ALLEY CROPPING OF MAIZE WITH NINE LEGUMINOUS TREES

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ABSTRACT

A maize-leguminous tree alley cropping system was studied on a N-deficient Vertic Haplustoll in Hawaii. Nine tree species were evaluated for green manure (GM) and intercropped maize yields. They included: *Calliandra calothyrsus*, *Cajanus cajan*, *Cassia siamea*, *Gliricidia sepium*, KX1--*Leucaena* hybrid (*L. pallida* X *L. diversifolia*), *L. leucocephala*, *L. pallida*, *L. salvadorensis*, and *Sesbania sesban*. *S. sesban*, *G. sepium*, *L. pallida*, and KX1 showed high potential for use as a hedge, producing between 5 and 12 dry t/ha GM with N yields between 140 and 275 kg N/ha in 4 prunings.

Maize yields responded linearly to nitrogen applied as green manure. Maize yield increased 12 kg for each kg of nitrogen applied. Addition of prunings from hedge rows was able to support maize grain yield at about 1800 kg/ha for two consecutive cropping seasons, while control plot yields averaged less than 600 kg/ha. *S. sesban* hedges produced the most GM and yielded the highest maize yields. Maize yields reflected the amount of N applied as GM, regardless of tree species from which the N was derived.

Green manure at five rates (0, 0.5x, 1x, 1x + 60 N from urea and 2x the amount produced by the hedge) were applied in the *G. sepium* and *L. pallida* plots. The full green manure

plus urea treatment was the most efficient in increasing yields. These plots produced significantly more maize, with less total N applied, than the double G. sepium and L. pallida treatments.

Significant reductions in maize yields were seen in maize rows near the hedge relative to those in the middle of the alley. Increasing the distance away from the hedge and coppicing the hedge earlier in maize growth significantly improved maize yields in the maize row closest to the trees.

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CHAPTER 1

INTRODUCTION AND OBJECTIVES

Rising demands of world population, now over 5 billion people, are destroying basic natural resources on which all life depends. Every year another Mexico is born into the world--about 80 million people (IEPD, 1987). Tropical forests are shrinking at a rate of 27 million acres a year; in Central America the area of forests and woodlands declined 38%, and in Africa by 23% between 1950 and 1983 (FAO, 1983). In 1982 it was estimated that 1.15 billion hectares of closed canopy forest still existed in the tropics; by 2010 approximately 1/2 of the present tropical forest will be lost (Brewbaker, 1987a).

A major cause of the loss of forestlands has been the conversion of forests to agricultural land. Since 1976, 6 to 8 million hectares of open forests and woodlands have been cleared each year for agriculture (FAO, 1982). Land scarcity has forced farmers to intensify their cropping systems and reduce bush fallow periods. These practices have led to decreasing soil fertility, since most farmers cannot afford adequate quantities of inorganic fertilizer.

Alley cropping has recently generated much interest in restoring soil fertility and in providing significant amounts of fuelwood to the subsistence farmer. Alley cropping refers to the planting of arable crops in the spaces between rows of trees or woody shrubs. These trees are pruned to minimize resource competition and maximize nutrient availability to the crop (Nair, 1984). Green manure (GM), leaves and green stems, supply nitrogen and other nutrients to the crop. Nitrogen fixing trees (NFTs) provide added advantages to resource poor farmers because they can fix atmospheric nitrogen which can become available to the crop, and thereby reduce dependence on expensive chemical N fertilizers. Nitrogen fixation is very important in ameliorating soil conditions for subsistence farmers. Trees may also recycle nutrients from the lower horizons of the soil and make them available for crop use. Coppiced stems and branches could provide a significant amount of fuelwood to the subsistence farmer. Substantial wood yields have been reported in Hawaii (Guevarra, 1976, Evensen, 1984), Africa (Budleman, 1986; Yamoah et al., 1986a), and Colombia (Rachie, 1983).

The objective of this study is to evaluate a number of different nitrogen fixing trees for alley cropping, and to determine the correlation between green manure applied and maize yield.

Specific objectives include:

- Evaluate the relationship between GM for several NFT species, fertilizer and maize yield.
- Evaluate competition effects in an alley cropping system.

CHAPTER 2

LITERATURE REVIEW

2.1 POTENTIAL OF ALLEY CROPPING

An important aspect of alley cropping is its ability to provide nutrients, especially nitrogen, to the crop. Leaves applied directly to the soil have increased yields markedly in a number of crops. Guevarra (1976) noted a 23% increase in maize yields over a control when *Leucaena leucocephala* GM was incorporated into the soil; Alferez (1980) reported a 56% increase in rice yields after incorporation. Experiments in Sri Lanka also indicated significant rice yield increases using *Gliricidia sepium* mulch (Amarasiri, 1978). In Hyderabad, India, mulched Leucaena loppings improved sorghum yields by 25% (Singh and Singh, 1987). Alley cropping has the added advantage of producing usable material in times of drought. For example, in 1984, Anantapur, India experienced a severe drought; all of the local staples, groundnut, pigeon pea, and sorghum, failed, but the leucaena hedgerow still managed to produce 2 t/ha of dry leaf material (Singh and Singh, 1987).

Although the advantages of alley cropping have been demonstrated on high fertility soils on research farms, villagers have been cautious in adopting this new technology onto their fields. Two villages in Southern Nigeria were introduced to a gliricidia alley cropping system with mixed success (Yamoah et al., 1986c). Farmers were concerned that gliricidia would shade the food crops, and no farmer agreed to maintain a tree population of 5,000 per hectare (4 m x 0.5 m). The farmers complained that the fast growth rate, which requires regular pruning, increased labor costs. One farmer remarked, "I do not want my farm to turn to a forest if I should fall sick," (Yamoah and Ay, 1986c). Only 25% of the farmers interviewed recognized gliricidia's soil improving qualities. Many questioned gliricidia's ability to supply N to the maize crop. Indeed, in southwest Nigeria gliricidia is called "agun mo niye" meaning "Grow tall for nothing" (NFTA, 1989). Agboola (1974) advanced 3 reasons why green manuring has not been readily adopted: 1. Many governments have initiated fertilizer subsidy policies, supplying fertilizers below cost, which promotes fertilizer use over green manure crops. 2. The costs of green manure seed and time consuming land preparation discourages farmers from planting green manure crops, especially on large areas. 3. Incorporating between 10-14 t/ha wet biomass into the soil is difficult, given animal draft power and traditional implements.

Pandey et al. (1983) suggest that in areas with strong infrastructural support, green manuring may not be adopted. Green manuring must fit into the farmer's traditional cropping system and the tasks must be agronomically manageable, not putting too much of a burden on the farmer. Thus, they conclude green manuring will most likely be successful in remote, resource-poor areas with highly self-sufficient farming systems.

2.2 CONTRIBUTION OF GM

Quantifying the GM contribution to crop yields has proven difficult. This difficulty arises from the fact that N bound in soil organic matter (SOM) mineralizes very slowly, usually over more than 1 cropping season (Rao, 1983; IITA, 1986), and that GM's contribution to soil organic matter varies considerably with different legumes and cropping systems (Yamoah et al., 1986a).

Plant products produced but not removed from the field accumulate in the soil. Soil microflora break these materials down, releasing nutrients, especially nitrogen (N), which can be used for future crop growth. Soil microbes assimilate N contained in residues for a period of days, weeks, or even years (Power and Legg, 1978). Nitrogen in SOM may be compartmentalized into many fractions (Jenkinson et al., 1987; Parton et al., 1987; van Veen et al., 1984). These fractions are split into pools based on their resistance to further degradation. For example, Parton (1987) divided SOM into 3 pools: an active pool, a slow pool, and a passive pool. The active pool consists of live microbes and microbial products with turnover times from 1 to 5 years. The slow pool represents organic matter that is either chemically resistant or physically protected against decomposition; turnover times range from 20 to 40 years. The passive pool contains highly lignified, recalcitrant organic matter with turnover times between 200 and 1500 years. Movements among these pools control the rates of production and decomposition over time. Thus, a substantial amount of N in SOM may be stored in the soil biomass (Ladd 1981), or may be lost via volatilization, leaching and denitrification.

Application of GM to the soil increases SOM which may improve soil structure. Green manure from gliricidia, flemingia, and cassia increased the soil's mean aggregate diameter and water holding capacity, and decreased its bulk density, on an Alfisol in Nigeria (Yamoah et al., 1986d). These improvements were attributed to the increased supply of organic matter from the prunings. These observations substantiated reports by Wilson et al. (1986) who noted an appreciable increase in the soil's water holding capacity after leuceana prunings were applied to the soil. In coarse textured soil, organic matter binds sand particles together increasing water retaining power. In clay soils, it loosely joins fine particles, creating air spaces which increase the porosity and friability of the soil (Agboola, 1974).

Two important factors regulating the rate of residue decomposition are precipitation and temperature. Decomposition of residues into mineral nutrients occur the fastest at moisture levels between 60 and 100% of field capacity, while flooded or dry soils inhibit decomposition (Power and Legg, 1978). Between the range of 5 to 40 C, mineralization and nitrification approximately double for every 10 degree C increase, with very little microbial activity occurring outside this temperature range (Stanford et al., 1973).

Decomposition rates among leguminous trees may differ substantially from one another. Mulched leaves and green stems decomposed at a rate of 5.8% dry matter loss per week for *Gliricidia sepium*, but at a rate of only 2.7% loss per week for *Cassia siamea* (Yamoah et al., 1986a). Because *Cassia siamea* decomposes slowly, it increased soil moisture content, reduced soil temperature and controlled weeds better than *Gliricidia sepium* (Yamoah et al., 1986b). In *Leucaena leucocephala* alley cropping, Wilson et al. (1986) also noted improved soil conditions with earthworm activity markedly increased in shaded plots compared to unshaded plots. Mulching also produced a better environment for the crop. In Nigeria, high soil temperatures inhibit maize germination and delay growth of the plant; mulching hastened germination and improved early growth of maize (IITA, 1984).

2.3 TREE COMPETITION IN ALLEY CROPPING

To maximize crop production a hedge management program must be established to decrease light, nutrient, and water competition and maximize green leaf manure applied to the crop. Until recently researchers have paid little attention to tree-crop competition suggesting that trees exploit different soil horizons than the crop and thereby minimize competition.

However, recent studies in Latin America and Africa indicate that trees may occupy similar horizons as crops. Jordan (1985) examined a number of tropical forest ecosystems in Central and South America and found that most of the roots were concentrated within the top 25 cm of soil. He attributed this high surface concentration to low nutrient availability in the lower horizons. Trees of the upper Rio Negro region of the Amazon Basin, for example, developed thick root mats on the soil surface as a response to low fertility in the lower horizons (Stark and Jordan 1978). Studies in Tanzania examined the vertical fine root distribution of 5 trees and compared them to that of mature maize (Jonsson et al., 1988). The report concluded that the trees and maize had similar patterns of root distribution, which were likely to cause significant competition for nutrients and water.

Trees and crops can exploit similar soil horizons which may lead to aggressive nutrient competition. Atta-Krah (1983) in Nigeria found significant competition for available nutrients and water between leucaena and a maize crop. When prunings were put on the surface of the soil as a mulch without tilling, leucaena grew vigorously and decreased the maize yield compared to a control. However, when the land was tilled before the prunings were applied on the surface, maize yield increased significantly. Tillage may have dislodged the leucaena roots and hence decreased competition for available nutrients.

Hedges can increase or decrease soil moisture content depending on the type of management used. Alley cropping experiments in Hyderabad, India demonstrated significant water competition between _L. leucocephala_ hedgerows and castor, cowpea, and sorghum (Singh et al., 1989). Soil moisture was significantly reduced at a 0.3 m distance from the hedge, causing crop yields to decreased approximately 30 % of the sole crop. Installing a polyethylene root barrier along the leucaena row eliminated reduction in crop yields in rows close to the hedge. Tree-crop root interactions are not static, however, and may vary with the season. Examining the distribution of functional roots of Arabica coffee in Kenya, Huxley et al. (1974) reported that moisture gradients modified nutrient uptake. At the beginning of the rainy season nutrient uptake occurred in the topsoil but shifted to the lower horizons as the season progressed and the drying of the surface layers increased.

Hedge prunings applied on the soil can increase soil moisture by decreasing evaporation from the soil surface. Wilson et al. (1986), and Budelman (1986) demonstrated that prunings applied as a mulch in a corn crop resulted in significantly better soil moisture retention than corn in bare soil.

Light competition is one of the most widely observed forms of competition in alley cropping. In an Alfisol in Nigeria corn yields increased dramatically with distance from the leucaena hedge. This was attributed to shading because there were adequate amounts of moisture in the soil and few leucaena roots were found 1 meter from the row (Kang et al., 1981a). Similarly, yield reductions were also noted for cowpea grown in 2 m alleys (IITA, 1983). Shading from leucaena hedges managed as live stakes for yams appreciably reduced yam yield in plots in Nigeria (Balasubramanian, 1983). Girdling the stems increased the yield significantly.

Studies on the effects of shade applied at different stages of maize development have indicated that timing of tree coppicing is important. Early et al. (1967) examined the effects of various levels of shade treatment at 3 periods of maize maturity on grain yield. He found that shading for 21 days during the reproductive phase dramatically decreased grain yields compared with shading for longer periods during vegetative and maturation phases. Plants grown under 60% shade cloth or greater during the reproductive phase had the same number of leaves as the control but developed only a limited number of kernels. This suggests that trees should be coppiced before the maize reaches the silking stage to reduce light competition.

2.4 MANAGEMENT OF ALLEY CROPPING SYSTEMS

Alley width and coppicing height are critical to the success of a hedge row intercropping, in view of all these competitive factors. Comparative advantages of narrow vs. wide alleys suggest that tree hedges planted 2 m apart compete directly with corn for available nutrients, water, and light (Escalada, 1980). Although wide alley widths had a marked positive influence on maize yield, they also yielded smaller tree biomass per unit area, because of the lower tree population (IITA, 1983). Trials in Hawaii also demonstrated a decrease in leucaena dry matter, per unit land area, with wider plant spacing (Guevarra, 1976). Stems planted in narrow alleys, however, developed long and lanky branches, which decreased herbage and forage quality. On a comparatively fertile soil in Colombia, Rachie (1983) reported that increasing leucaena population densities from 13,000 to 40,000 plants per hectare decreased maize yields by 35%. Plant populations between 10,000 and 20,000 proved most effective at supplying sufficient nutrients to the crop without competing with the maize.

Cutting height also directly affects the total production of green leaf biomass. There is a trade-off between lowering coppice height to reduce light competition and green leaf production; lower coppicing height decreases herbage output. In Kenya, Vonk (1983) determined that the average number of new branches on leucaena was determined by cutting height. The taller stumps produced more branches because they had a higher number of buds.

Timely application of GM depends on the nutrient needs of the maize crop at different stages of growth. Phosphorous uptake occurs throughout the season but is at a maximum during the first few weeks of growth and ceases after the early denting stage of grain development (Hanway, 1962a). Potassium accumulates in the plant at a faster rate than either N or P during the initial weeks of growth, with 90% taken up prior to silking.

2.5 MAIZE RESPONSE TO APPLIED NITROGEN

Maize grains contain substantially more nitrogen than any other soil derived nutrient (Table 2.1), which results in considerable outlays of money for its use (Olson and Sander, 1988). Because of its high demand for N, maize is a good indicator crop for N application. For example, studies in Oxisols and Ultisols demonstrated that maize yields leveled off between 5 and 6 t/ha with urea applications of 70 to 120 kg/ha (Fox et al., 1974; Grove, 1979). Under good management and fertile soils in Waimanalo, Hawaii, maize yield increased linearly up to 200 kg/ha of applied N (Fox, 1973). Such N levels are much above the means of subsistence farmers, who usually apply little or no inorganic fertilizer.

Table 2.1 Nutrients in above ground plant from a typical field in the Corn Belt (Barber and Olson, 1968).

Element	Grain	Stover
	----------kg/ha-------------	
N	129	62
P	31	8
K	39	157
Ca	2	39
Mg	11	33
S	12	9

Maize N uptake is sigmoidal with time and follows dry matter accumulation curves. Hanway (1962a) reported minimal N uptake during initial stages of plant growth, which increased with increasing growth, reaching a maximum between the onset of flowering and early grain formation, 50 to 60 days after planting. Over 50% of the leaf weight and 31% of the total season's uptake of N occurred during this 2 week period (Hanway, 1962b). Even after this period, maize needs a continuous supply of N, P, and K or the lower leaves will senesce early due to translocation of nutrients to grain.

To determine if maize plants are under nitrogen stress, the whole ear leaf of the uppermost ear at tasseling or silking should be analyzed for percent nitrogen. Nitrogen levels in the ear leaf are then compared with a critical concentration value. A critical value is that concentration below which yields decrease or deficiency symptoms appear (Jones and Eck, 1973). Critical N percentages in the ear leaf vary between 2.76 and 3.50, depending on the maize variety (Melsted et al., 1969; Jones and Eck, 1973). Tissue sampling provides a useful tool to diagnose suspected nutrient deficiencies and to monitor the soil-plant environment.

Another tool used to evaluate maize response to applied N is harvest index. Harvest index is defined as the ratio of grain yield to total above ground production (Donald and Hamblin, 1976). Large indices indicate that plants are efficiently channelling photosynthate to grain, while small indices suggest that photosynthate is being partitioned into herbage rather than grain. Harvest index for maize increases with N applied (Evensen, 1984), leveling off around 0.38 in Hawaii (Chung, 1982).

2.6 SPECIES SELECTION

The species in this study were chosen because of their fast growth, high GM and fuelwood yields, nutritious forage, and low disease and pest susceptibility. A brief summary of the nitrogen fixing trees in the study follows:

Calliandra calothyrsus Meissn. is a small bushy tree native to Central America, which has been widely planted by Indonesian villagers for fuelwood, fodder and fertilizer. Its dry wood yields between 4500 and 4750 kcal and the dense wood is also used for fence posts and building materials. The leaves and young shoots are high in crude protein (22%) and can yield over 46 t/ha/yr wet fodder (Kidd and Taogaga, 1984). Unfortunately, high tannin content limits its dry matter digestibility (DMD) to 35-42% (Baggio and Hueveldop, 1982). Leaves can also be applied to the soil as a mulch. In Java, many farmers plant calliandra to reduce the fallow period. Because it coppices readily, its popularity as an alley cropping species is increasing (NAS 1983).

Cassia siamea Lam. is native to Southeast Asia from Indonesia to Sri Lanka. Because of its wide tolerance of soil conditions and good firewood qualities, it was planted extensively throughout Africa, particularly from 1910 to 1924 (NAS, 1980). The trees coppice readily and produce significant amounts of green manure and fuelwood (Yamoah et al., 1986a). Leaves decompose slowly, suppressing weeds and improving soil moisture (Budelman, 1986). In northern Nigeria, cassia has reforested many denuded hillsides caused by tin mining (NAS, 1980). Although the young trees are browsed by livestock, the pods and foliage contain toxic substances which limits its fodder value. The species does not fix nitrogen.

Sesbania sesban (L.) Merrill is a short-lived, shrubby tree native to the drier areas of Asia and Africa. It can survive drought, tolerate chilling and altitudes up to 1200m, and is adapted to acid soils (NAS 1983). This allows sesbania to grow where many other legumes could not. A close relative of *S. sesban*, *S. bispinosa*, has been successfully alley cropped with rice in the Philippines, providing the inorganic equivalent of between 60 and 120 kg/ha of N fertilizer (NFTA, 1986). *S. sesban* is planted as a green manure crop in Pakistan and India where it is plowed into the soil before rice is planted. Although there are conflicting reports on its coppiceability and fodder value, *S. sesban* has many promising characteristics as an alley cropping species.

The pigeon pea, *Cajanus cajan* (L.) Millsp., is of uncertain origin, probably northeast Africa. With over 2 million hectares planted in 1980, India supplies over 90% of the world's production (NAS, 1980). Villagers use the woody stems extensively for cooking purposes, and the seeds are an important source of protein for humans. The leaves can be used as a fodder (DMD 42%) or can be fed to silkworms (NAS, 1980). ICRISAT has recently alley cropped pigeon pea with promising results.

Gliricidia sepium (Jacq.) Steud. is a small, thornless tree native to Mexico, Central America, and northern South America. Gliricidia provided significant amounts of green manure and fuelwood, while controlling weeds and stabilizing soil in alley cropping experiments in Nigeria (IITA, 1983). Spaced at 5,000 plants/ha and pruned 5 times a year, gliricidia produced 100 to 200 kg N/ha annually, which could supply most of maize's N requirement (IITA, 1984, 1986; Yamoah et al., 1986a). In addition to its soil improving qualities, gliricidia has been used as a support plant for yams in Ivory Coast, vanilla in Uganda, pepper in Costa Rica, and passionfruit in Sri Lanka. Gliricidia foliage contains 20 to 24 percent crude protein, but getting animals to eat gliricidia can be a difficult task (Brewbaker, 1986). Leaf malodors repel most animals; however, once the initial repulsion is broken, the animals prefer it to many other browses (Atta-Krah and Sumberg, 1987).

Leucaena (Lam.) de Wit is a genus of small to medium sized Latin American trees. Adapted to low-elevation tropics, the trees generally do not tolerate frost, nor poorly drained or acidic soils. However, the genus of 13 or 14 validated species varies in their tolerance to different environments and pests (Zarate 1984; Brewbaker 1987b). One of the most intensively tested species for alley farming is *Leucaena leucocephala*. For example, *L. leucocephala* prunings applied continuously for six years in Nigeria stabilized maize yields at 2 t/ha (Kang et al., 1985). The advent of psyllids to Hawaii in 1984 and S.E. Asia in 1986, and the resultant defoliation and death of many *L. leucocephala*, have forced researchers to look to other species for psyllid resistance. The 2 species (*L. pallida*, *L. salvadorensis*) and 1 hybrid (*L. pallida* (K376) X *L. diversifolia* (K163) called KX1) were chosen for this study because of their psyllid tolerance and fast growth. In a leucaena psyllid research trial at Waimanalo Research Station in Hawaii, *L. pallida* produced more green manure than 6 *L. leucocephala* varieties and 4 *L. diversifolia* varieties (Wheeler, 1988). *L. pallida* is native to the central and western highlands of Mexico from 800 to 1500m; the variety in this experiment was collected from Oaxaca. The tree forks at the base and grows 5 to 10m in height. *L. pallida* is resistant to psyllids and produces copious amounts of GM. *L. salvadorensis* is the newest validated species in the leucaena genus and little is known about it. Trees grow commonly over 15m in height, have some psyllid tolerance, and produce medium dimension poles which are used for house corner posts and firewood in Central America (Hughes, 1988).

CHAPTER 3

MATERIALS AND METHODS

3.1 SITE DESCRIPTION AND SPECIES SELECTION

The experiment was conducted on field A2 at the University of Hawaii's Waimanalo Research Station, which is located on the east coast of Oahu, elevation 21 m, longitude 157°, 43'W and latitude 20°, 20' 30" N. The soils at the site are Vertic Haplustolls belonging to the Waialua series. They are well drained and derived from basic igneous rock with a pH of 6.4 in the surface horizon. Some sections of the field were moderately eroded as indicated by wide runoff furrows caused by winter storms.

Species selected for this thesis had the following attributes:

1. Rapid growth.
2. Capable of resprouting after coppicing. Sprouts from lopped stems grow much faster than seedlings since they regenerate from established root systems. Another advantage of trees with coppicing abilities is that farmers are spared replanting costs.
3. Ease of establishment by seed.
4. Suitable for firewood.
5. N-fixing systems which produce high N leaves; (Note: <u>Cassia siamea</u> (nonfixing) was selected as a comparison to the other N-fixing trees.)

6. Rapid GM decomposition rates releasing avialable nutrients to the intercropped maize.

7. Tolerant of leucaena psyllid (Heteropsylla cubana) attack.

Species used in the following trials are:

1) Control--No trees no nitrogen
2) Calliandra calothyrsus
3) Cajanus cajan
4) Cassia siamea (non N-fixing)
5) Gliricidia sepium
6) Leucaena leucocephala (K584)
7) Leucaena pallida
8) Leucaena salvadorensis
9) KX1 -- Leucaena hybrid (L. pallida X L. diversifolia)
10) Sesbania sesban

3.2 NURSERY METHODS AND SITE PREPARATION

Seeds used in this trial were obtained from the Nitrogen Fixing Tree Association. The Leucaena leucocephala (K584), Leucaena pallida, Leucaena salvadorensis, KX1, and Calliandra calothyrsus seeds were scarified by placing them in concentrated sulfuric acid for ten minutes and then rinsed well in water. All the seeds were then inoculated by Rhizobium strains provided by the NifTAL Project and planted in dibble tubes. The seeds were planted at the Waimanalo Research Station greenhouse on March 19, 1988. The potting medium used was a 1:1 mixture of peat moss and vermiculite with 4.0 g/l of dolomite and 3.0 g/l of micronutrients added to improve growth. Because N application inhibits nodulation (Sprent and Raven, 1985) a low N fertilizer (7-40-6) was used every two weeks. The seedlings were grown for 3 months and then transplanted into the field.

The planting site was prepared by a tractor using a moldboard plow followed by discing. The three month old seedlings were planted into the field on March 12, 1988. No fertilizer was applied. Water was applied by overhead sprinkler irrigation about once a week.

During alley hedge establishment, three crops of field maize were grown between the tree rows without any N fertilizer to deplete the soil N. Three depletion crops were deemed necessary because the field had been cropped with highly fertilized maize for many years. After harvest of the third N depletion crop, four ramdom soil samples were taken and analyzed for N, P, and K content. Using these results, 50 kg/ha of P and 150 kg/ha of K were broadcast uniformly over all treatments (supplied as Triple superphosphate and Muriate of potash) and incorporated along with Eptam (Sutan) herbicide. Alachlor (Lasso) was sprayed over the surface at a rate of about 2.4 kg a.i./ha to help control purple nutsedge (Cyperus rotundus).

3.3 EXPERIMENTAL DESIGN

A randomized complete block design was used with 14 trees per treatment in one long row spaced 0.5 m within the row and 3 m between the rows. The treatments were replicated four times. The harvest area of the plots was 6.0 m^2 which was similar to plots sizes of 4 m^2 used by

Guevarra (1976) and 6 m^2 used by Evensen (1984). Data were collected from the row closest to the tree (tree row) and from the next adjacent row (middle row) to analyze competition effects caused by the trees (Fig. 3.1).

H1	O	O	O	O	H2	O	O	O	O
H1	O	O	O	O	H2	O	O	O	O
H1	M1	M2	O	O	H2	M1	M2	O	O
H1	M1	M2	O	O	H2	M1	M2	O	O
H1	M1	M2	O	O	H2	M1	M2	O	O
H1	M1	M2	O	O	H2	M1	M2	O	O
H1	O	O	O	O	H2	O	O	O	O
H1	O	O	O	O	H2	O	O	O	O

H1 = Hedge 1
H2 = Hedge 2
O = border maize plants
M1 = maize row closest to hedge
M2 = middle of the alley maize row

(Note: All the GM from the tree rows were evenly applied to the four maize rows.)

Fig. 3.1 Plot layout of two adjacent plots.

All the GM produce in the plot was applied to the soil, for all species except *Gliricidia sepium* and *Leucaena pallida*. Since tree growth varied from block to block, differing amounts of GM were applied to each block. This approach was felt to better represent species growth variability than placing a set amount of GM in each block. Equal amounts of green manure at rates of 0, 0.5x, 1x, and 2x times the amount produced were applied in the *Gliricidia sepium* and *Leucaena pallida* plots. These treatments were used to quantify the relationship between N applied and maize yield at both high and low applications of GM. As a comparison to these treatments a 1x GM treatment was sidedressed with 60 kg of urea during the second hedge coppicing.

3.4 DATA COLLECTION AND ANALYSIS

Six months after sowing, the trees in most plots had grown over 2 m tall and were setting seeds. They were coppiced on March 3, 1988, nine months after planting, at the height of 50 cm using hand shears (on some plots a chain saw had to be used). The biomass was separated into GM and wood fractions; any branch with a diameter of 8 mm or greater was considered wood. Both fractions were weighed and dry matter was determined by drying random samples at 100 C for 10 days. In addition to these samples, GM samples were also taken to determine the ratio of leafy to woody fractions in all the species. These samples were then dried and the total N in the leaf and small stems was determined. This separation was important because small stems decompose slowly, supplying little N to the intercropped maize.

A field corn hybrid (Pioneer X304C) was planted a week after coppicing using a hand held corn planter. In each alley, four rows of maize were planted 60 cm between rows and 15 cm between plants to give a plant population of about 60,000 plants/ha. The plots were weeded four weeks after planting using a 5% solution of "Roundup" (glyphosate). A hand wick applicator was used which allowed precise placement of the herbicide.

Seven weeks after maize planting the trees were coppiced again to provide nutrients during maize's grain filling stage and to reduce light competition. The GM from this coppicing was broadcast on the soil surface, since mechanical incorporation was not feasible. Green manure samples were taken following the same procedure as after the first coppice.

At harvest, maize yield data were taken from the tree row and from the middle row to assess competition for light and soil nutrient competition. Stover weight, filled ear length, and number of kernels per row were also measured for each plot to try to identify the time of N deficiency.

Days to 50% tasseling and diagnostic N sampling were also recorded during maize growth. For the diagnostic N sampling, all plots were sampled when they reached 50% silking. The entire ear leaf blade just below the topmost ear was taken from 10 plants per plot. The leaves were subsequently dried at 70 C for five days and then ground in a Wiley Mill through a 1 mm screen. Semi-micro Kjeldahl for total N analysis was done at the University of Hawaii

Diagnostic Service Center following the procedures of Nelson and Sommers (1980).

All statistical analyses were done on the personal computer using either Lotus 123 or Statistical Analysis Systems for the personal computer (PC SAS). All data entry and simple ANOVA tables were performed on Lotus 123, while linear regressions, curve fitting analyses, and single degree of freedom contrasts were done using PC SAS.

A second crop of maize was planted soon after the first trial ended. It was planted on July 11, 1989 and harvested on October 24, 1989. This experiment will be referred to as the July trial, while the previously discussed experiment will be called the March trial. The July trial followed the same procedures as in March with the following exceptions:

1) The plot dimensions remained the same but maize rows closest to the hedge were planted 60 cm away from the hedge. Distance between maize rows was reduced to 60 cm. The plant population remained at about 60,000 plants per hectare.
2) GM coppicing and application onto the field were done at 5 weeks instead of 7 weeks after planting as in the Summer Trial. This earlier application was done to maximize N availablity from the GM.
3) The <u>Cajanus</u> <u>cajan</u> plots were abandoned after the March trial because they suffered heavy mortality after the first coppicing.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 YIELD OF ALLEY CROPPED TREES

4.1.1 PLANT HEIGHT, GREEN MANURE, AND WOOD YIELDS

Hedges were grown for 9 months after planting to establish strong roots and shoots. Plant heights averaged about 2.5 m for the whole trial and ranged from 1.4 to 3.8 m (Fig. 4.1), creating a virtual jungle in less than a year. Sesbania grew significantly taller than all other species, reaching an average height of almost 4 meters. This rapid growth was reflected in sesbania's superior yields of green manure (leaves and twigs less than 8 mm diameter).

Average green manure yields for the March and July trials are listed in order of decreasing performance in Table 4.1. Average yields per species ranged from 1.3 to 12.1 dry t/ha, with daily increments ranging from 2.9 to 45.8 kg/day (based on coppiced regrowth only). Sesbania was the most productive tree after the first coppice and consistently outproduced all the other species throughout the 2 trials.

The cajanus plots (Table 4.1) suffered heavy mortality after the first coppice which caused GM production to drop from 4500 kg/ha to under 500 kg/ha. Only 13% of the plants survived the first coppicing (9 months after planting). The long interval between planting and coppicing may have caused

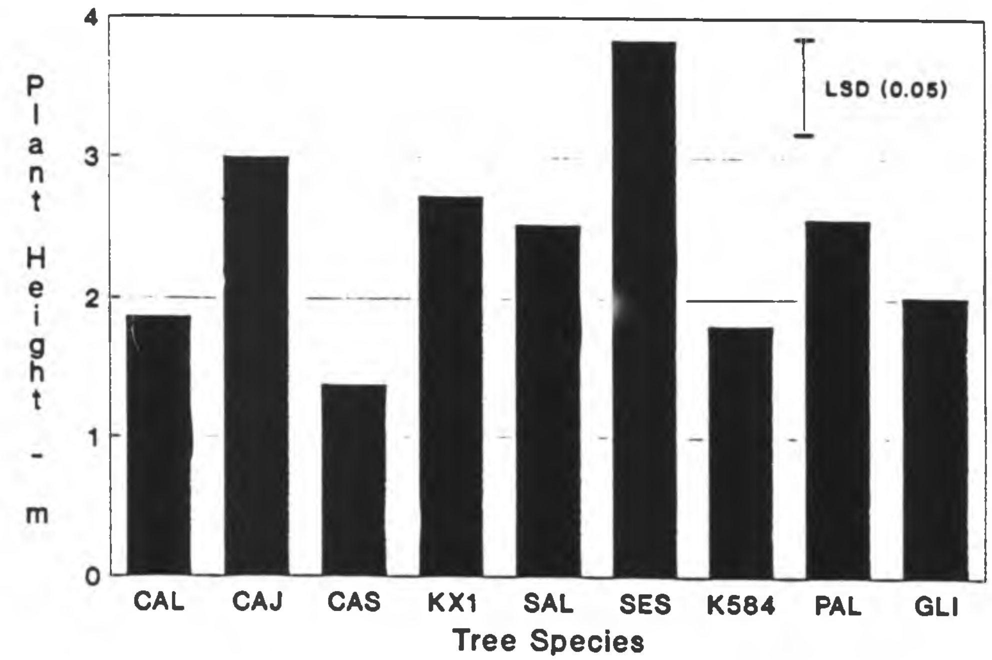

Fig. 4.1 Plant heights of 9 month old tree species. Vertical line is LSD (0.05) value to compare species means.

Table 4.1. -- Average green manure yields (dry matter) over four harvests in the March and July Trials.

	March Trial		July Trial			
		Harvest Date				Daily *
Spec	3/12	4/30	7/11	8/17	TOTAL	kg/ha
	----------	----------	t/ha	----------	----------	
Ses	4.92 a	1.48 a	3.55 a	2.17 a	12.12	45.84
Pal	2.19 b	1.16 b	2.97 ab	1.00 bc	7.31	32.61
Gli	2.09 b	0.92 bc	2.50 b	0.86 cd	6.38	27.31
KX1	1.83 bc	0.78 c	1.69 c	0.78 cd	5.09	20.71
Caj	4.49 a	0.45 e	0.00	0.00	4.94	2.87
Cal	1.79 bc	0.74 cd	1.33 c	0.42 de	4.27	15.84
K584	1.06 cd	0.57 de	0.47 d	0.83 cd	2.92	11.90
Cas	0.57 d	0.56 de	0.19 d	0.24 e	1.55	6.26
Sal	0.41 d	0.20 f	0.30 d	0.40 de	1.31	5.73
LSD	0.97	0.20	0.62	0.48		
C.V.	33	19	38	43		

* Daily accrual based on last 3 harvests only

this high mortality. In a nearby trial of 20 provenances of perennial Cajanus cajan, the provenance planted for the present trial was coppiced at 4 month intervals and over 80 % of the trees survived (Rosecrance et al., 1989). At 4 months, stems were green and less rigid than stems at 9 months. Poor coppicing ability of mature stems has also been noted for Casuarina equisetifolia (Reshid, 1989) and many other trees.

After coppicing, wood fractions (twigs larger than 8mm) were separated carefully from GM, weighed, and sampled for dry matter. Wood was harvested only at beginning of the March and July trials (representing 9 months growth and 2.5 months regrowth, respectively) because hedges were frequently coppiced, allowing little time for trees to produce wood (Table 4.2). Wood yields following first coppicing dropped drastically, and were negligible in subsequent harvests. Sesbania and cajanus produced significantly higher yields than all the other species. Even though sesbania and cajanus do not produce dense, high quality wood, many farmers in India and Africa use this wood for cooking (NAS, 1980; NAS, 1983).

4.1.2 CORRELATIONS AMONG MEASURED TRAITS

There was a strong linear relationship between plant height and total above ground biomass (Fig. 4.2). An exception was salvadorensis, which produced tall hedges with

Table 4.2. -- Wood yields (dry t/ha) after 9 months tree establishment and 2.5 months coppiced regrowth.

Species	9 Month Growth	2.5 Coppiced Regrowth	TOTAL
	---------t/ha----------		
Ses	5.81	2.73	8.54
Caj	4.92	0.00	4.92
Pal	3.29	1.84	5.13
KX1	2.57	1.52	4.09
Gli	2.11	0.95	3.06
Cal	1.03	0.00	1.03
K584	0.61	0.00	0.61
Sal	0.40	0.00	0.40
Cas	0.34	0.00	0.34
LSD (0.05)	1.24	0.67	

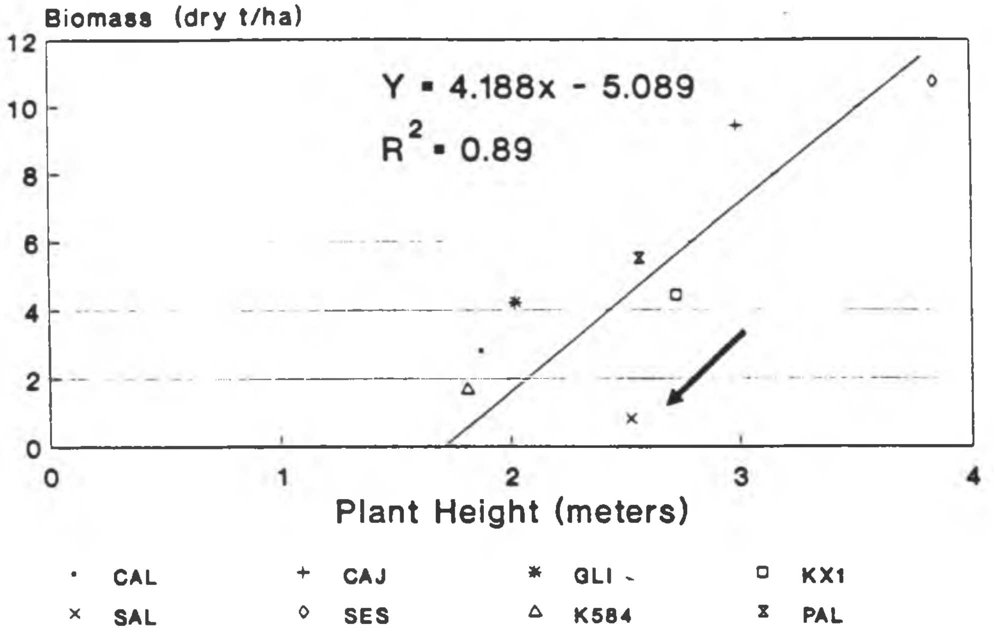

Fig. 4.2 Relationship between plant height and total above ground biomass of the hedge.

little above ground biomass (see arrow in Fig. 4.2). These trees had strong apical dominance, and grew tall and lanky, even after coppicing. Little information has been published on growth rates of salvadorensis, but results from this trial indicated that it is not suitable for alley cropping.

K584 (Leucaena leucocephala) and calliandra also grew poorly in this trial (Table 4.1). Psyllids infested the K584 hedges. Frequent coppicing initiated new shoot growth, providing psyllids a plentiful food source. Comparing growth from hedges that received frequent insecticides with hedges that received no treatment, Bray (unpublished data) found that the psyllids reduced dry leaf yields by approximately 50%.

Calliandra may not be suited to the environmental conditions of Waimanalo, since this provenance (N-4028) has done well in other locations (Nancy Glover, personal communication). Evensen (1989) found in Indonesia that calliandra grew slowly during the first year after planting, producing only 500 kg of dry leaf matter. However, leaf yields doubled after the second year, and more than tripled after the third year. Trees on stressful sites have been found to allocate more energy to developing strong root systems relative to leaves and stems than better sites (Keyes and Grier, 1981). Linder and Ingestad (1977) found that stress increased the carbon allocation to roots for a number of different tree seedlings. Waring (1983) concluded that carbohydrate allocation patterns strongly depended upon a tree's environment, with stressful sites favoring root development.

Cassia siamea also grew very slowly. Although no data were recorded, it was noted 8 months after completion of the trial that cassia plants were growing vigorously. These results suggest that long-term experiments are needed to make valid conclusions on NFT species as hedges for alley cropping.

4.1.3 NITROGEN CONTENTS OF LEAVES AND TWIGS

Percentages of nitrogen in leaves and twigs in the green manure for the two trials is shown in Table 4.3. The N contents averaged between 2.85 and 3.93 % for leaves and 0.97 and 1.70 % for twigs. The species varied little in terms of percent N in leaves and twigs. Cassia produced the lowest % N leaf levels. This result was expected since cassia was the only non-nitrogen fixer in the trial. Twigs tend to be low in N, high in lignin and cellulose, and not nearly as accessible to microbial attack. Twigs decompose and release nitrogen much more slowly than leaves (Singh and Singh, 1936), which suggest that this nitrogen probably was not readily available to the intercropped maize.

Percent leafy material in the green manure for the March and July trials varied from 30 to 80 % (Fig. 4.3). Twigs and small stems composed over 60 % of cajanus green manure. This large percentage of twigs suggests that

Table 4.3. -- Nitrogen percent of leaves and twigs in combined March and July trials.

Species	Leaves	Twigs
K584	3.86	1.18
KX1	3.81	1.08
Sal	3.61	1.12
Ses	3.60	0.81
Pal	3.27	0.90
Gli	3.25	1.83
Cal	3.03	1.31
Cas	2.36	0.95
LSD	1.04	1.03

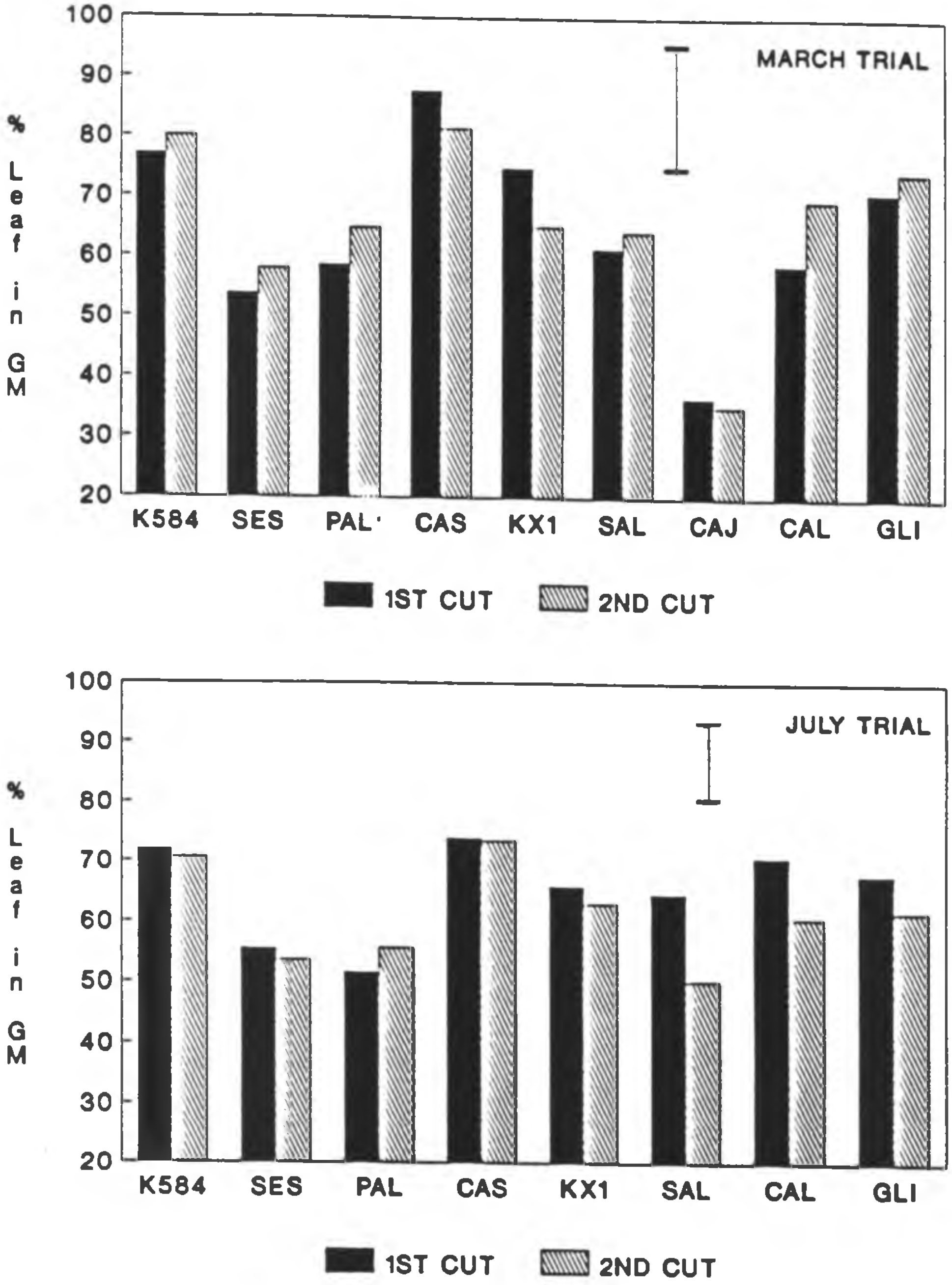

Fig. 4.3 Percent leafy fractions over the March and July seasons. Vertical lines are LSD (0.05) to compare species means.

cajanus may have a strong residual effect, with N in the green manure becoming available slowly over subsequent maize crops. Rao et al. (1983) found that a preceding cajanus crop substantially increased maize yields compared to a fallow control. Six months after planting, cajanus plants were removed and maize planted. Maize yield and total dry matter increased 57% and 32%, respectively, with residual effects of cajanus calculated to be 38 to 49 kg N per ha (Rao et al., 1983). Palm (1988) found that cajanus green manure had high levels of polyphenolics which correlated with slow N release.

4.2 MAIZE YIELD RESPONSE TO GREEN MANURE

4.2.1 DEPLETION CROPS

Three maize depletion crops were grown in between the alleys in 1987 during hedge establishment, with all stubble removed (Fig. 4.4). Maize plants became progressively stunted and suffered severe nitrogen deficiency during the third maize depletion crop; essentially no grain could be harvested from this planting. Many plants appeared spindly, with yellowish green upper leaves and firing of lower leaves. These symptoms indicate that maize plants were under severe N stress.

Fig. 4.4 Four rows of maize grown between hedges to deplete the soil nitrogen pool.

4.2.2. TASSELING DATES AND LEAF NITROGEN VALUES

After the third depletion crop, hedges were coppiced, green manure applied (Fig. 4.5), and the first experimental corn planted. Plots which received large quantities of green manure were much greener and grew more quickly than plots that received little green manure. Analysis of variance showed significantly earlier maturity (days to tasseling) for plots which had liberal applications of green manure (Table 4.4). Treatment degrees of freedom were partitioned in orthogonal comparisons of various species treatment effects. Maturity accelerated significantly for high green manure producers vs. low, and for the top producers--sesbania and cajanus vs others.

Tissue samples were taken at silking on the leaf just below the developing ear and analyzed for percent nitrogen. A significant linear relationship was found between percent N in maize diagnostic samples and N applied in both the March and July crops (Fig. 4.6). Nitrogen in the ear leaf did not vary much, however, ranging from 0.8 to 1.5 percent. These values are much below the 2.8-3.5 % N levels that Jones and Eck (1973) considered representative of optimal maize growth. This suggests that all treatments were suffering, to some degree, from N deficiency at silking.

Fig. 4.5 Gliricidia green manure applied on the soil prior to March planting.

Table 4.4. -- Analysis of variance of days to tasseling for the March Maize Crop.

Source	df	Mean Squares
Rep	3	2.27 ns
Tree Species	9	10.62 **
Control vs Rest	1	12.10 **
High vs Low GM	1	42.05 ***
Ses & Caj vs others	1	33.07 **
Ses vs Caj	1	6.12 **
KX1 vs Others	1	0.00 ns
Pal vs Gli	1	0.00 ns
Among Low GM	1	1.00 ns
Cal vs K584	1	0.13 ns
Cas vs Sal	1	1.13 ns
Error	27	1.08
CV (%)	15.49	

** Significance at 0.01 level of probability

*** Significance at 0.001 level of probability

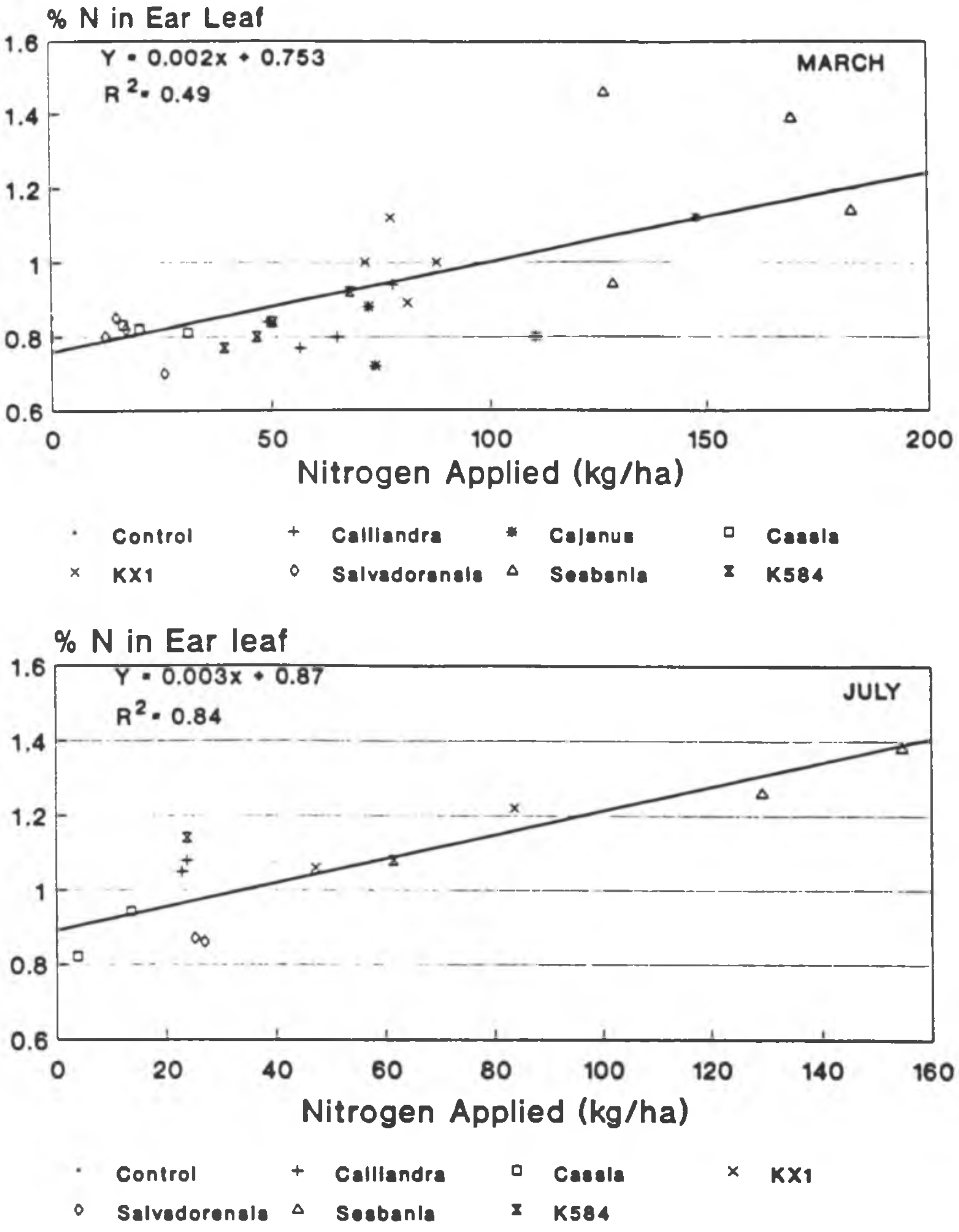

Fig. 4.6 Relationship between % N in the maize ear leaf at 50 % silking and N applied as GM in the March and July crops, respectively.

4.2.3 GRAIN YIELDS

Grain yields in March and July averaged 1.11 and 1.25 t/ha, respectively (Table 4.5). The best yields were from the sesbania plots, averaging over 2.0 t/ha. In table 4.4, averages are calculated for 'treatments' (excluding control and cassia). These treatments averages were 1.25 and 1.47 t/ha in the March and July crops, respectively. Yields were very low compared to the 8 to 10 t/ha yields Jong and colleagues (1982) obtained on the same fields at Waimanalo, under high fertilizer levels. However, the 0.5-2.0 t/ha yields are typical of those in developing countries.

Combined analysis of variance with orthogonal contrasts for the two cropping seasons is presented in Table 4.6 (following McIntosh, 1983). Effects of season were not significant, indicating that possible residual N values and differences in climate did not strongly affect maize yields. The interaction term of seasons x species was also not significant, which obviated the need of separate technology recommendations for each planting season.

Single degree of freedom comparisons were used to evaluate individual species plots. Sesbania, cajanus, gliricidia, pallida, and KX1 plots were identified as high maize yielding plots, while calliandra, K584, and salvadorensis were identified as low yielders. Since cassia does not fix N, it was also considered a control. Green manure from high yielding tree plots produced significantly

Table 4.5. -- Effect of green manure nitrogen on maize grain yield for March and July crops.

	MARCH CROP		JULY CROP	
Species	N Applied	Maize Yield	N Applied	Maize Yield
	--------------kg\ha		---------------	
* Cont	0.0	462.3	0.0	349.0
Caj	100.9	1390.2		
Cal	62.1	950.6	23.2	1096.4
* Cas	29.2	593.8	16.3	560.8
KX1	79.3	1366.0	63.8	1413.3
Sal	17.3	662.1	23.1	838.7
Ses	151.8	2200.1	126.8	2093.5
K584	51.0	927.6	42.5	1375.1
Gli	90.0	1195.5	102.7	1860.7
Pal	85.4	1336.1	91.0	1636.8
Averages				
* Controls		528.0		454.9
Treatments		1253.5		1473.5
Overall		1108.4		1247.1
CV (%)		28.5		25.3

Table 4.6. -- Combined analysis of variance of maize yield for the March and July crop.

Source	df	Mean Squares
Seasons	1	364.2 ns
Reps in Seasons	6	342.2 **
Tree Species	8	2380.2 ***
Control vs Rest	1	4963.9 ***
Cassia vs Rest	1	4028.6 ***
High vs Low GM	1	6803.3 ***
Among High	1	1276.0 **
Ses vs Gli	1	1531.0 **
KX1 vs Pal	1	37.4 ns
Cal vs Rest	1	97.4 ns
Sal vs K584	1	304.6 *
Seasons*Species	8	117.4 ns
Error	27	101.0

CV (%) 27.6

* Significance at 0.05 level of probability
** Significance at 0.01 level of probability
*** Significance at 0.001 level of probability

greater maize yields than from low yielding species plots, although within these groups there were only modest differences. Sesbania plots yielded the significantly highest maize yields, outproducing gliricidia which produced the second highest maize yields.

Maize yield data for the March and July crops were combined, and regressed against N applied (Fig. 4.7). A highly significant linear relationship was found between N applied and maize yield. The regression coefficient was 12.2 kg of maize grain per kg of N applied. Deviations from regression appeared to be randomly distributed, with regression accounting for 97 % of the variance. Yield data from the March and July crops are listed in the Appendix Table 3.

4.2.4 COMPARISON BETWEEN GREEN MANURE OF DIFFERENT SPECIES

Covariance analysis was conducted with species as the Y variable and N applied as the X variable (Table 4.7). In both March and July crops, the N linear response was highly significant, while species were not significant. Thus, maize yields reflected the amount of N applied as GM, regardless of tree species from which the N was derived.

This result was surprising because green manures may contain recalcitrant fractions such as lignin and polyphenols, which decompose slowly making N unavailable for intercropped maize. Large differences in N release from

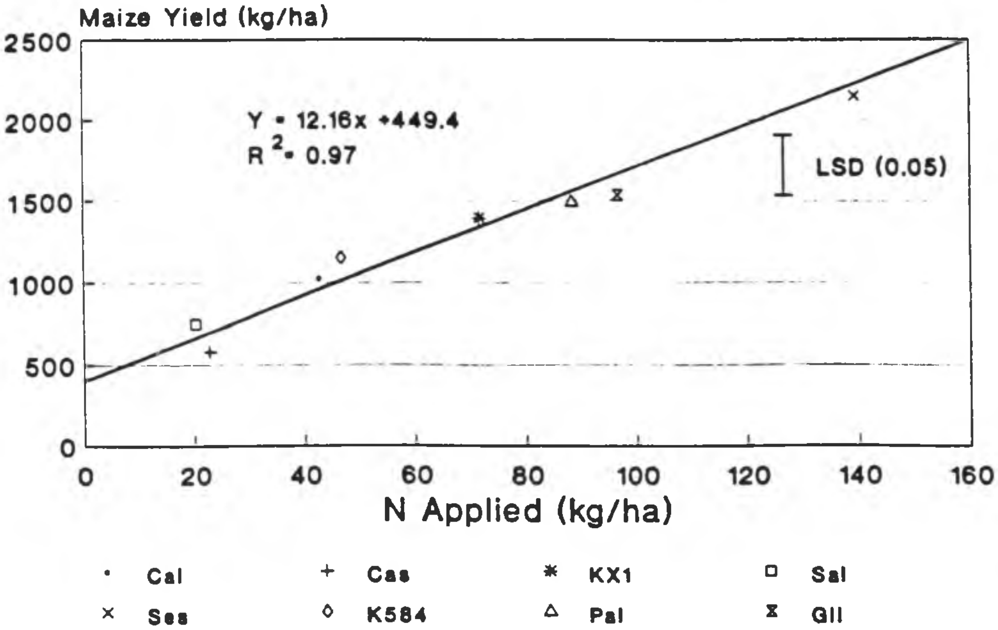

Fig. 4.7 Relationship between N applied as GM and grain yield combined over the March and July crops. Each plot is the mean of 4 plots over 2 seasons.

green manure characterize different nitrogen fixing tree species (Palm, 1988; Ogelsby, 1990). Palm (1988) concluded that Cajanus cajan decomposed much more slowly than Erythrina spp. because of high levels of soluble polyphenols in the cajanus leaf. Species in this trial, however, all have small leaflets (less than 5 cm in diameter) and appeared to breakdown quickly under environmental conditions in Waimanalo.

4.2.5. CORRELATIONS AMONG YIELDS AND YIELD COMPONENTS

Grain yield, total dry matter yield, harvest index, filled ear length, and kernels per row all highly correlated with amounts of N applied (Table 4.8). Seventy four percent of the variation in grain yield could be attributed to N applied in the March maize crop and seventy two percent in July's crop. Correlation coefficients between grain yield and both filled ear length and kernels per row ranged from 0.91 to 0.94. These parameters are good predictors of grain yield and could be easily calculated by farmers. The significant correlations between harvest index and N applied was surprising, since in wheat, as applications of N increases, harvest index decreases (Donald and Hamblin, 1976). They attributed this result to increased levels of N being converted into leafy tissue and not being diverted to grain production. In the present trials, however, initial soil N content was so low that perhaps much of the N applied went directly to increase grain production.

Table 4.7. -- Analysis of covariance for maize yield with nitrogen as covariant in the March and July trials.

Source	df	Mean Squares March	Mean Squares July
Rep	3	239.25 *	508.27 *
Nitrogen (X)	1	8283.49 **	10529.75 **
Species (Y)	9	147.17 ns	104.70 ns
Error	26	76.32	150.13
CV		24.9	31.0

* Significance at 0.05 level of probability
** Significance at 0.01 level of probability

Table 4.8. -- Correlation coefficients among yield and yield components for the March and July crops. (Note: Upper and and Lower values are March and July maize crops, respectively.

	DM Yield	Harvest Index	N Applied	Filled Length	Kernels Per Row	Avg No. of Ears
Grain Yield	0.94 **	0.90 **	0.86 **	0.91 **	0.93 **	0.55 *
	0.87 **	0.64 *	0.85 **	0.94 **	0.94 **	0.73 **
DM Yield		0.73 **	0.85 **	0.86 **	0.88 **	0.56 *
		0.31	0.71 **	0.84 **	0.84 **	0.76 **
Harvest Index			0.78 **	0.83 **	0.86 **	0.47
			0.62 *	0.65 *	0.64 *	0.38
N Applied				0.78 **	0.82 **	0.42
				0.90 **	0.91 **	0.58 *
Filled Ear Lgth					0.94 **	0.51
					0.98 **	0.71 **
Kernels Per Row						0.47
						0.72 **

* Significant at 0.05 level of probability
** Significant at 0.01 level of probability

Components of yield (kernels per row, filled ear length) are fixed at different stages of maize growth. Ovules per row is determined in Hawaii approximately 30 days after planting, and filled kernel number fixed within a week of pollination (Jong, 1980). After fertilization is complete, filled ear length is fixed. Number of kernels per row and filled ear length were highly correlated in these studies with N applied and maize yield (Table 4.8). Results from the diagnostic ear samples (Section 4.2.2) showed that maize plants were under severe N stress at silking, and observations made in the field (plant size, color) support this view. Plots with total N applications over 50 kg produced vigorous and healthy maize plants during the first month of growth. By silking time, however, most plants exhibited general leaf yellowing, and lower leaf firing was noted on many plots. The only dark green, healthy looking plants were in plots having double green manure or green manure plus urea treatments.

These observations suggest that maize plants had sufficient N during early growth, but N stress increased as plants matured. Evensen (1984) also concluded from his green manure studies that the most severe N stress occurred during grain fill. Applying GM to the soil surface after the second coppicing may have resulted in significant losses of N by volatilization. Kang et al. (1981b) and Evensen (1984) found that Leucaena leucocephala prunings incorporated into the soil were much more effective in increasing maize yields than when applied as a mulch.

4.2.6 GRAIN YIELDS IN GLIRICIDIA AND PALLIDA PLOTS

Fixed amounts of green manure were applied in gliricidia and pallida plots of each replicate, as an "experiment within the experiment". Treatments included 1/2X, 1X, 1X + 60 kg N, and 2X the amount of green manure produced by hedges. The purpose of these treatments was to develop regressions for N applied vs maize yield for gliricidia and pallida. Maize ears responded strikingly to the mulch treatments (Fig. 4.8).

Grain yields in March and July averaged 1.51 and 2.08 t/ha, respectively (Table 4.9). The best yields were from plots supplemented both with green manure and urea, averaging up to 4.4 t/ha. In table 4.9, averages are calculated for 'treatments' (excluding control, and check plots 0 pallida and 0 gliricidia). These treatments averages were 1.9 and 2.7 t/ha in the March and July crops, respectively.

Yields generally improved in the July crop compared to yields in March. Analysis of variance over seasons was conducted, showing this increase to be highly significant (Table 4.10). In the combined analysis, the interaction of

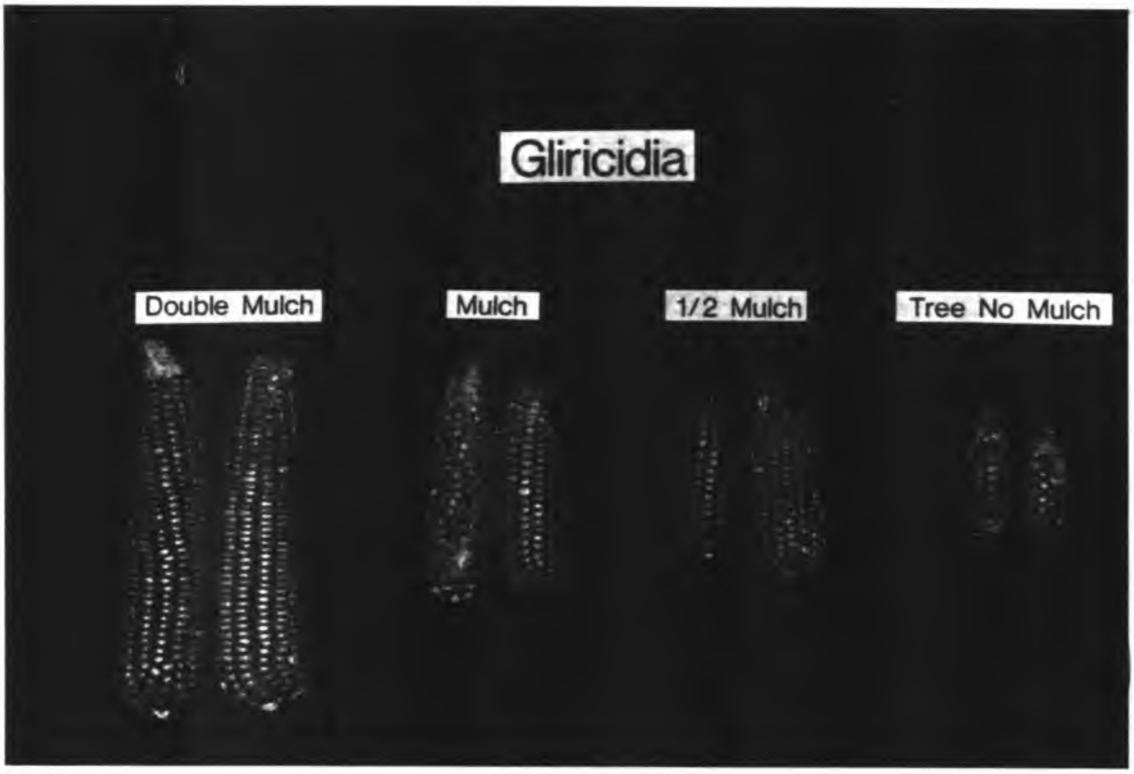

Fig. 4.8 Mulch effects on filled ear length: 2x, 1x, 0.5x and 0 mulch treatments representing 180, 90, 45, and 0 kg N/ha, respectively.

Table 4.9. -- Effect of green manure nitrogen on maize grain yield for pallida and gliricidia in March and July

		MARCH CROP		JULY CROP	
	Species	N Applied	Maize Yield	N Applied	Maize Yield
		--------------kg\ha		---------------	
*	Cont	0.0	462.3	0.0	349.0
* 0	Pal	0.0	504.4	0.0	537.0
0.5X	Pal	42.7	1009.6	45.5	1508.8
1X	Pal	85.4	1336.1	91.0	1636.8
2x	Pal	171.1	2319.5	182.0	2588.7
1X + UREA	Pal	145.4	3013.7	151.0	4428.6
* 0	Gli	0.0	711.6	0.0	760.5
0.5X	Gli	45.2	1029.1	51.3	1434.8
1X	Gli	90.0	1195.5	102.7	1860.7
2x	Gli	180.4	2157.9	205.2	3451.5
1X + UREA	Gli	150.0	2845.0	162.6	4343.4
Averages					
* Controls			559.4		548.8
Treatments			1863.3		2656.7
Overall			1507.7		2081.8
CV (%)			24.2		25.2

Table 4.10. -- Combined analysis of variance for maize yield in the gliricidia and pallida plots for the March and July crops.

Source	df	Mean Squares
Seasons	1	7252.2 **
Reps in Seasons	6	142.8 ns
Tree Species	10	11077.2 ***
Control vs Rest	1	16977.7 ***
Gli vs Pal	1	164.3 ns
Gli(2x & Fert) vs (0,0.5x,1x)	1	39719.8 ***
Gli 2x vs Gli_Fert	1	2492.8 **
Gli 1x vs Gli(0 & 0.5x)	1	1578.8 **
Gli 0 vs Gli 0.5x	1	983.8 **
Pal(2x & Fert) vs (0,0.5x,1x)	1	38354.8 ***
Pal 2x vs Pal_Fert	1	6421.4 ***
Pal 1x vs Pal(0 & 0.5x)	1	1897.5 **
Pal 0 vs Pal 0.5x	1	2181.5 **
Seasons*Species	10	6660.2 **
Error	27	204.3
CV (%)	25.1	

** Significance at 0.01 level of probability
*** Significance at 0.001 level of probability

species x seasons was also highly significant. Possibly increased residual soil N from the green manure application in March and decreased competition between the hedge and maize (see section 4.3) boosted yields in July.

Single degree of freedom contrasts were used to determine more specific effects (Table 4.10). Maize yields in gliricidia and pallida plots were not significantly different from each other. In comparing treatments that produced high yields, GM + 60 kg N produced significantly higher maize yields than the double GM treatment. By sidedressing urea, an active root system can take up N as it is applied, and decreases leaching and volatilization losses (Russelle et al., 1981). Delayed N application also minimizes vegetative entrapment and maximizes N available for grain formation (Olson and Sander, 1988).

In comparing treatments that produced low maize yields, the 1/2 GM treatment produced significantly higher yields than the 0 GM treatment. This suggests that even small amounts of N applied as GM can significantly increase yields.

Nitrogen applied from the mulched plots was regressed against maize yield in the March and July trials in Fig 4.9. Regression coefficients significantly increased from 9.1 kg of maize per kg of N in March to 12.0 kg maize per kg of N in July. The full GM plus 60 kg N treatment was not included in these regression equations. These treatments

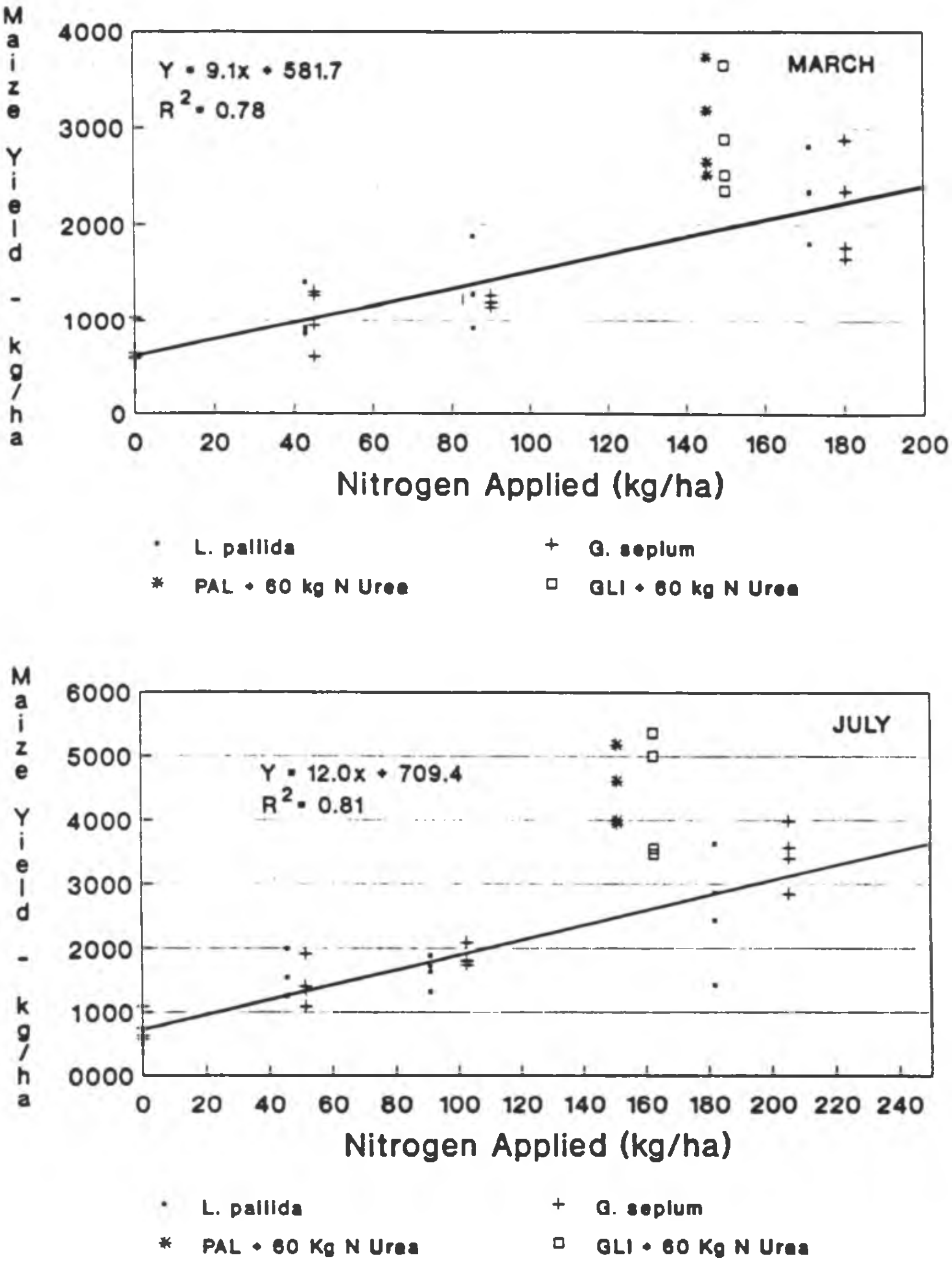

Fig. 4.9 Relationship between maize yield and N applied as GM for the gliricidia and pallida plots in the March and July crops, respectively. (Note the boost in yields with the urea treatment).

yielded more grain than expected by applying green manure alone. A possible explanation for this boost in yield is that urea N is readily available for plant uptake, while green manure N must first be broken down by micro-organisms. Guevarra (1976) found mulch applied as green manure to be only 32% as efficient as urea N in increasing maize grain yield.

Urea treatments also produced significantly higher harvest indices than the 2x GM plots (Fig. 4.10), indicating that the urea was much more efficient in converting N to grain than green manure. Plants in the urea plots produced more grain and less stover than the 2x treatment. The regressions between harvest index and N applied were linear in the March and July crops. At higher N levels, however, maize harvest index values stabilize around 0.38 in Hawaii (Chung et al., 1982). The harvest index is important because it measures the efficiency of the plant's ability to partition photosynthate to grain. Thus, harvest index provides additional evidence that urea is more efficient than green manures in converting N to grain.

4.3 COMPETITION BETWEEN HEDGE AND MAIZE

Grain yields and values for selected yield components were recorded for the row closest to the tree ("tree row") and the next adjacent row ("middle row"), to determine

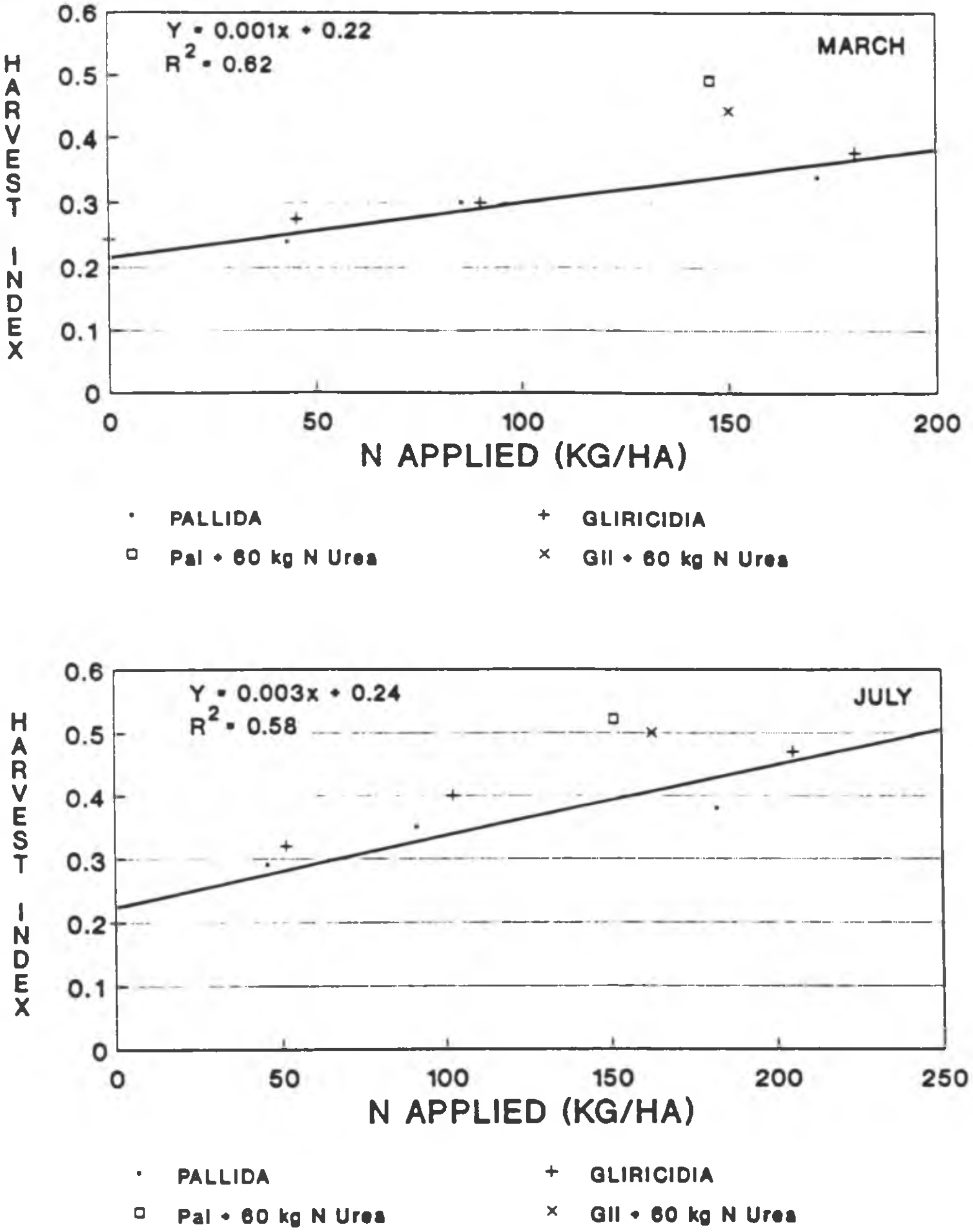

Fig. 4.10 Relationship between harvest index and N applied for the gliricidia and pallida plots in the March and July crops, respectively. Each point is mean of four plots.

Table 4.11 Effect of row position on maize grain yields for March and July crops.

	MARCH CROP		JULY CROP	
Specie	Mid row Yield	Tree row Yield	Mid row Yield	Tree row Yield
	kg/ha			
Cont *	501.2	423.5	261.2	436.8
Cal	1228.7	672.6	1314.5	878.4
Caj	1699.7	1080.7		
Cas *	745.5	442.0	545.0	576.6
KX1	1770.0	962.1	1659.9	1166.7
Sal	680.7	643.5	865.4	811.9
Ses	3000.7	1399.4	2220.1	1966.9
K584	1094.5	760.8	1609.8	1140.3
0 Pal *	578.5	430.4	626.9	447.1
0.5X Pal	1394.2	625.1	1797.3	1220.3
1X Pal	1714.2	958.0	1762.2	1511.4
2x Pal	3223.3	1415.7	2865.3	2312.2
1X+Fert Pal	4297.9	1729.5	4970.9	3886.3
0 Gli *	774.1	649.1	764.2	756.8
0.5X Gli	1229.1	829.1	1636.0	1233.7
1X Gli	1703.2	687.8	2182.8	1538.6
2x Gli	3370.4	945.5	3910.3	2992.7
1X+Fert Gli	4400.9	1289.1	5224.2	3462.5
AVG Controls *	649.8	486.2	549.3	554.3
AVG Treatments	2176.7	1023.7	2287.0	1723.0

effects of competition between the hedge and maize crop (Table 4.11). The tree row and middle row were located 40 cm and 110 cm from the hedge in March, and 60 and 120 cm from the hedge in July, respectively. Data were taken on these rows separately to assess competition with the hedge (e.g., light, nutrients, and water). Maize yields in the tree and middle rows were similar in control plots (Control, Cas, 0 Pal, and 0 Gli), ranging from 480 to 650 kg/ha. Tree row yields, however, were conspicuously decreased in Treatment plots. Tree row yields were reduced by about 50 % in March and 25 % in July. The following sections discuss reasons for these reduced yields in the tree row.

4.3.1 MARCH TRIAL

Maize yields in the tree row were reduced in all species plots (Fig. 4.11). Sesbania, which produced the most N as green manure, also competed the most with the maize crop. The regression line for maize yields in the tree row was significantly lower than in the middle row. One kg of N produced 16 kg of grain in the middle row, while only yielding 7 kg of grain in the tree row. Regressions were linear with R^2 values of 87 and 95 % for the tree and middle row, respectively.

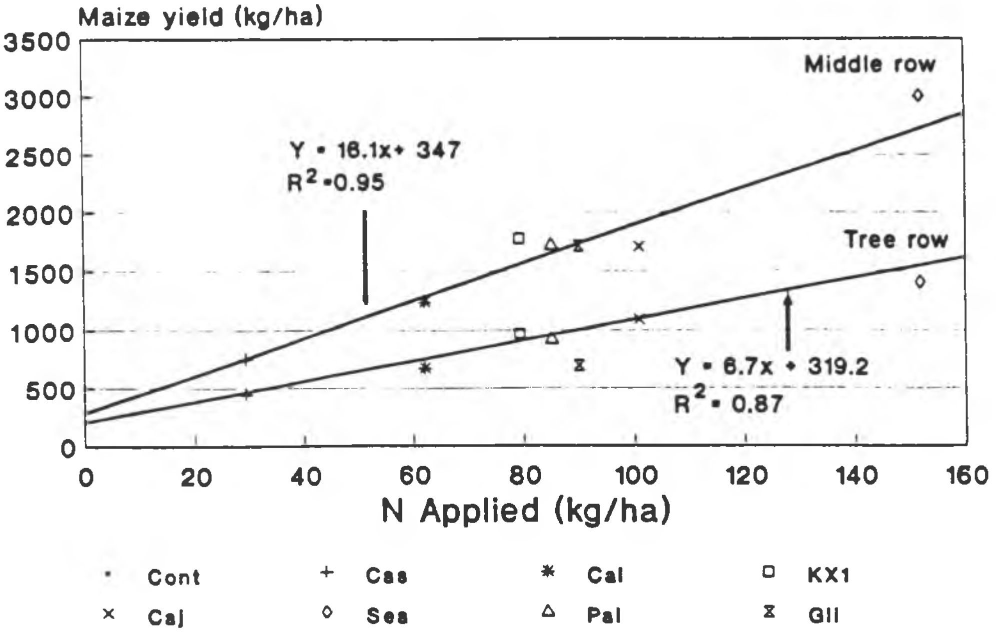

Fig. 4.11 Relationship between N applied and row position in the March crop. Each point is mean of four plots.

Table 4.12. -- Analysis of variance for maize grain and stover yield, filled ear length, and number of kernels per row in the tree and middle row ("Positions") for the March and July crops.

March crop Source	df	Mean Squares Grain Yield	 Stover Yield	 Filled Ear	 Kernels per row
Species	9	2076.4**	2.1**	7.2**	90.6**
Rep	3	586.5**	2.6**	9.4**	44.4**
Error(a)	27	166.5ns	0.4ns	1.2ns	11.7ns
Positions	1	5919.9**	18.7**	12.3**	55.1**
Spp. * Positions	9	613.9**	0.2ns	2.2*	20.2*
Error(b)	30	115.7	0.3	0.7	7.3
CV		30.6	18.4	10.8	16.6

July crop Source	df	Mean Squares Grain Yield	 Stover Yield	 Filled Ear	 Kernels per row
Species	8	2755.9**	1.4**	6.6**	98.6**
Rep	3	1016.5**	7.8**	8.4**	56.5**
Error(a)	24	316.2ns	2.2**	2.4ns	21.5ns
Positions	1	1272.7*	4.0**	15.4**	63.6**
Spp.* Positions	8	148.5ns	0.4ns	2.2ns	27.8*
Error(b)	27	206.3	0.2	0.8	8.5
CV		36.4	16.1	12.3	20.5

* Significance at 0.05 level of probability
** Significance at 0.01 level of probability

Analysis of variance showed that grain and stover yields, cob lengths, and numbers of kernels per row were significantly reduced in the tree row (Table 4.12). Species differences were highly significant for all measured traits. There was also a highly significant interaction of Tree Species x Position. As more nitrogen was added to the plots in the form of green manure, competition for that N also increased.

Rototilling the field just before maize planting should have destroyed tree roots in the upper 20 cm of soil, reducing root competition for nutrients and water. Atta-Krah (1983) found significant competition for available nutrients and water between the hedge and maize, in a 'no till' alley cropping experiment with maize in Nigeria. When the land was tilled, however, maize yields increased significantly. Frequent irrigations also should have minimized competition for water in the present study.

Light competition may have played a role in reducing yields in the tree row. In the March trial, hedges were coppiced 50 days after maize planting. Hedges had overtopped some of the maize plants in the pallida, gliricidia, and sesbania plots. Jong et al. (1982) determined from yield averages of 41 maize plantings under well fertilized and irrigated conditions in Waimanalo that solar radiation was the climatic factor most strongly correlated with maize grain yields. Evensen (1989) also argued that light competition was the most significant factor in depressing yields in an alley cropping with rice.

An important confounding factor in this analysis was that after the rows were planted, a tractor sprayed Lasso, a pre-emergent herbicide, along the alleys. The tractor tires unfortunately may have compacted the surface soil in the tree row and thereby amplified competition effects.

4.3.2 JULY TRIAL

Tree and middle maize rows were planted 60 cm and 120 cm away from the hedge, respectively, in order to avoid tire tracks in the July trial. Hedges were coppiced 37 days after maize planting, instead of 50 days to minimize shading. This spacing and coppicing time led to an overall improvement in maize yields in tree rows (Fig. 4.12). KX1 and gliricidia hedges decreased tree row yields the most in this trial. The slopes of maize yield versus added N increased from 6.7 in March to 11.2 in July, almost doubling the response to applied N. The slopes of maize yield versus added N in the middle row remained around 15 kg maize/kg N for the two trials.

Average percent decrease in maize yield due to position in the alley was calculated by dividing yield of the tree row by yield of the middle row (Table 4.13). Yield decreases averaged 30 % in the March trial, but only 10 % in

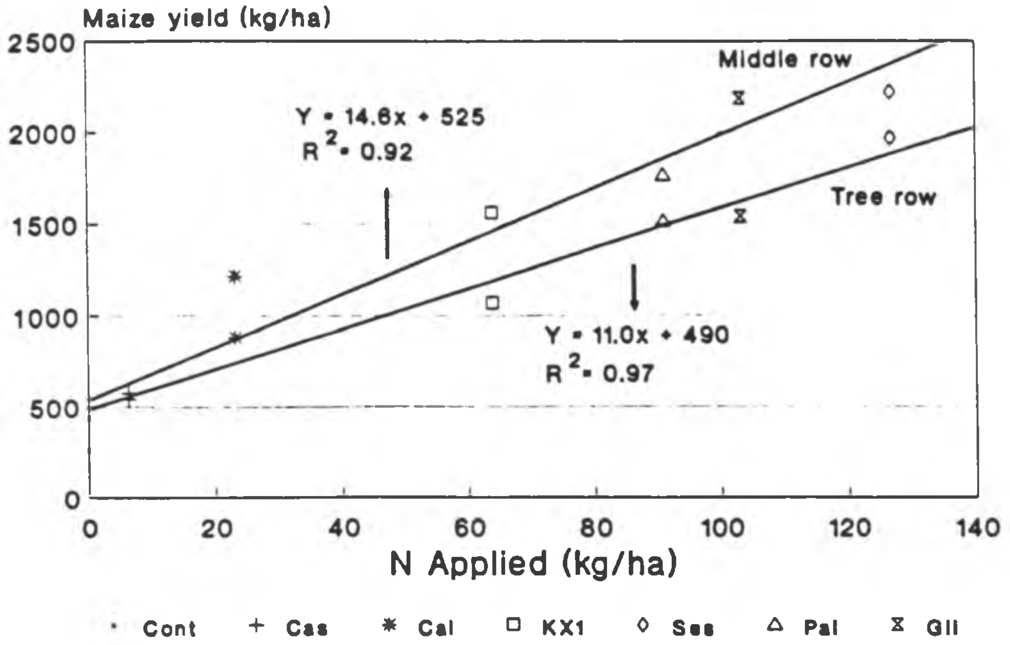

Fig. 4.12 Relationship between N applied and row position in the July crop. Each point is mean of four plots.

Table 4.13. -- Average percent decrease of maize yield in the tree row compared to the middle row.

	Average Percent Decrease	
	March Crop	July Crop
calliandra	36.31	13.74
cajanus	29.57	
cassia	41.00	3.02
KX1	45.95	29.21
K584	40.50	24.79
salvadorensis	8.38	1.65
sesbania	47.42	19.58
gliricidia(1x)	38.81	28.86
pallida (1x)	35.71	20.11
AVG	34.39	10.26

July. In the March trial much competition was found at a distance 40 cm from the hedge; in July the distance was increased to 60 cm with a concomitant boost in tree row yields. This increase in the distance away from the hedge undoubtedly played an important role in improving yields in the tree row. Evensen (1989) compared rice yields at 20, 60, 100, 140 and 180 cm from Paraserianthes falcataria, Gliricidia sepium, and Calliandra calothyrsus hedges. Only in the row adjacent to the Paraserianthes and gliricidia hedge were rice yields significantly reduced, while calliandra hedges significantly reduced rice yields out to 60 cm away from the hedge. Such differences are clearly to be expected due to different patterns of root development.

Analysis of variance for positions was conducted for the July maize and stover yields, number of kernels per row and filled ear length (Table 4.12). All these yield components were significantly reduced in the tree row compared to the middle row. The interaction term, species x positions, however, was nonsignificant. This suggests that competition from the hedge reduced the tree row of maize evenly, regardless of hedge species or N applied. This result is contrary to that in March where increasing levels of N significantly increased competition effects.

Buildup of soil N may have masked competition effects, resulting in a nonsignificant interaction term. Although competition by the hedge is significant, it is small compared to stress induced by lack of nitrogen. Typical N deficiency symptoms of yellowish green plants with lower leaf firing was found in most July plots. Increases in residual soil N in July may have boosted yields in the tree row, counteracting competition effects to some extent.

4.4 COMPARISON BETWEEN OF RESULTS FROM PRESENT TRIAL AND FROM A CUT AND CARRY LEUCAENA MULCH TRIAL

A cut-and-carry Leucaena mulch trial (referred to as "Evensen's Trial") was conducted at Waimanalo Research Station in the summer of 1984 (Evensen, 1984). Three maize crops depleted the residual soil nitrogen, as was done in the present trial. Evensen's trial differed from the March and July trials in the following ways: 1) In Evensen's Trial, Leucaena mulch was carried onto the plots, and therefore no competition effects were caused by a hedge; 2) Evensen applied only dried leaves and rachises, whereas in the present trials stems less than 8 mm were also applied.

To minimize these differences, maize yields in the present trials were calculated from only the middle maize rows and only nitrogen applied as leaves was used to calculate the regression lines. These lines were then compared with maize yield data from Evensen's trial (Fig.

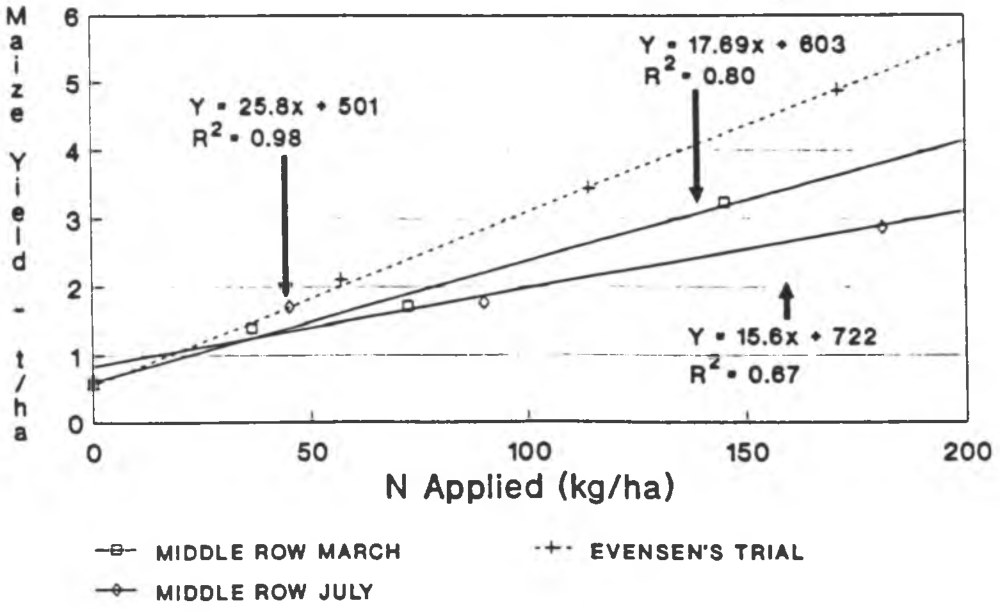

Fig. 4.13 Regression lines for maize yields from the middle row of the March and July crops versus Evensen's cut and carry leucaeana trial initiated in 1983. Each point is mean of four plots.

4.13). The regression lines for the March and July trials were considerably lower than Evensen's regression line. The slopes were 25.8, 17.7, and 15.6 kg maize/kg N for Evensen's trial, and middle row yields in March and July, respectively. Possibly, hedge competition affected yields as far as 120 cm away from the hedge. Competition effects, climatic differences, as well as immobilization caused by twig decomposition may explain the lower yields in the March and the July maize crops compared to Evensen's trial.

CHAPTER 5

SUMMARY AND CONCLUSIONS

Tests of the effects of nitrogen in green manure were made possible in this study by care in depleting nitrogen from experimental plots. Three maize crops resulted in an extremely N-depleted soil, with control plots producing 0.55 t/ha (vs 8-10 t/ha considered normal on the same field). Most plots were under N stress during grain fill.

Leguminous tree species *Sesbania sesban*, *Gliricidia sepium*, *Leucaena pallida* and KX1 (*L. pallida* X *L. diversifolia*) showed high potential in these trials for use in alley cropping. Soil and environmental conditions at Waimanalo probably represent almost ideal conditions for growing trees, with good soils and a warm, humid environment. *Calliandra calothyrsus* and *Cassia siamea* grew slowly for the first 1.5 years, but growth increased after the termination of the experiment. *Leucaena salvadorensis* grew tall but produced little green manure, and did not appear to be an appropriate species for alley cropping. Psyllids severely curbed *Leucaena leucocephala* (K584) growth. *Cajanus cajan* grew very vigorously, but coppiced poorly in this trial.

Maize yields responded linearly to N applied as GM in both the March and July harvests. Yields did not depend on the hedge species from which the GM was derived. Sesbania hedges produced the most GM, resulting in the highest maize yields (2200 kg/ha in March and 2093 kg/ha in July) of any treatment in the trials. Maize yields in the gliricidia and pallida plots were high and not significantly different from each other. The full green manure plus urea treatment was the most effective in increasing yields. These plots produced significantly more maize, with less total N applied, than the double gliricidia and pallida GM treatments.

Significant decreases in yields were noticed when comparing production from the row nearest the trees vs middle rows. Competition for available light may have been the most important factor in decreasing yields, because the plots were plowed, minimizing root competition. Maize yields in the tree row were noticeably lower in March than in July. Increasing the distance from the hedge and early coppicing time probably decreased competition effects in the July trial.

These trials clearly indicated that significant amounts of N via green manure can be made available to a maize crop. Maize grain yield increased from 10-20 kg for each kg of N applied as green manure; thus, assuming an average tropical maize grain yield of 1.2 t/ha (Brewbaker, 1985), then an application of 50 kg N as GM could as much as double yield. Thus, alley cropping could be an effective cropping system in improving maize yields in developing countries, while supplying significant amounts fuel wood and stakes to resource poor farmers.

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APPENDIX

Table 1. -- Analysis of variance of green manure yields during the 1988 March and July trials.

Source	df	Mar 15	Apr 30	Jul 11	Aug17
		----------Mean Square Values----------			
Rep	3	1.66 *	0.02 **	0.99	0.23
Tree Species	8	10.07 **	0.58 **	6.44 **	1.40 **
High vs Low GM	1	41.12 **	2.46 **	34.69 **	3.95 **
Ses & Caj vs others	1	34.22 **	cajanus trees died		
Ses vs Caj	1	0.36			
Ses vs Others	1	-----	0.82 **	4.04 **	5.01 **
KX1 vs Others	1	0.24	0.17 *	2.88 *	0.06
Pal vs Gli	1	0.01	0.10 *	0.43	0.03
Among Low GM	1	3.49 *	0.24 **	1.50	0.24
Cal vs K584	1	1.06	0.06	1.46	0.33
Cas vs Sal	1	0.04	0.19 **	0.08	0.15
Error	24	0.51	0.03	0.41	0.14
CV (%)		33	19	38	43

* Significance at 0.05 level of probability
** Significance at 0.01 level of probability

Table 2. -- Nitrogen applied and maize yields for the March maize crop.

Rep #	Species	N Appld Leaves	N Appld Twigs	Total N Appld	Maize Yield	Avg
				kg/ha		
1	Cont				566.15	462.31
2	Cont				232.75	
3	Cont				467.30	
4	Cont				583.05	
1	Cal	52.43	12.53	64.96	868.05	950.63
2	Cal	46.00	10.56	56.56	595.30	
3	Cal	40.11	9.20	49.31	766.05	
4	Cal	62.34	15.26	77.59	1573.10	
1	Caj	76.43	34.08	110.51	1234.80	1390.19
2	Caj	50.88	22.69	73.58	1028.60	
3	Caj	49.89	22.25	72.13	1683.25	
4	Caj	102.17	45.56	147.73	1614.10	
1	Cas	14.92	1.30	16.22	455.05	593.75
2	Cas	18.27	1.61	19.88	593.00	
3	Cas	28.50	2.38	30.88	419.20	
4	Cas	46.29	3.52	49.81	907.75	
1	KX1	73.50	7.41	80.91	1168.90	1366.03
2	KX1	63.92	7.45	71.37	1323.25	
3	KX1	79.25	8.45	87.70	1344.80	
4	KX1	70.25	7.03	77.28	1627.15	
1	Sal	14.47	2.45	16.91	717.10	662.10
2	Sal	21.82	3.74	25.56	415.45	
3	Sal	12.46	2.10	14.55	618.10	
4	Sal	10.31	1.86	12.17	897.75	
1	Ses	111.00	17.32	128.32	1484.00	2200.05
2	Ses	109.57	17.09	126.67	1911.75	
3	Ses	158.48	24.37	182.85	2543.05	
4	Ses	146.75	22.75	169.50	2861.40	
1	K584	42.95	7.38	50.33	1183.10	927.61
2	K584	36.04	3.12	39.16	625.95	
3	K584	42.79	3.75	46.54	837.35	
4	K584	62.31	5.56	67.87	1064.05	
0	Pal			0.00	236.70	504.40
0	Pal			0.00	501.00	
0	Pal			0.00	718.80	
0	Pal			0.00	561.10	
0.5X	Pal	36.27	6.45	42.71	846.80	1009.63
0.5X	Pal	36.27	6.45	42.71	874.60	
0.5X	Pal	36.27	6.45	42.71	1399.35	
0.5X	Pal	36.27	6.45	42.71	917.75	

1x Pal	72.53	12.90	85.43	1280.95	1336.08
1x Pal	72.53	12.90	85.43	1882.35	
1x Pal	72.53	12.90	85.43	913.95	
1x Pal	72.53	12.90	85.43	1267.05	
2x Pal	145.28	25.83	171.11	2336.15	2319.48
2x Pal	145.28	25.83	171.11	1802.30	
2x Pal	145.28	25.83	171.11	2804.35	
2x Pal	145.28	25.83	171.11	2335.10	
1X + fertPal	72.53	12.90	145.43	2640.20	3013.69
1X + fertPal	72.53	12.90	145.43	2510.60	
1X + fertPal	72.53	12.90	145.43	3731.90	
1X + fertPal	72.53	12.90	145.43	3172.05	
0 Gli	0.00		0.00	1028.95	711.58
0 Gli	0.00		0.00	609.60	
0 Gli	0.00		0.00	648.80	
0 Gli	0.00		0.00	558.95	
0.5x Gli	38.17	7.01	45.17	1299.30	1029.08
0.5x Gli	38.17	7.01	45.17	607.60	
0.5x Gli	38.17	7.01	45.17	947.50	
0.5x Gli	38.17	7.01	45.17	1261.90	
1X Gli	76.08	13.97	90.05	1142.70	1195.51
1X Gli	76.08	13.97	90.05	1262.95	
1X Gli	76.08	13.97	90.05	1184.35	
1X Gli	76.08	13.97	90.05	1192.05	
2x Gli	152.41	27.98	180.39	1644.95	2157.94
2x Gli	152.41	27.98	180.39	1762.20	
2x Gli	152.41	27.98	180.39	2878.85	
2x Gli	152.41	27.98	180.39	2345.75	
1X + fertGli	76.08	13.97	150.05	3644.70	2844.98
1X + fertGli	76.08	13.97	150.05	2510.60	
1X + fertGli	76.08	13.97	150.05	2878.85	
1X + fertGli	76.08	13.97	150.05	2345.75	

Table 3. -- Nitrogen applied and maize yields for the July maize crop.

Rep #	Species	N Appld Leaves	N Appld Twigs	Total N Appld	Maize Yield	Avg
		kg/ha				
1	Cont				542.30	348.98
2	Cont				245.00	
3	Cont				180.50	
4	Cont				428.10	
1	Cal	18.62	4.35	22.97	1098.90	1096.44
2	Cal	19.35	4.51	23.86	670.19	
3	Cal	18.27	4.26	22.54	603.28	
4	Cal	19.06	4.45	23.51	2013.39	
1	Caj				0.00	0.00
2	Caj				0.00	
3	Caj				0.00	
4	Caj				0.00	
1	Cas	3.35	0.42	3.76	628.04	560.78
2	Cas	12.02	1.50	13.52	425.55	
3	Cas	0.87	0.11	0.98	223.05	
4	Cas	6.21	0.78	6.99	966.48	
1	KX1	72.71	10.98	83.69	1580.12	1413.27
2	KX1	41.05	6.20	47.26	708.66	
3	KX1	74.03	11.18	85.21	1250.64	
4	KX1	33.78	5.10	38.89	2113.68	
1	Sal	21.78	5.16	26.94	1083.45	838.66
2	Sal	20.34	4.82	25.16	755.37	
3	Sal	13.87	3.29	17.16	790.50	
4	Sal	18.66	4.42	23.09	725.34	
1	Ses	114.76	14.66	129.41	1717.46	2093.52
2	Ses	137.25	17.53	154.78	1764.53	
3	Ses	93.72	11.97	105.69	2532.20	
4	Ses	103.90	13.27	117.17	2359.91	
1	K584	54.92	6.57	61.49	1375.89	1125.08
2	K584	21.29	2.55	23.84	516.70	
3	K584	50.26	6.01	56.26	1442.60	
4	K584	25.21	3.01	28.23	1165.11	
0	Pal				358.98	537.02
0	Pal				494.74	
0	Pal				582.03	
0	Pal				712.34	
0.5X	Pal	26.21	4.69	45.49	1252.93	1508.82
0.5X	Pal	26.21	4.69	45.49	1245.90	
0.5X	Pal	26.21	4.69	45.49	1996.36	
0.5X	Pal	26.21	4.69	45.49	1540.08	

1x Pal	77.18	13.81	90.99	1881.67	1636.85
1x Pal	77.18	13.81	90.99	1632.63	
1x Pal	77.18	13.81	90.99	1308.95	
1x Pal	77.18	13.81	90.99	1724.13	
2x Pal	179.12	32.06	181.98	2870.28	2588.75
2x Pal	179.12	32.06	181.98	3632.68	
2x Pal	179.12	32.06	181.98	1414.50	
2x Pal	179.12	32.06	181.98	2437.53	
1X + fertPal	77.18	13.81	150.99	3992.19	4428.58
1X + fertPal	77.18	13.81	150.99	3947.40	
1X + fertPal	77.18	13.81	150.99	5171.88	
1X + fertPal	77.18	13.81	150.99	4602.84	
0 Gli				1089.24	760.47
0 Gli				748.70	
0 Gli				573.07	
0 Gli				630.85	
0.5x Gli	31.24	9.02	51.30	1915.22	1434.83
0.5x Gli	31.24	9.02	51.30	1089.24	
0.5x Gli	31.24	9.02	51.30	1334.07	
0.5x Gli	31.24	9.02	51.30	1400.80	
1X Gli	79.68	23.01	102.69	1794.74	1860.69
1X Gli	79.68	23.01	102.69	2086.28	
1X Gli	79.68	23.01	102.69	1744.16	
1X Gli	79.68	23.01	102.69	1817.57	
2x Gli	176.55	51.00	205.20	2843.23	3451.52
2x Gli	176.55	51.00	205.20	3984.99	
2x Gli	176.55	51.00	205.20	3401.90	
2x Gli	176.55	51.00	205.20	3575.95	
1X + fertGli	79.68	23.01	162.60	5350.49	4343.35
1X + fertGli	79.68	23.01	162.60	3471.45	
1X + fertGli	79.68	23.01	162.60	4996.07	
1X + fertGli	79.68	23.01	162.60	3555.40	

Table 4. -- Analysis of variance of maize yield for the March Maize Crop.

Source	df	Mean Squares
Rep	3	293.282 **
Tree Spp.	9	1038.201 ***
Control vs Rest	1	1855.383 ***
cassia vs Rest	1	1547.736 ***
High vs Low GM	1	3176.465 ***
Among High	1	1180.470 **
Ses vs Caj	1	1311.754 ***
KX1 vs Rest	1	26.790 ns
Pal vs Gli	1	39.515 ns
Cal vs Rest	1	64.703 ns
Sal vs K584	1	140.993 ns
Error	27	83.278
CV (%)	26.035	

** Significance at 0.01 level of probability
*** Significance at 0.001 level of probability

Table 5. -- Analysis of variance of maize yield for the July Maize Crop.

Source	df	Mean Squares
Rep	3	1524.805 **
Tree Spp.	8	1102.397 ***
Control vs Rest	1	3630.154 ***
cassia vs Rest	1	2915.721 ***
High vs Low GM	1	2876.572 ***
Among High	1	817.371 **
Ses vs Gli	1	108.427 *
KX1 vs Pal	1	99.970 ns
Cal vs Rest	1	.289 ns
Sal vs K584	1	575.471 *
Error	27	158.102
CV (%)	31.882	

* Significance at 0.05 level of probability
** Significance at 0.01 level of probability
*** Significance at 0.001 level of probability

Table 6. -- Analysis of covariance for maize yield with nitrogen as covariant in the March and July trials. (Note the nonsignificant interaction between nitrogen and species).

March Trial Source	df	Mean Squares
Rep	3	293.28 *
Nitrogen	1	8283.49 ***
Species	9	147.17 ns
Nitrogen * Species	6	105.46 ns
Error	20	67.58
CV	23.4	

July Trial Source	df	Mean Squares
Rep	3	508.27 *
Nitrogen	1	10529.75 ***
Species	8	104.47 ns
Nitrogen * Species	5	306.54 ns
Error	18	106.68
CV	26.1	

* Significance at 0.05 level of probability
*** Significance at 0.001 level of probability

Table 7. -- Maize yields in the middle and tree rows and percent of middle row yields in the tree row for the March maize crop.

Rep #	Species	Yield Middle ro kg/ha	Yield Tree row kg/ha	Percent yield of middle row
1	Cont	591.70	540.60	91.36
2	Cont	148.60	316.90	213.26
3	Cont	533.60	401.00	75.15
4	Cont	730.80	435.30	59.56
1	Cal	1099.40	636.70	57.91
2	Cal	599.90	590.70	98.47
3	Cal	967.10	565.00	58.42
4	Cal	2248.30	897.90	39.94
1	Caj	1224.10	1245.50	101.75
2	Caj	1177.10	880.10	74.77
3	Caj	1932.10	1434.40	74.24
4	Caj	2465.40	762.80	30.94
1	Cas	501.60	408.50	81.44
2	Cas	744.30	441.70	59.34
3	Cas	681.20	157.20	23.08
4	Cas	1054.80	760.70	72.12
1	KX1	1537.50	800.30	52.05
2	KX1	1788.10	858.40	48.01
3	KX1	1834.40	855.20	46.62
4	KX1	1920.00	1334.30	69.49
1	Sal	736.60	697.60	94.71
2	Sal	493.70	337.20	68.30
3	Sal	707.60	528.60	74.70
4	Sal	784.90	1010.60	128.76
1	Ses	1580.60	1387.40	87.78
2	Ses	2636.80	1186.70	45.01
3	Ses	3703.00	1383.10	37.35
4	Ses	4082.30	1640.50	40.19
1	K584	865.80	1500.40	173.30
2	K584	614.20	637.70	103.83
3	K584	723.30	951.40	131.54
4	K584	839.80	1288.30	153.41
0	Pal	245.60	227.80	92.75
0	Pal	466.60	535.40	114.74
0	Pal	910.40	527.20	57.91
0	Pal	691.20	431.00	62.36
0.5x	Pal	909.00	784.60	86.31
0.5x	Pal	970.70	778.50	80.20
0.5x	Pal	2313.50	485.20	20.97
0.5x	Pal	1383.50	452.00	32.67

1x Pal	1647.60	914.30	55.49
1x Pal	2174.10	1590.60	73.16
1x Pal	1241.90	586.00	47.19
1x Pal	1793.00	741.10	41.33
2x Pal	3488.10	1184.20	33.95
2x Pal	2265.00	1339.60	59.14
2x Pal	3966.40	1642.30	41.41
2x Pal	3173.70	1496.50	47.15
1X + fertPal	4035.60	1244.80	30.85
1X + fertPal	3531.90	1489.30	42.17
1X + fertPal	5413.70	2050.10	37.87
1X + fertPal	4210.30	2133.80	50.68
0 Gli	1367.40	690.50	50.50
0 Gli	612.10	607.10	99.18
0 Gli	492.30	805.30	163.58
0 Gli	624.50	493.40	79.01
0.5x Gli	1360.60	1238.00	90.99
0.5x Gli	695.10	520.10	74.82
0.5x Gli	1053.00	842.00	79.96
0.5x Gli	1807.70	716.10	39.61
1x Gli	1540.00	745.40	48.40
1x Gli	1671.80	854.10	51.09
1x Gli	1923.50	445.20	23.15
1x Gli	1677.60	706.50	42.11
2x Gli	2846.10	443.80	15.59
2x Gli	2375.50	1148.90	48.36
2x Gli	4550.30	1207.40	26.53
2x Gli	3709.80	981.70	26.46
1X + fertGli	5811.50	1477.90	25.43
1X + fertGli	3531.90	1489.30	42.17
1X + fertGli	4550.30	1207.40	26.53
1X + fertGli	3709.80	981.70	26.46

Table 8. -- Maize yields in the middle and tree rows and percent of middle row yields in the tree row for the July maize crop.

Rep #	Species	Yield Middle ro kg/ha	Yield Tree row kg/ha	Percent yield of middle row
1	Cont	575.84	708.83	123.09
2	Cont	251.74	338.26	134.37
3	Cont	221.53	239.56	108.13
4	Cont	395.86	460.50	116.33
1	Cal	1519.18	678.62	44.67
2	Cal	577.11	763.28	132.26
3	Cal	566.57	639.99	112.96
4	Cal	2595.07	1431.71	55.17
1	Cas	473.84	782.24	165.09
2	Cas	524.42	326.67	62.29
3	Cas	252.55	193.54	76.63
4	Cas	929.07	1003.89	108.05
1	KX1	1986.70	1173.54	59.07
2	KX1	796.29	621.02	77.99
3	KX1	1502.32	998.97	66.50
4	KX1	2354.11	1873.24	79.57
1	Sal	1271.19	895.70	70.46
2	Sal	655.79	854.95	130.37
3	Sal	657.90	923.10	140.31
4	Sal	876.73	573.95	65.46
1	Ses	1771.38	1663.54	93.91
2	Ses	2334.09	1194.97	51.20
3	Ses	2122.28	2942.11	138.63
4	Ses	2652.68	2067.14	77.93
1	K584	2340.06	2411.72	103.06
2	K584	608.72	424.67	69.76
3	K584	1664.25	1220.96	73.36
4	K584	1826.17	504.05	27.60
0	Pal	406.05	311.91	76.82
0	Pal	544.45	445.04	81.74
0	Pal	661.06	503.00	76.09
0	Pal	896.05	528.64	59.00
0.5x	Pal	1729.23	776.62	44.91
0.5x	Pal	1254.33	1237.47	98.66
0.5x	Pal	2327.41	1665.30	71.55
0.5x	Pal	1878.16	1201.99	64.00

1x Pal	1907.31	1856.03	97.31
1x Pal	1745.03	1520.23	87.12
1x Pal	1776.30	841.61	47.38
1x Pal	1620.34	1827.93	112.81
2x Pal	3015.52	2725.04	90.37
2x Pal	4174.66	3090.69	74.03
2x Pal	1743.28	1085.73	62.28
2x Pal	2527.63	2347.44	92.87
1X + fertPal	4470.77	3513.60	78.59
1X + fertPal	4187.31	3707.50	88.54
1X + fertPal	5575.47	4768.29	85.52
1X + fertPal	5649.94	3555.75	62.93
0 Gli	1242.04	936.45	75.40
0 Gli	990.54	506.86	51.17
0 Gli	364.95	781.19	214.05
0 Gli	459.09	802.62	174.83
0.5x Gli	2163.03	1667.41	77.09
0.5x Gli	1242.04	936.45	75.40
0.5x Gli	1481.59	1186.54	80.09
0.5x Gli	1657.22	1144.39	69.05
1x Gli	2829.01	760.47	26.88
1x Gli	1665.30	2507.26	150.56
1x Gli	2427.52	1060.79	43.70
1x Gli	1809.31	1825.82	100.91
2x Gli	3482.34	2204.12	63.29
2x Gli	4513.27	3456.70	76.59
2x Gli	3209.06	3594.74	112.02
2x Gli	4436.70	2715.20	61.20
1X + fertGli	6395.65	4305.33	67.32
1X + fertGli	4389.98	2552.92	58.15
1X + fertGli	5570.20	4421.95	79.39
1X + fertGli	4541.02	2569.78	56.59

Table 9. -- Analysis of variance for maize yield and position for the March and July maize crops.

March Trial

Source	df	Mean Squares
Rep	3	586.564 **
Tree Species	9	2076.403 ***
Error(a)	27	166.556 ns
Position	1	5919.916 ***
Species*Position	9	613.977 ***
Error(b)	30	115.752
CV (%)	30.69	

July Trial

Source	df	Mean Squares
Rep	3	1016.560 **
Tree Species	9	2755.906 ***
Error(a)	27	316.201 ns
Position	1	1272.733 *
Species*Position	9	148.512 ns
Error(b)	30	206.262
CV (%)	36.41	

* Significance at 0.05 level of probability
** Significance at 0.01 level of probability
*** Significance at 0.001 level of probability

Table 10. -- Analysis of variance for maize yield and position (tree and middle row) in the gliricidia and pallida plots for the March and July maize crops.

March Trial

Source	df	Mean Squares
Rep	3	480.003 ns
Species	1	47.702 ns
GM Level	4	14429.023 **
Species*GM Level	4	105.690 ns
Error(a)	27	293.390 ns
Position	1	34461.656 **
Species*Position	1	211.305 ns
GM Level*Position	4	5074.454 **
Species*GMLevel*Position	4	167.262 ns
Error(b)	30	188.821
CV (%)	26.95	

July Trial

Source	df	Mean Squares
Rep	3	66.064 ns
Species	1	1059.551 *
GM Level	4	34304.539 **
Species*GM Level	4	592.249 *
Error(a)	27	605.737 **
Position	1	8136.339 **
Species*Position	1	236.792 ns
GM Level*Position	4	980.663 **
Species*GMLevel*Position	4	142.409 ns
Error(b)	30	201.714
CV (%)	19.91	

* Significance at 0.05 level of probability
** Significance at 0.01 level of probability