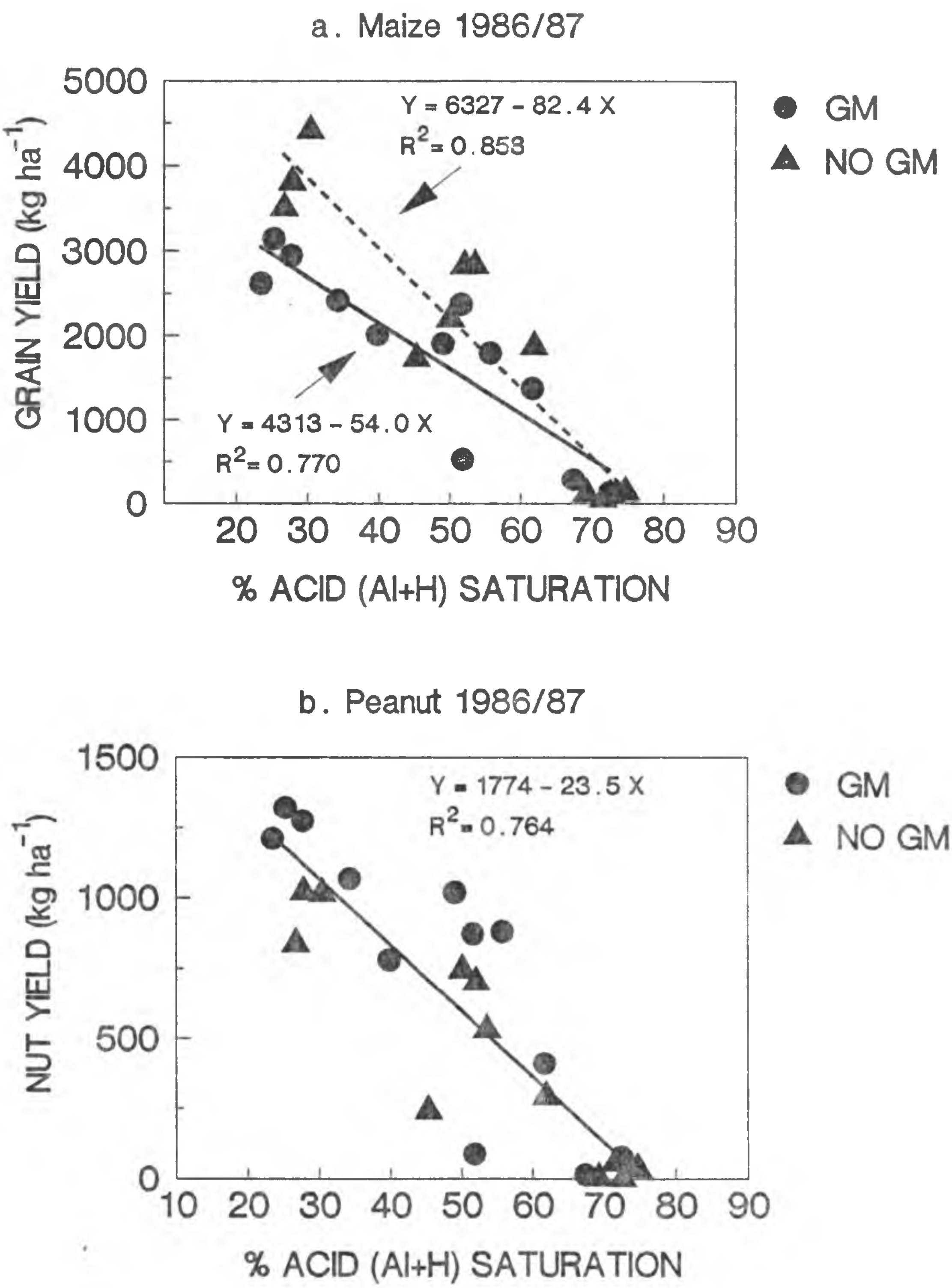


Figure 5.2 Crop response to percent acid saturation (Al+H/ECEC) in the 1986/87 season.

CHAPTER 6

GENERAL SUMMARY

Green manuring and alley cropping were tested as means of improving upland crop production on acid and infertile soils in Sitiung, West Sumatra. This research was conducted over the years 1984 - 1988 with the TropSoils Indonesia Project as a part of an effort to develop improved soil management methods for farmers with limited resources. These studies followed up on the results of previous research by TropSoils researchers in Sitiung which suggested the potential for ameliorating soil acidity and infertility problems by green manure application.

In alley cropping plantings, the tree species Paraserianthes falcataria and Calliandra calothyrsus were shown to be well adapted to the acid and infertile soils at the experimental site in Sitiung. These species produced an average of about 3 tons of leafy dry matter and about 4 tons of woody dry matter ha^{-1} $year^{-1}$ from hedgerows at 4 m spacings. Growth of these species was good at high Acid (Al+H) saturations (70 - 90%) and there was little response to lime application. Gliricidia sepium did not grow well in this study, producing only about 1/2 ton of leafy dry matter and about 400 kg of woody dry matter ha^{-1} $year^{-1}$. The poor growth of Gliricidia was most strongly related to low Ca availability, with growth reduced at soil exchangeable Ca levels below about 1 $cmol_cL^{-1}$ and at soil acid (Al+H) saturation levels above about 65%.

Initial growth of Paraserianthes was very good; this was the most vigorous species and produced the most leaf and wood biomass during the first year of growth. Calliandra, however, grew more slowly at first and was stunted and had chlorotic leaves up until the first pruning, which took place nine months after planting. Thereafter, Calliandra grew much more vigorously and produced the greatest amount of leaf and wood biomass in subsequent prunings. Four years after planting, Paraserianthes trees began to decline in vigor and die. This may have been caused by a pruning regime that was too intensive for this species; less frequent pruning (less than 4 times per year) and increasing the height of cutting the hedges at each pruning should be studied as possible ways of increasing the longevity of Paraserianthes hedges. Conversely, because Calliandra hedges heavily shaded alley crops, more frequent and lower pruning heights should be studied to try to reduce competition.

Yields of upland rice and cowpea crops increased with both lime and green leaf manure (GLM) application. The first crop of upland rice after tree pruning began did not respond significantly to alley cropping, but the subsequent three crops of cowpea and two crops of upland rice all produced highest yields when intercropped with Paraserianthes hedges. Paraserianthes alley cropping approximately doubled rice yields and quadrupled cowpea yields as compared to control plots. Crop response to Calliandra alley cropping was less, probably due to shading competition, while Gliricidia hedges did not grow well enough to influence crop yields.

It is likely that part of the crop response to Paraserianthes alley cropping was due to the amelioration of Al toxicity. With application of Paraserianthes GLM, crop yields did not decrease at the highest acid saturation levels, while without GLM, crop yields decreased above critical acid saturation levels (of 70% for upland rice and about 60% for cowpea). If labile Al-organic matter complexes are important in reducing Al toxicity to crops, the frequent application of GLM in alley cropping would be especially beneficial. Beneficial effects of GLM addition on crop yields may be transient, therefore, the repeated application of prunings at regular intervals through the cropping season may help to maintain crop responses.

Of the green leaf manures, Paraserianthes GLM also contained the highest concentrations of Mg and Mn (which were probably very deficient in the soils) and returned important amounts of plant nutrients to the soils (e.g. about 80 kg N, 30 kg K, and 6 kg Mg ha^{-1} $year^{-1}$). Therefore, improved mineral nutrition may also explain the crop response to Paraserianthes alley cropping.

The highest crop yields were obtained in the Paraserianthes + Low lime rate (750 kg ha^{-1}) treatment in all harvests, with the exception of the initial rice crop when the effects of alley cropping were just being established. This suggests that the beneficial effects of alley cropping with Paraserianthes went beyond simply substituting for lime and may be beneficial even in areas where upland rice and cowpea crop yields are not limited by soil acidity. Economic analysis also indicated that Paraserianthes alley cropping + the low rate of lime application was the most profitable treatment. However, if lime is not available, Paraserianthes alley cropping was shown to be more profitable than the control treatment, which was considered to be current farmer practice.

In a related study, Crotalaria usaramoensis, Calopogonium mucunoides and Centrosema pubescens were grown as green manure crops during two dry seasons in Sitiung and the green manures were use on a rotation of upland rice or maize followed by peanuts. On many farms in Sitiung, the dry season is a fallow period so food crops were not displaced by the green manure crops. Green manure yields (stems and leaves) of 1.7 to 3.7 tons dry matter ha^{-1} were obtained with Crotalaria while yields of 1.6 to 2.4 tons dry matter ha^{-1} were obtained with Calopogonium and Centrosema. Crotalaria was grown at four lime rates, to which it responded strongly, with biomass and nutrient yields more than doubling with increasing lime application.

The first crop of upland rice did not respond to either liming or green manure application, probably because of adequate soil fertility for this acid tolerant crop. However, maize and peanut crops responded strongly to liming and less strongly to Crotalaria green manuring. Increases in maize and peanut yields were more strongly related to soil exchangeable Ca than to Al+H saturation. Overall, there was little response to green manure application. Also, different methods of green manure application (grown in place, cut and carried within the field, and residue remaining after cutting) did not cause significant differences in crop yields.

Four rates of inorganic N application were also applied and there was little or no response of the upland crops to this N during the two cropping seasons. Apparently, adequate amounts of N were available in the soil for the moderate yields (which averaged 2.7 T ha^{-1} for maize, 3.3 T ha^{-1} for upland rice, and 1.1 T ha^{-1} for peanut). Therefore, the response of crops to the N contained in the green manures was probably limited and the slight maize and peanut crop responses to Crotalaria green manure may have been related to increased availability of bases. It is also possible that the green manure additions reduced aluminum toxicity.

Overall, crop response to green manuring was slight and the increased labor costs of this activity may make green manuring unattractive to farmers. These results are quite different from the large yield increases obtained with green leaf manure application in the alley cropping experiment. Although the sites were fairly similar, the green manure management experiment had a slightly more fertile and less acid soil, which may explain the lack of response to the herbaceous green manures. Also the amounts of nutrients contained in the green manures was slightly less than in the Paraserianthes GLM.

Another major difference between alley cropping and green manuring may be the timing of application of GLM versus herbaceous green manure. All of the green manure was applied at the beginning of the rainy season, while the GLM was applied in four smaller applications over the rainy season. The nutrients contained in the GLM may have been more readily available to crops at times of greatest requirement. Conversely, the green manures were somewhat fibrous and had low N, P, Ca and Mg concentrations, which may have resulted in some immobilization of these nutrients in microbial biomass and decomposing materials.

This research was conducted on soils with high variability which resulted in a lack of precision in testing differences between treatments. However coefficients of variation were generally lower and replication effects more frequently significant in the green manure management experiment than in the alley cropping experiment. This indicates that the special efforts taken in conducting a uniformity trial and in stratifying variability into replications in the former experiment were successful and might be useful in other experimentation on such soils.

A general philosophy which was followed in designing and managing these experiments was to set fertilizer rates and crop management practices within the ranges of current farmer practice and to deviate from farmer practice only in experimental factors. This "farming systems" approach to research was intended to insure that research results would be more readily applicable to farmers needs and resources than research conducted under high input systems or under more controlled conditions. However, by not making blanket applications of nutrients such as Mg or micronutrients, crop yield responses to treatments could have been confounded with variability in availability of these non-treatment nutrients. The treatment effects which caused significant increases in crop yields, such as response to Paraserianthes alley cropping, were very strong and such technology will hopefully be readily transferred to Sitiung farmers.

APPENDIX I

Table I.1. Names of Crops Commonly Grown in Sitiung

English	Indonesian	Latin
Banana	Pisang	*Musa* cvs.
Cardamom	Kepulaga	*Elattaria cardamomum*
Cassava	Ubi kayu	*Manihot esculenta*
Chili	Cabe	*Capsicum* spp.
Citrus	Jeruk	*Citrus* spp.
Clove	Cengke	*Eugenia caryophyllus*
Coconut	Kelapa	*Cocos nucifera*
Coffee	Kopi	*Coffea* spp.
Corn	Jagung	*Zea mays*
Cowpea	Kacang tunggak	*Vigna unguiculata*
-------	Duku (or Langsat)	*Lansium domesticum*
Durian	Duren (or Durian)	*Durio zibethinus*
Eggplant	Terung	*Solanum melongena*
Ginger	Jai (or Jahe)	*Zingiber officianale*
Guava	Jambu biji	*Psidium guajava*
Jackfruit	Nangka	*Artocarpus heterophyllus*
Kapok	Kapok	*Ceiba pentandra*
-------	Katuk	*Sauropus androgynus*
-------	Laos	*Lunguas galanga*
Mango	Mangga	*Mangifera indica*
Mangosteen	Manggis	*Garcinia mangostana*
Longbean	Kacang panjang	*Vigna sesquipedalis*
Mung bean	Kacang hijau	*Phaseolus aureus*
Papaya	Pepaya	*Carica papaya*
Peanut	Kacang tanah	*Arachis hypogaea*
Pigeon pea	Kacang gude	*Cajanus cajan*
Pineapple	Nenas	*Ananas comosus*
Rambutan	Rambutan	*Nephelium lappaceum*
Rice	Padi gogo (upland) Padi sawah (flooded)	*Oryza sativa*
Soybean	Kacang kedelai	*Glycine max*
Stinkbean	Jengkol	*Pithecellobium jiringa*
Sugarcane	Tebu	*Saccharum* cvs.
Swamp cabbage	Kangkung	*Ipomea aquatica*
Sweet potato	Ubi jalar	*Ipomea batatas*
Taro	Talas	*Colocasia esculenta*
Turmeric	Kunyit	*Curcuma domestica*
Yam bean	Bengkuang	*Pachyrrhizus erosus*

SOURCE: Purseglove, J. W. 1977. Tropical Crops Dicotyledons.
1976. Tropical Crops Monocotyledons.
Longman Group Ltd., London.

Direktorat Gizi Departmen Kesehatan R.I. 1979. Daftar komposisi bahan makanan. Jakarta.

APPENDIX II

Table II.1. Leaf yields of tree hedgerows during the 1985/86 season.

Tree Species		Tree Pruning Date				Total: 4 Prunings
		Sept.'85	Nov.'85	Feb.'86	Apr.'86	
		kg ha^{-1}				
Paraseri-anthes	* No lime	1301	542	312	215	2369
	Low lime	1743	540	184	220	2687
	High lime	1425	532	297	224	2477
Calliandra	* No lime	430	565	579	318	1891
	Low lime	478	567	589	341	1975
	High lime	282	462	604	336	1683
Gliricidia	* No lime	70	74	28	20	192
	low lime	210	221	88	74	593
	High lime	236	294	153	109	791
SPECIES MEANS:						
	Paraserianthes	1489	538	264	220	2511
	Calliandra	397	531	590	332	1850
	Gliricidia	172	196	90	68	525
LIME RATE MEANS:						
	No Lime	600	394	306	184	1484
	Low Lime	811	443	287	212	1752
	High Lime	648	429	351	223	1651
LSD(0.05) BETWEEN:						
-Species means		335	49	141	87	600
-Lime rate means		ns	ns	ns	ns	ns
-Lime means for same sp.		ns	ns	ns	77	ns
-Species means for same or different lime rates		ns	ns	ns	107	ns

Table II.2. Wood yields of tree hedgerows during the 1985/86 season.

Tree Species		Sep'85	Nov'85	Feb'86	Apr'86	Total: 4 Prunings	Fuel[1] Wood
		----- Tree Pruning Date -----					
		kg ha^{-1}					
Paraseri- anthes *	No lime	2344	443	456	95	3338	2800
	Low lime	3365	389	319	106	4179	3684
	High lime	2347	418	447	102	3314	2794
Calliandra *	No lime	588	419	498	156	1661	1086
	Low lime	631	427	477	156	1690	1107
	High lime	269	326	406	139	1140	675
Gliricidia *	No lime	68	31	25	7	131	93
	low lime	201	122	73	23	418	273
	High lime	272	179	133	39	623	405
SPECIES MEANS:							
Paraserianthes		2685	416	408	101	3610	3093
Calliandra		496	391	460	150	1497	956
Gliricidia		180	111	77	23	390	257
LIME RATE MEANS:							
No Lime		1000	297	326	86	1710	1326
Low Lime		1399	312	289	95	2095	1688
High Lime		962	308	329	93	1692	1291
LSD(0.05) BETWEEN:							
-Species means		969	120	139	30	1092	1069
-Lime rate means		ns	ns	ns	ns	ns	ns
-Lime means for same sp.		ns	ns	ns	ns	ns	ns
-Species means for same or different lime rates		ns	ns	ns	ns	ns	ns

Table II.3. Leaf yields of tree hedgerows during the 1986/87 season.

Tree Species		Sept.'86	Nov.'86	Feb.'87	Mar.'87	Total: 4 Prunings
		-------- Tree Pruning Date --------				
		kg ha^{-1}				
Paraseri-anthes *	No lime	1024	208	327	197	1756
	Low lime	1060	209	254	186	1709
	High lime	997	235	293	184	1709
Calliandra *	No lime	1128	423	742	363	2656
	Low lime	1447	608	963	458	3475
	High lime	1168	621	1140	516	3444
Gliricidia *	No lime	60	24	20	12	124
	low lime	73	119	61	54	307
	High lime	168	223	161	143	696
SPECIES MEANS:						
Paraserianthes		1027	217	292	189	1725
Calliandra		1248	550	948	446	3192
Gliricidia		101	122	81	70	379
LIME RATE MEANS:						
No Lime		738	218	394	191	1639
Low Lime		860	312	426	232	1830
High Lime		778	360	531	281	1950
LSD(0.05) BETWEEN:						
-Species means		271	124	249	95	628
-Lime rate means		ns	87	ns	59	ns
-Lime means for same sp.		ns	152	292	102	736
-Species means for same or different lime rates		ns	174	344	126	863

Table II.4. Wood yields of tree hedgerows during the 1986/87 season.

Tree Species		Sep'86	Nov'86	Feb'87	Mar'87	Total: 4 Prunings	Fuel[1] Wood
		----- Tree Pruning Date -----					
		kg ha^{-1}					
Paraseri- anthes *	No lime	2765	38	547	81	3431	3312
	Low lime	2784	46	463	70	3363	3247
	High lime	2492	51	513	74	3130	3006
Calliandra *	No lime	2530	158	805	170	3663	3335
	Low lime	2948	212	930	212	4302	3878
	High lime	2441	186	1023	209	3858	3463
Gliricidia *	No lime	29	9	14	3	57	48
	low lime	82	24	47	16	169	129
	High lime	289	59	159	45	552	448
SPECIES MEANS:							
Paraserianthes		2680	45	508	75	3308	3188
Calliandra		2640	185	919	197	3941	3559
Gliricidia		133	31	79	21	264	212
LIME RATE MEANS:							
No Lime		1774	69	495	85	2595	2430
Low Lime		1938	94	480	99	2611	2418
High Lime		1741	99	565	109	2514	2306
LSD(0.05) BETWEEN:							
-Species means		928	45	273	60	1155	1075
-Lime rate means		ns	ns	ns	ns	ns	ns
-Lime means for same sp.		ns	ns	ns	ns	ns	ns
-Species means for same or different lime rates		ns	ns	ns	ns	ns	ns

Table II.5. Leaf yields of tree hedgerows during the 1987/88 season.

Tree Species		Oct.'87	Dec.'87	Feb.'88	May'88	Total: 4 Prunings
		Tree Pruning Date				
		kg ha^{-1}				
Paraseri- anthes *	No lime	2370	479	936	346	4131
	Low lime	2304	482	770	115	3671
	High lime	2595	412	946	323	4276
Calliandra *	No lime	1476	748	1772	570	4566
	Low lime	1992	839	1916	624	5371
	High lime	2047	763	1534	972	5316
Gliricidia *	No lime	16	11	44	40	112
	low lime	180	77	161	13	432
	High lime	463	401	888	119	1871
SPECIES MEANS:						
Paraserianthes		2423	458	884	261	4026
Calliandra		1838	783	1741	722	5084
Gliricidia		220	163	365	57	805
LIME RATE MEANS:						
No Lime		1287	413	917	318	2936
Low Lime		1492	466	949	251	3158
High Lime		1702	525	1123	471	3821
LSD(0.05) BETWEEN:						
-Species means		490	118	327	166	780
-Lime rate means		ns	ns	ns	114	ns
-Lime means for same sp.		ns	ns	617	197	1270
-Species means for same or different lime rates		ns	ns	599	231	1295

Table II.6. Wood yields of tree hedgerows during the 1987/88 season.

Tree Species		Oct.'87[1]	Dec.'87	Feb.'88	May'88	Total: 4 Prunings
		kg ha^{-1}				
Paraseri- anthes	* No lime	4767	663	243	229	5903
	Low lime	4390	733	203	84	5410
	High lime	4602	622	274	217	5714
Calliandra	* No lime	2895	1013	472	467	4848
	Low lime	3716	1073	554	444	5787
	High lime	3939	1277	495	601	6312
Gliricidia	* No lime	17	10	7	4	38
	low lime	100	89	39	8	236
	High lime	720	474	208	93	1495
SPECIES MEANS:						
Paraserianthes		4586	673	240	177	5676
Calliandra		3517	1121	507	504	5649
Gliricidia		279	191	85	35	590
LIME RATE MEANS:						
No Lime		2560	562	241	234	3596
Low Lime		2735	632	265	179	3811
High Lime		3087	791	326	304	4507
LSD(0.05) BETWEEN:						
-Species means		1429	211	79	134	1647
-Lime rate means		ns	178	ns	ns	ns
-Lime means for same sp.		ns	309	ns	180	ns
-Species means for same or different lime rates		ns	328	ns	198	ns

1 Fuel wood was removed from the plots only at the October harvest, since the usual pruning schedule was delayed and the three subsequent prunings had to be applied as mulch.

APPENDIX III

III.A CROP YIELDS

Table III.A.1. Rice and cowpea yields during the 1985/86 season.

TREATMENT		-- Upland Rice -- Grain	Straw	---- Cowpea ---- Grain	Straw
		kg / ha			
No Tree *	No lime	464	1558	121	155
	Low lime	2113	4131	478	521
	High lime	2349	3865	536	798
Paraseri -anthes *	No lime	939	2875	427	435
	Low lime	1219	3622	849	989
	High lime	1804	3557	921	940
Calliandra *	No lime	883	2305	213	225
	Low lime	1511	3557	510	519
	High lime	1901	3371	652	770
Gliricidia *	No lime	562	2668	138	173
	Low lime	1938	3919	459	539
	High lime	2013	3633	556	790
SPECIES MEANS:					
No Tree		1642	3185	209	491
Paraserianthes		1321	3351	732	788
Calliandra		1432	3077	458	505
Gliricidia		1504	3406	384	501
LIME RATE MEANS:					
No Lime		712	2351	225	247
Low Lime		1695	3807	574	642
High LIme		2017	3606	666	825
LSD(0.05) BETWEEN:					
-Species means		ns	ns	208	224
-Lime rate means		288	627	143	124
-Lime means for same sp.		575	1253	287	248
-Species means for same or different lime rates		774	1204	313	301

Table III.A.2. Rice and cowpea yields during the 1986/87 season.

TREATMENT		Upland Rice Grain	Upland Rice Straw	Cowpea Grain	Cowpea Straw
		kg / ha			
No Tree *	No lime	631	1425	50	100
	Low lime	1236	2315	172	378
	High lime	1224	2857	166	510
Paraseri -anthes *	No lime	1254	2982	266	458
	Low lime	1619	3515	490	748
	High lime	1162	2709	490	688
Calliandra *	No lime	908	2181	168	346
	Low lime	797	2083	324	294
	High lime	961	2268	289	479
Gliricidia *	No lime	777	2047	47	94
	Low lime	1338	2439	188	332
	High lime	1306	2421	265	415
SPECIES MEANS:					
	No Tree	1031	2199	129	329
	Paraserianthes	1345	3069	429	647
	Calliandra	889	2177	260	373
	Gliricidia	1140	2302	167	280
LIME RATE MEANS:					
	No Lime	893	2159	123	235
	Low Lime	1247	2588	294	438
	High Lime	1163	2563	302	523
LSD(0.05) BETWEEN:					
-Species means		ns	ns	217	231
-Lime rate means		197	332	103	132
-Lime means for same sp.		394	664	206	264
-Species means for same or different lime rates		466	894	274	316

Table III.A.3. Rice and cowpea yields during the 1987/88 season.

TREATMENT		Upland Rice Grain	Upland Rice Straw	Cowpea Grain	Cowpea Straw
		kg / ha			
No Tree *	No lime	14	99	0	0
	Low lime	136	1190	32	148
	High lime	341	1888	45	225
Paraseri -anthes *	No lime	308	1995	98	157
	Low lime	555	2875	309	356
	High lime	368	1970	252	399
Calliandra *	No lime	228	1307	31	90
	Low lime	181	1147	69	115
	High lime	324	1848	96	194
Gliricidia *	No lime	29	233	8	45
	Low lime	124	966	22	117
	High lime	361	2086	118	236
SPECIES MEANS:					
No Tree		164	1059	25	124
Paraserianthes		410	2280	220	304
Calliandra		245	1434	65	133
Gliricidia		171	1095	49	132
LIME RATE MEANS:					
No Lime		145	909	34	73
Low Lime		249	1544	108	184
High LIme		349	1948	128	263
LSD(0.05) BETWEEN:					
-Species means		121	831	77	77
-Lime rate means		101	500	38	65
-Lime means for same sp.		203	1000	76	130
-Species means for same or different lime rates		205	1163	99	131

III.B SOIL ANALYSES

Table III.B.1 Soil analysis (0 - 15 cm depth) of samples taken on 10 September 1985. (Sampled before first GLM application.)

TREATMENT		Al+H[a]	Ca[a]	Mg[a]	K[b]	ECEC	Acid Sat.	P[b]
		------	(cmol$_c$ / liter)			------	(%)	(mg kg^{-1})
No Tree *	No lime	2.16	0.38	0.05	0.06	2.64	82	8.8
	Low lime	1.95	0.79	0.14	0.07	2.94	66	8.0
	High lime	1.34	1.97	0.07	0.06	3.40	40	7.8
Paraseri -anthes *	No lime	2.15	0.38	0.06	0.08	2.66	82	9.0
	Low lime	1.75	0.93	0.16	0.09	2.92	63	10.0
	High lime	0.99	2.12	0.05	0.10	3.26	32	8.3
Calliandra *	No lime	2.30	0.38	0.08	0.14	2.91	79	8.5
	Low lime	1.94	0.61	0.09	0.11	2.74	71	6.5
	High lime	1.07	2.44	0.06	0.16	3.73	29	8.8
Gliricidia *	No lime	2.23	0.38	0.05	0.08	2.73	82	7.5
	low lime	1.93	0.70	0.05	0.06	2.73	71	10.8
	High lime	1.08	2.26	0.09	0.06	3.49	31	8.0
SPECIES MEANS:								
No Tree		1.82	1.03	0.09	0.06	2.99	63	8.2
Paraserianthes		1.63	1.14	0.09	0.09	2.95	59	9.1
Calliandra		1.77	1.14	0.08	0.14	3.12	59	7.9
Gliricidia		1.75	1.11	0.06	0.07	2.98	61	8.8
LIME RATE MEANS:								
No Lime		2.21	0.38	0.06	0.09	2.73	81	8.4
Low Lime		1.89	0.75	0.11	0.08	2.83	68	8.8
High Lime		1.12	2.19	0.07	0.09	3.47	33	8.1
LSD(0.05) BETWEEN:								
-Species means		ns	ns	ns	0.05	ns	ns	ns
-Lime rate means		0.02	0.23	ns	ns	0.24	7	ns
-Lime means for same sp.		0.44	0.47	ns	ns	0.48	15	ns
-Species means for same or different lime rates		0.45	0.50	ns	ns	0.47	15	ns

[a] Extracted with 1 N KCl.
[b] Extracted with Mehlich I (double acid) extractant.

Table III.B.2. Analysis of variance for soil analysis of samples taken on 10 September 1985.

TREATMENT Source	df	Al+H	Ca	Mg	K	ECEC	Acid Sat.	P
		-------------------			P values		------------------	
Rep	3	0.015	0.039	0.075	0.328	0.104	0.035	0.257
Tree Spp.	(3)	0.468	0.859	0.817	0.043	0.485	0.784	0.734
Tree vs No Tree	1	0.325	0.429	0.697	0.095	0.806	0.439	0.666
GLI. vs Others	1	0.645	0.804	0.446	0.049	0.624	0.549	0.806
PAR. vs CAL.	1	0.258	1.000	0.723	0.087	0.161	0.855	0.334
Error A	9							
Lime Rates	(2)	0.000	0.000	0.217	0.772	0.000	0.000	0.768
Lime vs No lime	1	0.000	0.000	0.231	0.811	0.000	0.000	0.934
Low vs High lime	1	0.000	0.000	0.199	0.502	0.000	0.000	0.475
Lime * Tree Spp.	6	0.876	0.398	0.613	0.964	0.510	0.709	0.352
Error B	24							
Total	47							

Table III.B.3 Soil analysis (0 - 15 cm depth) of samples taken on 12 April 1986. (Sampled during cowpea crop.)

TREATMENT		$Al+H^a$	Ca^a	Mg^a	K^b	ECEC	Acid Sat.	P^b
		------	($cmol_c$ / liter)			------	(%)	(mg kg^{-1})
No Tree *	No lime	1.87	0.24	0.07	0.19	2.37	79	7.5
	Low lime	1.45	0.83	0.16	0.22	2.66	54	5.5
	High lime	0.69	1.89	0.12	0.22	2.92	25	6.0
Paraseri -anthes *	No lime	1.75	0.27	0.10	0.23	2.35	76	4.8
	Low lime	1.11	1.27	0.26	0.24	2.87	40	4.5
	High lime	0.54	1.61	0.13	0.25	2.53	22	5.8
Calliandra *	No lime	1.66	0.29	0.11	0.22	2.28	72	5.3
	Low lime	1.29	0.78	0.15	0.18	2.40	54	7.0
	High lime	0.87	1.58	0.13	0.18	2.76	32	7.0
Gliricidia *	No lime	1.41	0.58	0.10	0.21	2.30	63	6.8
	low lime	1.39	0.64	0.10	0.18	2.30	61	6.8
	High lime	0.94	1.41	0.11	0.21	2.66	36	4.5
SPECIES MEANS:								
No Tree		1.34	0.99	0.12	0.21	2.65	53	6.3
Paraserianthes		1.13	1.05	0.17	0.24	2.58	46	5.0
Calliandra		1.27	0.88	0.13	0.19	2.48	53	6.4
Gliricidia		1.25	0.87	0.10	0.20	2.42	53	6.0
LIME RATE MEANS:								
No Lime		1.67	0.34	0.10	0.21	2.32	73	6.0
Low Lime		1.31	0.89	0.17	0.21	2.56	52	5.9
High Lime		0.76	1.62	0.12	0.21	2.71	28	5.8
LSD(0.05) BETWEEN:								
-Species means		ns	ns	0.03	ns	ns	ns	ns
-Lime rate means		0.21	0.25	0.04	ns	0.16	9	ns
-Lime means for same sp.		0.43	0.51	0.08	ns	0.32	17	ns
-Species means for same or different lime rates		0.40	0.48	0.08	ns	0.39	16	ns

[a] Extracted with 1 N KCl.
[b] Extracted with Mehlich I (double acid) extractant.

Table III.B.4. Analysis of variance for soil analysis of samples taken on 12 April 1986.

TREATMENT Source	df	Al+H	Ca	Mg	K	ECEC	Acid Sat.	P
		P values						
Rep	3	0.136	0.050	0.021	0.077	0.014	0.051	0.389
Tree Spp.	(3)	0.201	0.378	0.009	0.230	0.320	0.093	0.642
Tree vs No Tree	1	0.130	0.569	0.184	0.988	0.162	0.385	0.605
GLI. vs Others	1	0.592	0.361	0.006	0.327	0.327	0.149	0.787
PAR. vs CAL.	1	0.141	0.172	0.027	0.073	0.433	0.045	0.271
Error A	9							
Lime Rates	(2)	0.000	0.000	0.007	0.877	0.000	0.000	0.946
Lime vs No lime	1	0.000	0.000	0.231	0.967	0.000	0.000	0.741
Low vs High lime	1	0.312	0.338	0.003	0.614	0.563	0.626	1.000
Lime * Tree Spp.	6	0.172	0.112	0.138	0.566	0.041	0.128	0.321
Error B	24							
Total	47							

Table III.B.5 Soil analysis (0 - 15 cm depth) of samples taken on 28 February 1987. (Sampled during cowpea crop.)

TREATMENT		$Al+H^{a}$	Ca^{a}	Mg^{a}	K^{b}	ECEC	Acid Sat.	P^{b}
		------	($cmol_c$ / liter)			------	(%)	(mg kg^{-1})
No Tree *	No lime	2.24	0.23	0.07	0.15	2.70	83	4.6
	Low lime	2.15	0.53	0.10	0.17	2.98	72	5.5
	High lime	1.12	1.17	0.08	0.15	2.53	44	4.6
Paraseri -anthes *	No lime	2.18	0.32	0.09	0.15	2.75	80	4.4
	Low lime	2.08	0.67	0.21	0.19	3.16	66	6.2
	High lime	1.07	1.16	0.12	0.16	2.52	43	4.1
Calliandra *	No lime	2.11	0.30	0.10	0.19	2.72	77	4.8
	Low lime	1.82	0.61	0.13	0.15	2.72	67	4.9
	High lime	1.19	1.35	0.11	0.18	2.84	42	5.2
Gliricidia *	No lime	2.12	0.30	0.07	0.15	2.64	80	4.5
	low lime	1.84	0.56	0.07	0.14	2.62	70	4.1
	High lime	1.15	1.01	0.09	0.15	2.40	48	4.1
SPECIES MEANS:								
No Tree		1.81	0.65	0.08	0.15	2.71	66	4.8
Paraserianthes		1.77	0.72	0.14	0.17	2.81	63	4.9
Calliandra		1.71	0.76	0.11	0.17	2.76	62	5.0
Gliricidia		1.70	0.62	0.07	0.15	2.55	66	4.3
LIME RATE MEANS:								
No Lime		2.16	0.29	0.08	0.16	2.70	80	4.6
Low Lime		1.96	0.60	0.13	0.16	2.86	69	5.2
High LIme		1.13	1.17	0.10	0.16	2.57	46	4.5
LSD(0.05) BETWEEN:								
-Species means		ns	ns	ns	ns	ns	ns	ns
-Lime rate means		0.18	0.14	0.033	ns	0.18	4	ns
-Lime means for same sp.		0.36	0.28	0.067	0.04	0.36	8	1.3
-Species means for same or different lime rates		0.34	0.32	0.078	ns	0.38	10	ns

[a] Extracted with 1 N KCl.
[b] Extracted with Mehlich I (double acid) extractant.

Table III.B.6. Analysis of variance for soil analysis of samples taken on 28 February 1987.

TREATMENT		Al+H	Ca	Mg	K	ECEC	Acid Sat.	P
Source	df	-------------------			P values			------------------
Rep	3	0.043	0.669	0.793	0.546	0.232	0.444	0.243
Tree Spp.	(3)	0.344	0.485	0.078	0.625	0.183	0.433	0.730
Tree vs No Tree	1	0.146	0.427	0.224	0.889	0.961	0.289	0.876
GLI. vs Others	1	0.552	0.213	0.030	0.221	0.039	0.222	0.286
PAR. vs CAL.	1	0.375	0.696	0.301	0.779	0.682	0.845	0.920
Error A	9							
Lime Rates	(2)	0.000	0.000	0.045	0.722	0.017	0.000	0.152
Lime vs No lime	1	0.000	0.000	0.038	0.802	0.889	0.000	0.418
Low vs High lime	1	0.000	0.000	0.128	0.443	0.005	0.000	0.074
Lime * Tree Spp.	6	0.730	0.601	0.153	0.101	0.124	0.897	0.151
Error B	24							
Total	47							

APPENDIX IV

Table IV.A. Crop Yields

(1) Upland Rice Yields:

Season	Control	Alley	Lime	Alley + Lime
	kg ha^{-1}			
1985	0	0	0	0
1985/86	464	939	2113	1219
1986/87	631	1254	1236	1619
1987/88	14	308	136	555
Mean of 85/86 & 86/87 Seasons	548*	1097	1675*	1419

(2) Cowpea Yields:

Season	Control	Alley	Lime	Alley + Lime
	kg ha^{-1}			
1985	0	0	0	0
1985/86	121	427	478	849
1986/87	49	266	172	490
1987/88	0	98	32	309
Mean of 85/86 & 86/87 Seasons	85*	347	325*	670

* Best estimates of average yields (ie. excluding the 1987/88 season which was planted late and grew under unusual drought and pest conditions).

(3) Fuelwood Yields:

Season	----- Pruning Times ----- September	February	Total
1985/86	2685	408	3093
1986/87	2680	508	3188
1987/88*	4586	240	--
Mean of 85/86 & 86/87 Seasons	2682	458	3141

* Due to a different pruning schedule, wood yields from the 1987/88 season were not included in the mean yields.

(4) Relative grain yields of treatments as percentages of the low lime treatment (750 kg ha^{-1})

Crop	Season	Alley	Alley+Lime
		------------- (%)	------------
Rice	1985/86	44	58
	1986/87	101	131
	1987/88*	227	408
Cowpea	1985/86	89	178
	1986/87	155	285
	1987/88*	306	966

* Drought and late planting caused extremely low yields that are probably unrepresentative of normal conditions.

(5) Estimated Alley Cropping Yields (as % of Lime treatment)

Year	Crop	Alley (% of Lime)	Alley+Lime (% of Lime)
		------------ (Kg ha^{-1})	------------
Year 1*	Cowpea	85	325
	Rice	737 (44)	972 (53)
Year 2	Cowpea	289 (89)	579 (178)
	Rice	1692 (101)	2194 (131)
Year 3-5	Cowpea	504 (155)	926 (285)
	Rice	1692 (101)	2194 (131)

* Trees hedges would be planted just prior to planting the cowpea crop. Therefore, cowpea yields are unaffected by the hedges. The hedge pruning would start with the rice crop in year 1.

(6) Fertilizer and Lime Use per Year

	Control	Alley	Lime	Alley+Lime
	----------------	---------- (kg ha^{-1})	----------	----------------
Lime	0	0	250	250
TSP	100	100	100	100
KCL	100	100	100	100

Note: Only the lime needs to be considered in total costs that vary between treatments. (All treatments also received initial applications of 200 kg TSP ha^{-1} at the beginning of the experiment.)

Table IV.B. Elements of the Partial Budget

(1) Field Price of Upland Rice:

a) Harvest costs:
8 days ha^{-1} => 750 kg rice
Women cut with "ani-ani" (hand knife), @ Rp 1500/day
Rp 12000 / 750 kg = Rp 16 kg^{-1} rice

b) Processing costs:

2 days to pack and carry home -->	2 x Rp 2000	=	Rp 4000
1 day drying -->	1 x Rp 1500	=	Rp 1500
5 days threshing and winnowing -->	5 x Rp 1500	=	Rp 7500
			Rp 13000

Rp 13000 / 750 kg = Rp 17 kg^{-1} rice

c) Transport to Market:
(assuming Rp 200 to transport a 30 kg sack to market)
Rp 200 / 30 kg = Rp 7 kg^{-1} rice

d) Market Price: Rp 125 kg^{-1} rice

Total Harvest Related Costs = Rp 16 + Rp 17 + Rp 7 = Rp 40

Field Price = Rp 125 - Rp 40 = Rp 85 kg / rice

(2) Field Price of Cowpea:

a) Harvest Costs:
8 days ha^{-1} --> 500 kg Cowpea harvested @ Rp 1500/day
Rp 12000 / 500 kg = Rp 24 kg^{-1} cowpea

b) Processing Costs:

1.5 days to pack and carry home	-->	1.5 x Rp 2000	=	Rp 3000
1 days drying	-->	2 x Rp 1500	=	Rp 1500
3 days threshing and winnowing	-->	3 x Rp 1500	=	Rp 4500
				Rp 13000

Rp 9000 / 500 kg = Rp 18 kg^{-1} cowpea

c) Transport and Marketing: (same as for rice)
Rp 7 kg^{-1} cowpea

d) Market Price: Rp 150 kg^{-1} cowpea

Total Harvest Related Costs = Rp 24 + Rp 18 + Rp 7 = Rp 49 kg^{-1}

Field Price = Rp 150 - Rp 49 = Rp 101 / kg cowpea

(3) Gross Benefits for Wood:

- 1st wood collection (September) --> 2600 kg ha^{-1}
- 2nd wood collection (January) --> 500 kg ha^{-1}

Value of Wood for the Year = <u>Rp 15500 / ha</u>
(assuming 3100 kg ha^{-1} produced at a value of @ Rp 5 kg^{-1})

(4) Liming Costs:

a) Market Price = <u>Rp 60 / kg</u> (delivered to farmer's village)
(Note: Cost in Indonesia may be free from government to over Rp 200 kg^{-1})

b) Transport Cost = Rp 5 kg^{-1}
(from village to field, assuming 1 day to carry 8 x 50 kg sacks @ Rp 2000/day)
c) Application = Rp 5 kg^{-1}
(assuming 1 day to apply 400 kg lime @ Rp 2000/day)
Total Labor Cost = <u>Rp 10 / kg lime</u>

Annual application of 250 kg ha^{-1} = <u>Rp 17500 / ha</u>

Note: Incorporation of lime is not included as a cost that varies between treatments, since it is assumed that soil tillage and incorporation of fertilizer would be done in all treatments.

(5) Tree Hedge Related Costs:

a) Alley Crop Tree Establishment Costs:
- Paraserianthes seed = <u>Rp 6250 / ha</u>
(assuming 4m alleys, 2500m hedge ha^{-1}, 40,000 seeds kg^{-1}, Rp 2500 kg^{-1} seed, 100,000 seed planted ha^{-1})
- Paraserianthes planting labor cost = <u>Rp 6000 / ha</u>
(assuming 2 days labor at Rp 2000/day)
Total Seed Cost = <u>Rp 12250 / ha</u>

b) Tree Pruning Costs:
- 1st pruning (September) = Rp 12000 ha^{-1}
(assuming 4 days for cutting and spreading and 2 days for removing wood @ Rp 2000/day)
- 2nd pruning (November) = Rp 4000 ha^{-1}
(assuming 4 days for cutting and spreading @ Rp 2000/day)
- 3rd pruning (January) = Rp 6000 ha^{-1}
(assuming 2 days for cutting and spreading and 1 day for removing wood @ Rp 2000/day)
- 4th pruning (March) = Rp 4000 ha^{-1}
(assuming 2 days for cutting and spreading @ Rp 2000/day)
Total Pruning Cost = <u>Rp 26000 / ha</u>

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