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**Alley cropping as a soil nitrogen management practice for maize  
production**

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University of Hawaii, 1994

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ALLEY CROPPING AS A SOIL NITROGEN MANAGEMENT PRACTICE  
FOR MAIZE PRODUCTION

A DISSERTATION SUBMITTED TO THE GRADUATE DIVISION OF  
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REQUIREMENTS FOR THE DEGREE OF

DOCTOR OF PHILOSOPHY

IN

AGRONOMY AND SOIL SCIENCE

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## ABSTRACT

Tropical maize yields are low, averaging 1.24 t/ha, compared to a 3.2 t/ha world average and a 6.3 t/ha average in the United States and Europe. Alley cropping is an attempt to increase yields and prevent the decline in soil fertility often found in traditional farming systems.

A maize alley cropping experiment was established on a Typic Gibbsihumox to measure 1) maize yield response to alley cropping, 2) apparent nitrogen recovery, 3) changes in soil organic nitrogen and carbon, and 4) to construct a partial nitrogen soil-crop system budget. Maize yield, maize nitrogen uptake, and dry matter and nitrogen yields of tree prunings were monitored for six consecutive maize crops in alley cropping systems with *Cassia siamea*, *Calliandra calothyrsus*, *Gliricidia sepium*, *Sesbania sesban*, *Cassia reticulata*, *Inga edulis*, and *Leucaena leucocephala*, and in a monocropped control treatment.

Maize yield response to alley cropping varied with tree species and cropping period. Total maize yield for the six crops in the alley cropped plots was greater than or similar to the control plot. In the alley cropped plots, maize yields declined initially and remained relatively constant thereafter. In the control plot, maize yields were relatively constant for two cropping periods and declined steadily thereafter, due to increasing nitrogen deficiency.

Nitrogen applied via tree prunings ranged from an average of 42 to 115 kg/ha per maize crop. Apparent nitrogen recovery among the tree species ranged

from 0 to 68 percent during the six cropping periods, increasing with time.

Percent apparent nitrogen recovery was greatest for *G. sepium* and *C. siamea*, followed by *I. edulis*, *C. reticulata*, and *C. calothyrsus*.

After six maize crops, surface soil organic carbon increased in all treatments, ranging from 2.7 to 7.1 g/kg. Surface soil organic nitrogen increased in the *C. calothyrsus* plot by 0.32 g/kg, with no change found in the other treatments. Subsoil organic nitrogen decreased in all treatments. A net loss of nitrogen in the soil-crop system (0 to 0.50 m soil depth) occurred in all treatments.

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## CHAPTER 1

### INTRODUCTION TO DISSERTATION RESEARCH

#### RESEARCH CONTEXT

At current rates of population increase of 2.9, 2.2, and 2.7 percent in tropical Africa, Asia, and America respectively, the number of people in the tropics, now just over 2 billion, will rise to over 3 billion in the next decade. Tropical agriculture is faced with a serious challenge of feeding about 70 percent of the world's inhabitants. Not only is increased food production essential for improving food security, but a dynamic agricultural sector is also key to a balanced and robust economic development.

Farming is a significant economic activity for a large portion of the population in tropical developing countries. The majority of farmers in the tropics depend primarily upon small-scale agriculture, supplemented with a minimum of external inputs (Harwood 1979). Approximately 60 percent farm marginal land for their livelihood, including arid and semi-arid lands, low fertility soils, hilly upland areas, and steep slopes (Huijsman and Savenije 1991). It is against this background that increases in agricultural production in the tropical developing world need to be viewed and evaluated.

Most farmers in the tropics use farming methods almost identical to those of their ancestors (Wolf 1986). Shifting cultivation and related slash-and-burn cultivation systems are still the dominant land-use systems in vast areas of the tropics (Saouma 1974). Tropical cereal yields are low compared to world and

developed country averages (FAO 1981). Average tropical rice yields are 2.0 t/ha compared to a 5.3 t/ha average in Japan, China, South Korea, and the United States. Tropical maize yields are less than half of the world average, 1.24 and 3.2 t/ha respectively, and extremely low compared to a 6.3 t/ha average in the United States and Europe. Tropical sorghum yields average 0.8 t/ha, compared to a 1.4 t/ha world average and a 3.1 t/ha average in the USA, Mexico, and Argentina.

A major constraint to increased agricultural production in the tropics is the maintenance of soil fertility, particularly of the acid, infertile soils (Oxisols and Ultisols) that dominate the humid tropics (Sanchez 1976). The traditional shifting cultivation systems rely on the bush fallow period to restore soil fertility.

However, due to demographic and economic changes, fallow periods are being reduced, resulting in land degradation and declining yields. An estimated 20 million hectares are degraded annually in the tropics by agricultural activities and overgrazing (World Resources 1992). Water and wind erosion and chemical degradation are limiting productive capacity and making it more difficult and expensive for farmers to increase food production. Continued degradation could make providing an adequate food supply for growing populations extremely difficult.

Recent emphasis on agricultural sustainability arises from an increasing awareness about the widespread problem of soil degradation and the need to conserve soil resources for long-term use rather than exploitation for short-term gain. The concept of sustainable agriculture addresses maintaining acceptable

crop productivity without degrading soil resources, while making the most efficient use of non-renewable and on-farm resources and integrating natural biological cycles and controls. Approaches to the development of sustainable agriculture in the tropics include improving shifting cultivation systems by 1) improving the effectiveness of the fallow vegetation in restoring soil fertility and controlling weeds, and 2) integrating restorative functions of the fallow vegetation into the cropping period in a form of permanent farming. Alley cropping is an attempt of the latter approach. In alley cropping, annual crops are grown between hedgerows of trees in an effort to maintain crop yields and prevent soil degradation, thus contributing to agricultural sustainability (Kang et al. 1981). The trees are periodically cut back to prevent shading of the crop, with the residues retained in the field and used as green manure.

## **PREVIOUS AND CURRENT RESEARCH**

Alley cropping as a soil nitrogen management practice has been the primary focus of alley cropping research, with the use of nitrogen fixing tree prunings as a nitrogen source for associated crops. The most commonly performed alley cropping field experiment has been to cultivate maize, often rotated with cowpeas, between rows of nitrogen fixing trees. Evaluation has consisted of crop yield response to the application and removal of tree residues supplemented with various levels of inorganic nitrogen fertilizer, and in some cases comparing these treatments with monocropping controls. Many of the

published accounts of alley cropping have been conducted at the experimental station of the International Institute of Tropical Agriculture (IITA) in Nigeria (Kang et al. 1985, Yamoah et al. 1986a, Atta-Krah and Sumberg 1987, Gichuru and Kang 1989, Lal 1989a, Siaw et al. 1991). Maize yields ranged from 1.2 to 4.5 times greater in alley cropping plots with tree prunings applied compared to monocropped plots with no application of inorganic nitrogen fertilizer (Yamoah et al. 1986a, Siaw et al. 1991). Maize yields in alley cropping with tree prunings applied were similar to yields obtained with 45 to 90 kg/ha of inorganic nitrogen fertilizer applied to monocropping treatments (Yamoah et al. 1986a, Atta-Krah and Sumberg 1987, Siaw et al. 1991). In a more detailed study conducted over a six-year period, Lal (1989a) reported maize yields in alley cropping to be similar to monocropping in five out of six crops. Maize yield reduction due to alley cropping (22%) was observed in only the second maize crop. Removing tree prunings in alley cropping systems has resulted in either decreased maize yields (Kang et al. 1985, Gichuru and Kang 1989) or no effect on maize yield (Yamoah et al. 1986a).

In the study by Kass and colleagues (1989), a negative maize yield response to alley cropping occurred at the first maize harvest. In the subsequent five maize harvests, no significant difference in maize yield was found between the alley cropped plots and the monocropped plots with no inorganic nitrogen applied.

An equally important consideration in evaluating alley cropping systems is the sustainability of crop yields over time. Three or more years data from alley

cropping experiments with maize have been published only from three sites. A three-year study by Kang and colleagues (1985) reported that maize grain yield can be sustained at about 2.0 tons/ha with continuous application of *Leucaena leucocephala* (Lam.) deWit. prunings supplemented with 20 kg P/ha, 60 kg K/ha, 10 kg Mg/ha and 2 kg Zn/ha. However, this three-year study was imposed on a previous alley cropping experiment that was modified three times using different leucaena prunings applications and various levels of inorganic nitrogen fertilizer, making it impossible to evaluate the final modified treatments for sustainability of maize yields over time (Kang et al. 1981). Lal (1989a) conducted an alley cropping experiment with maize/*L. leucocephala* and maize/*Gliricidia sepium* (Jacq.) Walp. for six years supplemented with 120 kg/ha/crop cycle of inorganic nitrogen fertilizer. Maize yield was sustained at about 4.0 t/ha for four years, when droughts occurred in the fifth and sixth year, reducing yields to about 2.5 t/ha. In a study conducted in Costa Rica, six years of data with maize/*Erythrina poeppigiana* (Walpers) O.F. Cook and maize/*G. sepium* supplemented with 130 kg/ha/yr of  $K_2O_5$  and 88 kg/ha/yr of  $P_2O_5$  showed that when variation in yield due to annual climatic fluctuations is removed, maize yields increased over time (Kass et al. 1989, Sanchez 1989).

The question of whether alley cropping systems with maize can maintain soil fertility has been the focus of research at the International Institute of Tropical Agriculture (Kang et al. 1985, Yamoah et al. 1986b, Lal 1989b, Gichuru and Kang 1989) and the Centro Agronomico Tropical de Investigacion y

Ensenanza (Kass et al. 1989). The studies at the International Institute of Tropical Agriculture were conducted on soils that were previously degraded by cultivation, whereas the study by Kass and colleagues (1989) was established on a fertile site. Therefore, different questions were addressed at the two locations: 1) will alley cropping improve degraded soils, and 2) will alley cropping maintain soil fertility. The effect of alley cropping on soil fertility has been evaluated by measuring the change in percent soil organic carbon and nitrogen over time. For the experiments conducted at the International Institute for Tropical Agriculture, established on a Oxic Paleustalf, the reported effects of alley cropping on surface soil (0-15 cm) organic carbon and nitrogen were inconsistent. Kang and colleagues (1985) found little change in soil organic carbon, Lal (1989) found a decrease in organic carbon and nitrogen, Gichuru and Kang (1989) found an increase in organic carbon and no change in organic nitrogen, and Yamoah et al. (1986) found increasing and declining organic carbon and either no change or an increase in organic nitrogen. Salazar (1991) found an increase in surface soil (0-15 cm) organic carbon and no change in organic nitrogen on a Typic Paleudult soil. Kass et al. (1989) found no change or a decrease in organic carbon and no change in nitrogen on a Typic Humitropept soil. These studies with considerable variation in site factors, number of years under alley cropping, and management practices are inconclusive about the effect of alley cropping on soil fertility.

## RESEARCH APPROACH

The objective of this study was to evaluate alley cropping as a soil nitrogen management practice for maize production, and to compare alley cropping with monocropped maize with and without the use of inorganic nitrogen fertilizer. It is hypothesized that alley cropping systems will maintain crop yield and soil fertility over time, thus contributing to agricultural sustainability. It is further hypothesized that trees in alley cropping systems can contribute to the conservation of soil resources by 1) maintaining soil organic matter through carbon fixation in photosynthesis and its transfer via tree residues, 2) accumulating nitrogen by nitrogen fixation and translocation of nitrogen from soil layers beyond the reach of annual crops, and 3) reducing nitrogen losses through uptake by trees.

The specific objectives of the present study were to 1) measure maize yield response to alley cropping and trends in yield over time, 2) estimate nitrogen applied via tree prunings and apparent nitrogen recovery by maize, 3) quantify changes in soil nitrogen and carbon levels, and 4) construct a partial nitrogen-system budget to quantify nitrogen accumulation.

The alley cropping experiment was established on a newly cleared site, after a six- to eight-year fallow period. In contrast, the majority of previous alley cropping experiments were initiated on degraded sites. The experimental design, tree species and management treatments chosen were similar to previously conducted alley cropping experiments for comparison. An additional experiment

was established in the same field of monocropped maize with various levels of inorganic nitrogen fertilizer.

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## CHAPTER 2

### ALLEY CROPPING AS A SOIL NITROGEN MANAGEMENT PRACTICE FOR MAIZE PRODUCTION: YIELD PRODUCTIVITY AND SUSTAINABILITY

#### INTRODUCTION

Maize is the second most important cereal crop grown for human food in the tropics. Tropical maize yields are low, averaging 1.24 t/ha compared to a 3.2 t/ha world average and far below the 6.3 t/ha average in the United States and Europe (CIMMYT 1992). The vast majority of tropical maize is grown on small farms in shifting agricultural systems with a minimum of external inputs (Harwood 1979). Maize is often the first crop grown after the fallow period, when available soil nutrients are highest. Yields typically decline with successive cropping as a result of soil fertility depletion, particularly on low-base status soils (Sanchez 1976), and farmers shift to sites where soil fertility has been restored by fallowing. However, demographic and economic changes have caused shortened fallow periods, resulting in limited regeneration of soil fertility. Alternative soil management practices are needed for tropical maize production, with minimal external inputs.

Alley cropping as a soil nitrogen management practice for maize production has been the focus of research at the International Institute of Tropical Agriculture (Kang et al. 1981, Kang et al. 1985, Yamoah et al. 1986, Atta-Krah and Sumberg 1987, Gichuru and Kang 1989, Lal 1989, Siaw et al. 1991), at the Centro Agronomico Tropical de Investigacion y Ensenanza (Kass

and Araya 1987, Kass et al. 1989, Sanchez 1989, Haggard 1990) and at the University of Hawaii (Guevarra 1976, Chaudhary 1984, Rosecrance et al. 1992). Alley cropping experiments with maize have been established to evaluate crop yield response to the application and removal of tree prunings, and in some cases, to compare alley cropping to monocropping controls using various levels of inorganic nitrogen. Maize yields have ranged from 1.2 to 6.0 times greater in alley cropping plots with tree prunings applied compared to monocropped plots with no application of inorganic nitrogen fertilizer (Guevarra 1976, Chaudhary 1984, Yamoah et al. 1986, Siaw et al. 1991, Rosecrance et al. 1992). In alley cropping plots with tree prunings applied, maize yields were similar to yields obtained with 45 to 90 kg N/ha of inorganic nitrogen fertilizer applied to monocropping treatments (Yamoah et al. 1986, Atta-Krah and Sumberg 1987, Siaw et al. 1991). Lower maize yields at the first maize harvest were observed by Kass and colleagues (1989) in alley cropped plots with tree prunings applied compared to the monocropped control with no inorganic nitrogen applied, with no difference in maize yield between treatments at the subsequent five maize crops. In the same study, maize yields in the monocropped treatment with 150 kg N/ha were higher than in the alley cropped plots in four out of six maize crops, with no significant difference in yield in two out of the six maize crops.

Alley cropping studies comparing maize yield response to the application and removal of tree prunings have shown inconsistent results. Kang and colleagues (1985) reported reduced maize yields in alley cropped plots with tree

prunings removed compared to tree prunings applied, suggesting competition for nutrients between trees and crops. Gichuru and Kang (1989) observed reduced maize yield with tree prunings removed, but no additional benefit in maize yield was found by supplementing the prunings with 45 or 90 kg N/ha of inorganic fertilizer. Maize yields were similar between the alley cropped plots with tree prunings applied and the plots with tree prunings removed supplemented with 45 kg N/ha of inorganic fertilizer. These findings indicate that tree prunings may compensate for nutrient competition between trees and crops. Yamoah et al. (1986) observed no difference in maize yield between alley cropped plots with tree prunings applied and removed, implying no competition between trees and crops.

It is hypothesized that the depleting effects of continued maize cropping on soil nitrogen fertility will be mitigated by alley cropping, and that alley cropping is a viable alternative to inorganic nitrogen fertilizer. The objectives of this study were to evaluate the effect of alley cropping on maize yield, and to compare alley cropping to monocropping with and without the application of inorganic nitrogen fertilizer. In the alley cropping treatments, two tree pruning management practices were evaluated (tree prunings removed and applied) to provide additional information on competition between trees and crops. The specific objectives were to 1) measure maize yield response to alley cropping (tree prunings applied) and inorganic nitrogen, 2) quantify the trend in maize yield over time, and 3) compare the effect of alley cropping with tree prunings applied and

removed on maize yield. Maize nutrition was also monitored during the experiment to verify that nitrogen was the limiting factor for maize production.

## **METHODS**

### **Site Description**

The experiments were conducted at the University of Hawaii Wailua Agricultural Experiment Station located on the island of Kauai (22° 04' N, 159° 24' W) at an elevation of 150 m. Mean annual precipitation is 2489 mm, with mean monthly precipitation seldom less than 100 mm. Temperatures range from an average monthly minimum of 20.0° C to an average monthly maximum of 25.5° C, with an absolute daily minimum and maximum of 12° C and 35° C, respectively. Monthly precipitation and average daily temperature taken during the study period are shown in Figure 2.1. Average daily solar radiation ranges from approximately 250 to 500 cal/cm<sup>2</sup>, with the higher values occurring between May and September (Figure 2.2).

The soil is derived from basic igneous rock mixed with volcanic ash, classified as a clayey, ferritic, isothermic Typic Gibbsihumox with a gravelly, silty, clay texture (Ikawa et al. 1985). Surface soil (0 to 0.25 m) organic carbon and total nitrogen are high, 3.59 percent and 0.25 percent, respectively. The soil is low in bases and phosphorus; 2.0 cmol<sub>c</sub> Ca/kg, 0.34 cmol<sub>c</sub> Mg/kg, 0.17 cmol<sub>c</sub> K/kg, and < 0.03 mg P/kg (modified Truog method). Soil pH(H<sub>2</sub>O) is 4.5. The site was under grass fallow for six to eight years.

## Experimental Design

The experimental design for the alley cropping trial was a randomized incomplete block (Figure 2.3). Ten treatments were replicated in four blocks, with four additional treatments replicated twice. The ten treatments included four tree species (*Cassia siamea* (Lam. (Mal.), *Calliandra calothyrsus* Meissn., *Gliricidia sepium* (Jacq.) Walp., and *Sesbania sesban* (L.) Merrill) each with two management practices (tree prunings applied and tree prunings removed), and two identical control treatments with no tree species and no tree prunings applied (monocropping treatment). The four additional treatments included the four tree species *Cassia reticulata* Willd., *G. sepium*, *Inga edulis* Mart., and *Leucaena leucocephala* (Lam.) deWit. (K636) with tree prunings applied. Trees were planted at a spacing of 3.0 x 0.5 m. Each plot consisted of three rows of trees six meters in length, resulting in a plot size of 9 x 6 m (Figure 2.4).

Two seed sources of *G. sepium* were evaluated. In the *G. sepium* treatment with four replications, seed was obtained from a native population in Guatemala (Samala, Retalhulea). In the *G. sepium* treatment replicated twice, seed was collected from a seed orchard in Hawaii that was established using clones from eight selected provenances.

A nitrogen response experiment of monocropped maize was established in the same field with nitrogen fertilizer (urea) application rates of 0, 50 and 100 kg/ha broadcast at each maize planting. A randomized complete block design with two replications was used (Figure 2.3).

## **Tree and Crop Management**

Tree and crop management activities are presented in Table 2.1. Four-month-old, nursery-grown seedlings were transplanted in the field in March 1988. Two maize crops were planted per year, a summer crop (April to August) and a winter crop (September to January), with the first crop planted September 1988. The trees were cut twice per crop cycle, at maize planting and approximately 65 days after maize planting when tree heights were between 1.5 and 2.0 m. The trees were first cut at approximately 0.60 m above ground level. The pruning height of the trees increased at each tree harvest, reaching approximately 0.90 m above-ground level after twelve tree harvests. Tree biomass was separated into fuelwood (stems > 0.01 to 0.02 m in diameter) and green manure/fodder components. At maize planting, green manure was incorporated into the soil to a 0.25 m depth. Green manure was applied to the soil surface at the second cutting.

Three rows of maize (Pioneer Hi-Bred International Co. singlecross hybrid X304C) were planted in the alleys. At the first cropping season, maize was planted at a spacing of 0.75 x 0.25 m. At the second and subsequent cropping seasons, maize rows were spaced 0.90 m from tree rows and 0.60 m between maize rows with a 0.25 m within row spacing to reduce potential competition between trees and crops. In the control plot, maize was planted at the same spacing and density as in the alley cropped plots, not replacing tree species with maize plants but simply eliminating the tree species (Figure 2.4).

In the nitrogen response experiment with monocropped maize, maize (Pioneer x 304C) was always planted at a spacing of 0.75 x 0.25 m. At each maize planting, 100 kg P/ha as treble superphosphate and 100 kg K/ha as muriate of potash were broadcast on all plots in both experiments.

### **Data Collection**

Grain yields were determined following the methods described by the Benchmark Soils Project (1982). Maize was harvested from a 2 x 3 m subplot, with maize yield calculations based on the actual area harvested (Figure 2.4). Prior to maize harvesting, the number of maize plants per subplot was recorded. Grain was oven dried at 70° C and corrected to 15 percent moisture content for yield determinations. Crop residues in all plots were removed from the field after each harvest.

Maize earleaf samples were taken when maize reached 50 percent silking. The entire earleaf blade below and adjacent to the topmost ear was collected from five randomly selected plants per subplot. Samples were oven dried at 70° C, ground, and analyzed for percent N, P, K, Ca, and Mg.

### **Statistical Analysis**

The data was analyzed using the General Linear Model procedure of the Statistical Analysis System (SAS) developed by the SAS Institute. Treatment means for each crop harvest were compared using Least Significant Difference

(LSD). Single degree freedom comparisons were made to evaluate the effect of trees alone (control vs. prunings removed) and the effect of alley cropping (control vs. tree prunings applied) on maize yield and nutrition. Maize grain yield treatment means between harvest dates were compared using the split plot principle, with treatment means as main plots and harvests as subplots.

## RESULTS

### Maize Yield Response to Alley Cropping

Maize yields ranged from 2.66 to 3.27 t/ha at the first harvest with no significant effect of alley cropping (tree prunings applied or removed) on maize yield (Table 2.2). A negative maize yield response to alley cropping (tree prunings applied and removed) occurred at the second maize harvest. The reduction in maize yield among alley cropping treatments with tree prunings applied was similar. Among alley cropping treatments with tree prunings removed, the reduction in maize yield was greatest with *C. calothyrsus* followed by *S. sesban*, *G. sepium*, and *C. siamea*.

At the third maize harvest, there was no effect of alley cropping with tree prunings applied on maize yield. A positive maize yield response to alley cropping with tree prunings applied began in the *G. sepium* and *C. calothyrsus* plots at the fourth harvest, and occurred in the *I. edulis*, *C. siamea*, and *C. reticulata* plots at the sixth harvest. There was no effect of alley cropping with *L. leucocephala* on maize yield. Maize yields were approximately 1.5 times higher in

the *G. sepium* and *C. calothyrsus* plots than in the control plot at the fourth harvest, increasing to 3.2 times higher at the sixth harvest (Figure 2.5A). In the *I. edulis*, *C. siamea*, and *C. reticulata* plots, maize yield was 2 to 2.5 times higher than the control plot by the sixth harvest.

The negative maize yield response to alley cropping with tree prunings removed disappeared by the fourth harvest in the *G. sepium* and *C. siamea* plots, and by the fifth harvest in the *C. calothyrsus* plot (Figure 2.5B). There was no significant difference in maize yield between the two *G. sepium* seed source treatments or between the two control treatments during the entire experiment. By the third cropping season, mortality of the *S. sesban* hedgerows exceeded 50 percent, and the *S. sesban* treatments were eliminated from further analysis.

After six cropping seasons, overall average maize yield was 41 percent higher with *G. sepium*, 30 percent higher with *C. calothyrsus*, 20 percent higher with *C. siamea*, 13 percent higher with *I. edulis*, 2 percent higher with *C. reticulata*, and equal with *L. leucocephala* in the alley cropped plots with tree prunings applied compared to the control plot. In the control plot, overall average maize yield after six cropping seasons was 41 percent higher than *C. calothyrsus*, 17 percent higher than *G. sepium*, and 8 percent higher than *C. siamea* with tree prunings removed.

### **Maize Yield Response to Inorganic Nitrogen Fertilizer**

At the first and second harvests (1989), maize yields in the nitrogen-fertilized monocropping experiment were roughly 3.5 t/ha with no yield response to nitrogen observed (Figure 2.6, Table 2.3). A positive maize yield response to nitrogen fertilizer began in 1990. In 1991, maize yields increased by 31 and 17 kg/ha per kg of inorganic nitrogen applied during the summer and winter crops, respectively.

### **Trends in Maize Yield**

Maize plant density varied among planting dates (Table 2.4), primarily as a result of pheasant damage to young seedlings. However, there was no significant difference in maize plant density between treatments at each maize harvest. Seasonal fluctuation in maize yield was observed, with higher overall harvest means generally occurring in the summer planting seasons (April to August).

During the winter and summer cropping seasons, maize yields declined steadily in the control plot (Figure 2.7). In the alley cropped plots with tree prunings applied, maize yields declined during the winter cropping season, but remained relatively constant during the summer cropping seasons, with the exception of the plots with *G. sepium* and *C. calothyrsus*. In the *G. sepium* and *C. calothyrsus* plots, maize yields increased during the latter summer crops. In the alley cropped plots with tree prunings removed, maize yields declined initially

during the winter cropping season and remained relatively constant during the summer cropping seasons (Figure 2.8).

In the monocropping maize experiment, maize yields declined continuously in the treatment with no nitrogen applied during the summer and winter cropping seasons, similar to the control treatment in the alley cropping experiment (Figure 2.9). Maize yields in the 50 kg N/ha treatment remained relatively constant during the winter and summer cropping seasons until the latter cropping periods when yields declined in both seasons. In the 100 kg N/ha treatment, maize yields remained relatively constant during the winter and summer cropping seasons.

### **Maize Nutrition**

In the alley cropping plots with tree prunings applied and the control plot, maize yield was best correlated with maize earleaf nitrogen concentration, followed by maize earleaf calcium concentration (Table 2.5). Positive correlations between maize yield and maize earleaf nutrient concentrations were observed with all nutrients at the last maize harvest. Maize earleaf nitrogen concentration was positively correlated with maize earleaf calcium at the fourth and sixth maize harvests, and with maize earleaf magnesium at the sixth maize harvest. In the alley cropping plots with tree prunings removed and the control plot, similar positive correlations between maize yield and maize earleaf nutrient concentrations were observed, but at earlier maize harvests (Table 2.6).

In the maize monocropping experiment with various levels of inorganic nitrogen applied, maize yield was most consistently correlated with maize earleaf nitrogen and potassium concentrations (Table 2.7). Maize earleaf nitrogen concentration was positively correlated with maize earleaf potassium concentration at the third and sixth harvest.

Beginning at the third maize harvest, maize earleaf nitrogen, phosphorus, calcium, and magnesium concentrations were generally higher in the alley cropped plots with tree prunings applied than the control plot, although not always statistically higher (Figures 2.10 to 2.14). Maize earleaf nitrogen concentrations were statistically higher than the control in the *C. calothyrsus* and *G. sepium* alley cropping plots beginning at the third maize crop, in the *C. siamea* plots beginning at the fifth crop, and in the *I. edulis* plots at the sixth crop (Figure 2.10, Table A2.2). There was no effect of alley cropping with *C. reticulata* and *L. leucocephala* on maize earleaf nitrogen concentration at all six crops. The difference in maize earleaf nitrogen concentration between the alley cropped plots and the control plot increased with time, reaching roughly 70 percent higher for *C. calothyrsus* and *G. sepium* and 40 percent higher for *C. siamea* and *I. edulis* at the sixth maize crop. In all treatments, earleaf nitrogen concentration dropped from sufficient levels to deficient levels (less than 25 g/kg) by the second or third maize crop (Table A2.1)

Maize earleaf phosphorus concentration was higher than the control in most alley cropped plots during the latter winter maize crops (Figure 2.11, Table

A2.3). In the latter summer crops, phosphorus concentration in maize earleaf samples was higher than the control in only the *C. calothyrsus* and *G. sepium* alley cropping plots, with the difference between the alley cropping plots and the control decreasing with time. Maize earleaf phosphorus concentrations were in the sufficiency range in the winter crops, but closer to the low range in the summer crops.

There was no significant difference in maize earleaf potassium concentration between the control and the alley cropping plots in the first five maize crops (Figure 2.12, Table A2.4). At the sixth crop, maize earleaf potassium concentration was roughly 16 percent higher than the control in the *C. calothyrsus*, *G. sepium*, and *C. siamea* alley cropping plots. Potassium concentration in maize earleaf samples was in the sufficiency range for all treatments at all six crops and remained relatively constant over time.

Maize earleaf calcium concentrations were higher in the *C. calothyrsus* and *G. sepium* alley cropped plots than the control beginning at the third maize harvest and in the *C. siamea* plot beginning at the fourth maize harvest (Figure 2.13, Table A2.5). The difference in maize earleaf calcium concentration between the control and the alley cropping plots increased over time. Maize earleaf calcium concentrations were in the sufficiency range for all treatments at all six crops and decreased over time.

Significantly higher maize earleaf magnesium concentrations were found in the *C. calothyrsus*, *G. sepium*, and *I. edulis* plots compared to the control at the

third maize harvest and in the *C. calothyrsus* plot at the sixth maize harvest (Figure 2.14, Table A2.6). The difference in maize earleaf magnesium concentrations between the *C. calothyrsus* plot and the control decreased over time. Maize earleaf magnesium concentration was in the low range for all treatments at all six crops and decreased with time in all plots.

In the alley cropping plots with tree prunings removed, maize earleaf nutrient concentrations were lower than the control at the second and third maize crop and lowest in the *C. calothyrsus* plot (Figures 2.15 to 2.19). Maize earleaf nitrogen, phosphorus, calcium, and magnesium concentrations were significantly lower in the *C. calothyrsus* plot compared to the control at the second maize crop. At the third harvest, only maize earleaf nitrogen and potassium concentrations were lower in the *C. calothyrsus* plot compared to the control. Interestingly, maize earleaf phosphorus concentrations were higher in the *C. calothyrsus* plot than the control at the third maize crop and thereafter. In the *G. sepium* plot, maize earleaf nitrogen and phosphorus concentrations were lower than the control at the second maize crop, with only potassium concentrations lower than the control at the third harvest. *C. siamea* trees had little effect on maize nutrition, with only maize earleaf potassium concentrations lower than the control at the third harvest.

The use of inorganic nitrogen had a positive effect on maize earleaf nitrogen and potassium concentrations beginning at the third maize harvest and on maize earleaf calcium concentration at the latter maize harvests (Figures 2.20

to 2.24). There was little effect of inorganic nitrogen on maize earleaf phosphorus and magnesium concentrations during the six maize crops. Maize earleaf nitrogen concentration in the 100 kg N treatment was in the sufficiency range at most maize harvests but declined to deficient levels in the 50 kg N treatment at the fourth maize harvest and in the 0 kg treatment at the second harvest. Maize earleaf magnesium concentrations were in the low range for all treatments at all six maize crops and declined over time in all treatments.

## DISCUSSION

There was little effect of alley cropping on maize yield during the winter cropping seasons, most likely as a result of low nutrient demand. Solar radiation for winter plantings in Hawaii is limited, and winter maize yields are generally half those of summer (Jong et al. 1982, Brewbaker 1985). Nitrogen appears to be the limiting nutrient for maize production in both experiments, as indicated by 1) the positive response to applied inorganic nitrogen, 2) the decline in maize earleaf nitrogen from sufficient to deficient levels over time, and 3) the positive correlation between grain yield and maize earleaf nitrogen concentrations. The effect of nitrogen on maize yield is most evident in the nitrogen fertilizer response experiment. During the six cropping periods, maize earleaf phosphorus, potassium and calcium were in the sufficiency range in all treatments. Maize earleaf calcium and magnesium concentrations declined over time in all alley cropping treatments, with only Mg levels dropping below sufficiency range. It is

most likely that other nutrients or the balance among nutrients may contribute to reduced yields over time. Significant correlations among maize earleaf nutrient concentrations make it difficult to conclude that, over time, nitrogen alone is the limiting factor for maize production.

Maize yield response to alley cropping with tree prunings applied ranged from no response for the first crop to a negative response for the second crop, followed by a positive response beginning in the fourth crop. A positive maize yield response to alley cropping with tree prunings applied occurred at the fourth crop in two out of the six alley cropping tree species tested, and in five out of six at the sixth crop. In most cases, a positive maize yield response to alley cropping occurred because of declining maize yields in the control plot and not as a result of increasing maize yields in the alley cropping plots. By the sixth crop, maize yields in the alley cropped plots with tree prunings applied ranged from 1.7 to 3.3 times higher than the control. The greater maize yield observed in the alley cropped plots with tree pruning applied compared to the control in the sixth crop are similar to yield increases found at other sites at the first or second crop (Chaudhary 1984, Yamoah et al. 1986, Siaw et al. 1991, Rosecrance et al. 1992). All of the above-mentioned studies were established on sites deficient in soil nitrogen for maize production, contributing to the initial positive response to alley cropping. In contrast, this experiment was established on a soil with sufficient soil nitrogen for maize production in the first crop.

Although in most cases greater maize yields were observed in the alley cropped plots with tree prunings applied than the control in the latter crops, total maize yield for the six crops was significantly higher in only three of the six tree species tested. Total maize yield for the six crops was roughly 1.3 times greater in the *G. sepium*, *C. calothyrsus*, and *C. siamea* alley cropped plots than the control. In the *C. reticulata*, *I. edulis*, and *L. leucocephala* plots, total maize yield for the six crops was similar to the control.

Maize yields in the nitrogen fertilized monocropping experiment were similar to yields obtained in the alley cropping plots with tree prunings applied for the first maize crop (Figure 2.25). For the second crop, maize yields in the monocropping experiment were approximately two times higher than in the alley cropping plots. The difference in maize yield between the monocropping treatments in the fertilizer trial and the alley cropping plots decreased with time. By the third maize harvest, maize yield in the monocropping treatment with no inorganic nitrogen applied were similar to some of the alley cropping treatments. By the fifth maize harvest, maize yields in some of the alley cropping plots were similar to the monocropping treatment with 50 kg N/ha applied. Maize yields in the alley cropped plots, however, never reached yields obtained in the monocropping treatment with 100 kg N/ha applied.

Total maize yield for the six crops in the *G. sepium* and *C. calothyrsus* alley cropping plots were similar to the monocropped plots with no nitrogen fertilizer applied, despite the reduction in crop area in the alley cropping plots. Total

maize yield for the six crops in the monocropping treatment with 50 kg N/ha applied were 1.3 to 1.8 times greater than the alley cropping treatments, and 1.5 to 2.2 times greater in the 100 kg N/ha treatments.

Although total maize yield for the six crops in the alley cropped plots were not substantially higher than in the control plot or reached average yields obtained in the nitrogen fertilizer trial, the trend in maize yield paints a more promising picture of alley cropping. The variability in maize plant density between cropping dates and the seasonal difference in yield makes it difficult to interpret yield trends. Figure 2.26 is an attempt to illustrate maize yield trends in alley cropping systems and in monocropping systems with and without nitrogen fertilizer based on the assumptions that 1) maize yields were reduced by 40 percent during the winter crops compared to summer crops (Jong et al. 1982, Brewbaker 1985), and 2) the effects of changes in maize density on maize yield comply with the model developed by Carmer and Jackobs (1965). Carmer and Jackobs (1965) generated a curve depicting the relationship between maize grain yield per unit area and plant density. The curve is always the same when yield and density are expressed as percentages of maximum yield and optimum plant density. Optimum plant density for this study was assumed to be 50,000 plants/ha at each cropping period. Rossman and Cook (1966) reviewed many plant characteristics affected by density. They indicated that published results show few instances where maize yields continued to increase above 45,000 to 50,000 plants/ha, unless irrigation was applied. However, there is no single

recommendation for all conditions because optimum plant density varies depending on maize variety, planting pattern, soil fertility, and climatic conditions.

In Figure 2.26, maize yields remained relatively constant for two cropping periods and continuously declined thereafter in the alley cropping trial control plot and in the monocropping plot with no inorganic nitrogen applied, as is typical in shifting cultivation systems. Only in the 100 kg N/ha treatment were maize yields maintained over time. The application of 50 kg N/ha was not sufficient to maintain maize yields for more than four cropping seasons. In the alley cropping plots with tree prunings applied, maize yields declined initially, and remained relatively constant thereafter, except for maize yields in the *L. leucocephala* and *C. reticulata* plots. It does appear that in some of the alley cropping treatments maize yields are beginning to increase slightly but do not reach initial yield levels. However, the imprecision in the transformed data make it tenuous to validate an increase in maize yields over time. Continued maize yield information is needed to confirm this hypothesis. The trend in maize yield in the alley cropping treatments with tree prunings applied and removed are somewhat similar, but with a greater decline in yield when tree prunings are removed, particularly with *C. calothyrsus*.

Removing tree prunings in alley cropping systems resulted in a substantial reduction in maize yield compared to the control plot, indicating competition between trees and crops. Lower maize yields and maize earleaf nutrient concentrations in the *C. calothyrsus* and *G. sepium* alley cropped plots with tree

prunings removed compared to the control plot suggest nutrient competition. However, lower maize yields but not maize earleaf nutrient concentrations were found with *C. siamea*, implying that competition for light may also have been a factor in reducing maize yields. Competition between trees and crops in alley cropping systems has been documented in a number of studies. Crop yields have been reported to be significantly reduced in crop rows adjacent to tree rows, with yields increasing with distance from tree rows (Kang et al. 1981, Evensen 1989, Rosecrance et al. 1992, Haggard and Beer 1993, Salazar et al. 1993).

In summary, the results of these experiments support the hypothesis that the depleting effects of continued maize cropping on soil nitrogen fertility can be mitigated by alley cropping, eliminating the continuous decline in maize yields often found in shifting agricultural systems when no inorganic nitrogen is applied. However, initial maize yields and soil nitrogen availability in the alley cropping treatments with tree prunings applied were not maintained over time, in part due to competition between trees and crops, and substantial overall yield benefits for the six crops were not always realized. Although maize yields eventually reached similar levels to those obtained with 50 kg N/ha applied in two of the six alley cropping systems evaluated, the use of inorganic nitrogen produced much higher overall maize yields for the six crops than alley cropping with tree prunings applied. It does appear, however, that the crop yield benefits of alley cropping accrue over time.

Table 2.1. Schedule of tree and crop management activities.

DATE	ACTIVITY
March 21, 1988	Trees planted
September 1, 1988	Trees cut
September 12, 1988	Maize planted - Crop 1
October 28, 1988	Trees cut
January 10, 1989	Maize harvested
April 10, 1989	Trees cut
April 14, 1989	Maize planted - Crop 2
June 14, 1989	Trees cut
August 14, 1989	Maize harvested
September 12, 1989	Trees cut
September 19, 1989	Maize planted - Crop 3
November 20, 1989	Trees cut
January 10, 1990	Maize harvested
April 17, 1990	Trees cut
April 24, 1990	Maize planted - Crop 4
June 25, 1990	Trees cut
September 12, 1990	Maize harvested
September 26, 1990	Trees cut
October 10, 1990	Maize planted - Crop 5
December 5, 1990	Trees cut
February 14, 1991	Maize harvested
April 24, 1991	Trees cut
May 1, 1991	Maize planted - Crop 6
June 25, 1991	Trees cut
August 29, 1991	Maize harvested

Table 2.2. Effect of alley cropping on maize grain yield in t/ha, adjusted to 15% moisture content.

TREATMENT	MAIZE HARVEST						MEAN
	Winter 1/89	Summer 8/89	Winter 1/90	Summer 9/90	Winter 2/91	Summer 8/91	
	- t/ha -						
CONTROL <sup>a</sup>	2.73	3.42	2.03	1.96	1.14	1.25	2.09
APPLIED <sup>b</sup> :							
<i>G. sepium</i> <sup>c</sup>	3.27	2.74	2.46	3.18	1.83	4.16	2.94
<i>G. sepium</i> <sup>d</sup>	2.90	2.83	2.46	3.26	1.58	3.80	2.81
<i>C. calothyrsus</i>	3.07	2.57	2.11	3.06	1.59	3.85	2.71
<i>C. siamea</i>	2.70	2.88	2.14	2.51	1.42	3.32	2.50
<i>I. edulis</i>	2.66	2.57	1.85	2.50	1.83	2.83	2.37
<i>L. leucocephala</i>	2.75	2.40	1.70	2.12	1.47	2.11	2.09
<i>C. reticulata</i>	2.94	2.49	1.99	1.96	0.89	2.56	2.14
<i>S. sesban</i>	2.87	2.61	--	--	--	--	
REMOVED <sup>e</sup> :							
<i>C. siamea</i>	2.90	2.47	1.46	2.14	0.97	1.71	1.94
<i>G. sepium</i> <sup>c</sup>	2.85	2.05	1.48	1.77	1.06	1.46	1.78
<i>C. calothyrsus</i>	2.89	1.86	1.04	1.20	0.68	1.29	1.49
<i>S. sesban</i>	2.73	2.06	--	--	--	--	--
LSD <sub>0.05</sub> between:							
4 rep trts	0.61	0.53	0.59	0.77	0.65	0.76	
2 rep trts	0.87	0.75	0.75	1.09	0.92	1.07	
4 & 2 rep trts	0.63	0.65	0.65	0.95	0.78	0.93	

<sup>a</sup>control plot means per block, <sup>b</sup>tree prunings applied to crop field, <sup>c</sup>Samala, Retalhulea seed source, <sup>d</sup>seed orchard seed source, <sup>e</sup>tree prunings removed from crop field

Table 2.3. Effect of nitrogen fertilizer (urea) on maize grain yield in t/ha, adjusted to 15% moisture content.

TREATMENT	MAIZE HARVEST						MEAN
	Winter 1/89	Summer 8/89	Winter 1/90	Summer 9/90	Winter 2/91	Summer 8/91	
	- t/ha -						
0 N kg/ha	3.55	5.32	2.70	3.63	1.38	2.57	3.19
50 N kg/ha	3.43	5.43	3.53	4.83	2.11	3.94	3.88
100 N kg/ha	3.44	5.73	3.57	5.51	3.10	5.67	4.50
LSD <sub>0.05</sub>	1.24	1.43	.85	.64	1.30	.90	.61

Table 2.4. Maize plant density, in number of plants per hectare.

TRIAL	MAIZE HARVEST					
	Winter 1/89	Summer 8/89	Winter 1/90	Summer 9/90	Winter 2/91	Summer 8/91
Alley Cropping	38,087	19,954	31,913	31,112	23,102	35,625
N Fertilizer	50,370	46,667	30,000	41,111	33,333	38,888

Table 2.5. Correlation coefficients of maize grain yield versus maize earleaf nutrient concentrations at silking for the alley cropped plots with tree prunings applied and control plot at each maize crop, (n=24).

MAIZE HARVEST	N	P	K	Ca	Mg
1/89 Winter	0.28	0.35	0.25	0.13	0.05
8/89 Summer	-0.34	0.02	0.07	-0.11	0.32
1/90 Winter	0.39	0.32	-0.04	0.06	0.12
9/90 Summer	0.71***	0.32	0.26	0.59**	0.32
2/91 Winter	0.35	0.58**	0.14	0.35	0.26
8/91 Summer	0.82***	0.51*	0.51*	0.73***	0.47*

\*p<0.05; \*\*p<0.01; \*\*\*p<0.001

Table 2.6. Correlation coefficients of maize grain yield versus maize earleaf nutrient concentrations at silking for the alley cropped plots with tree prunings removed and the control plot at each maize crop, (n=16).

MAIZE HARVEST	N	P	K	Ca	Mg
1/89 Winter	0.16	0.01	-0.17	0.47	0.35
8/89 Summer	0.67**	0.43	-0.14	0.56**	0.41
1/90 Winter	0.73**	-0.57*	0.58*	0.13	-0.16
9/90 Summer	0.58*	-0.62*	-0.27	0.46	0.38
2/91 Winter	0.18	-0.18	0.39	0.42	0.05
8/91 Summer	0.18	-0.42	0.19	0.42	0.18

\*p<0.05; \*\*p<0.01; \*\*\*p<0.001

Table 2.7. Correlation coefficients of maize grain yield at each harvest versus maize earleaf nutrient concentrations at silking in the N fertilizer experiment, (n=6).

MAIZE HARVEST	N	P	K	Ca	Mg
1/89 Winter	0.38	0.19	-0.22	0.48	0.22
8/89 Summer	0.30	0.02	0.42	0.51	0.43
1/90 Winter	0.90*	0.54	0.92**	-0.38	-0.28
9/90 Summer	0.89*	0.79	0.48	0.74	-0.16
2/91 Winter	0.62	0.66	0.89	0.94**	-0.67
8/91 Summer	0.98***	0.93**	0.99***	0.53	-0.48

\*p<0.05; \*\*p<0.01; \*\*\*p<0.001

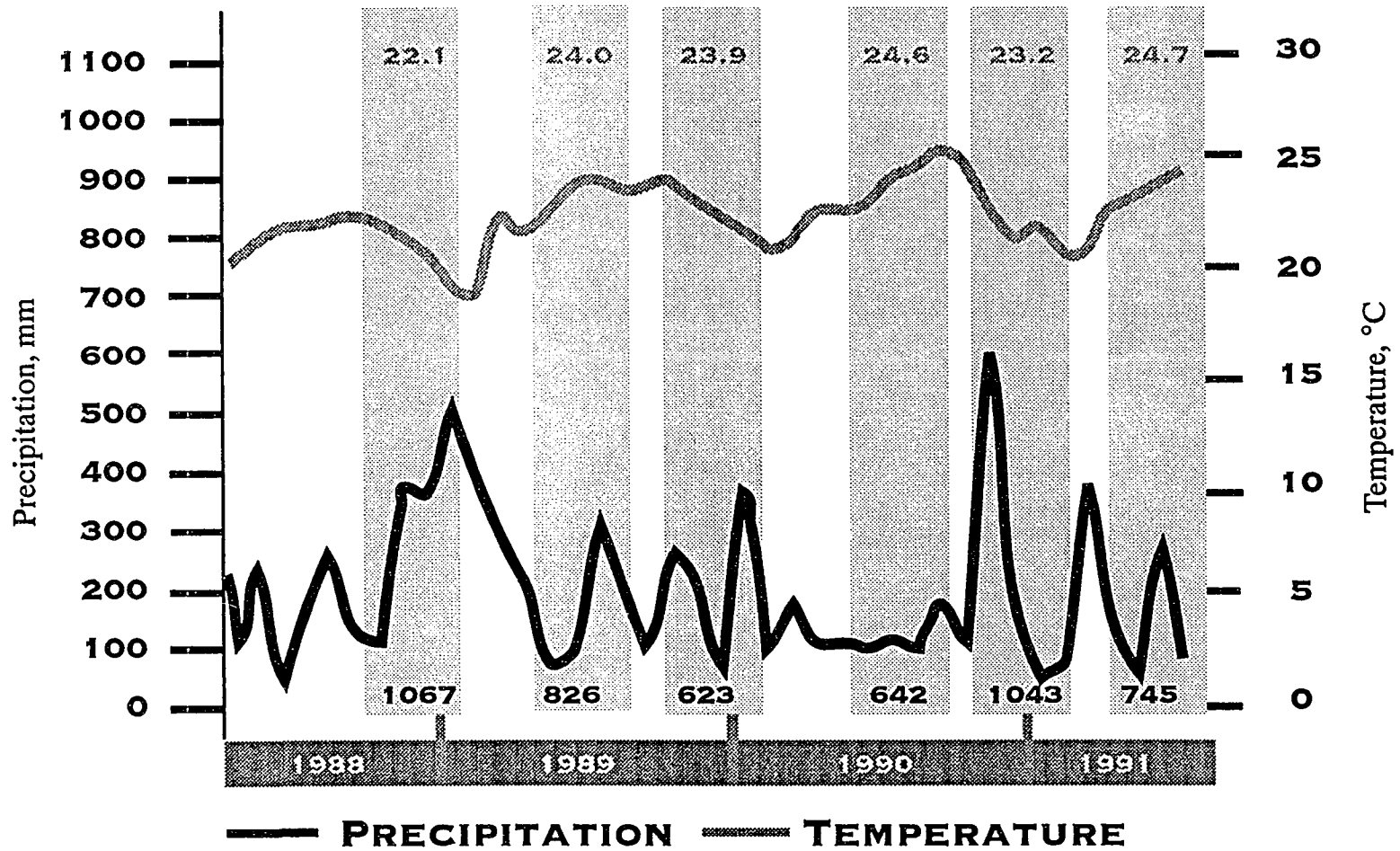


Figure 2.1. Monthly precipitation and average daily temperature during the research period. Bars represent maize cropping periods with average daily temperature and total precipitation given for each cropping period.

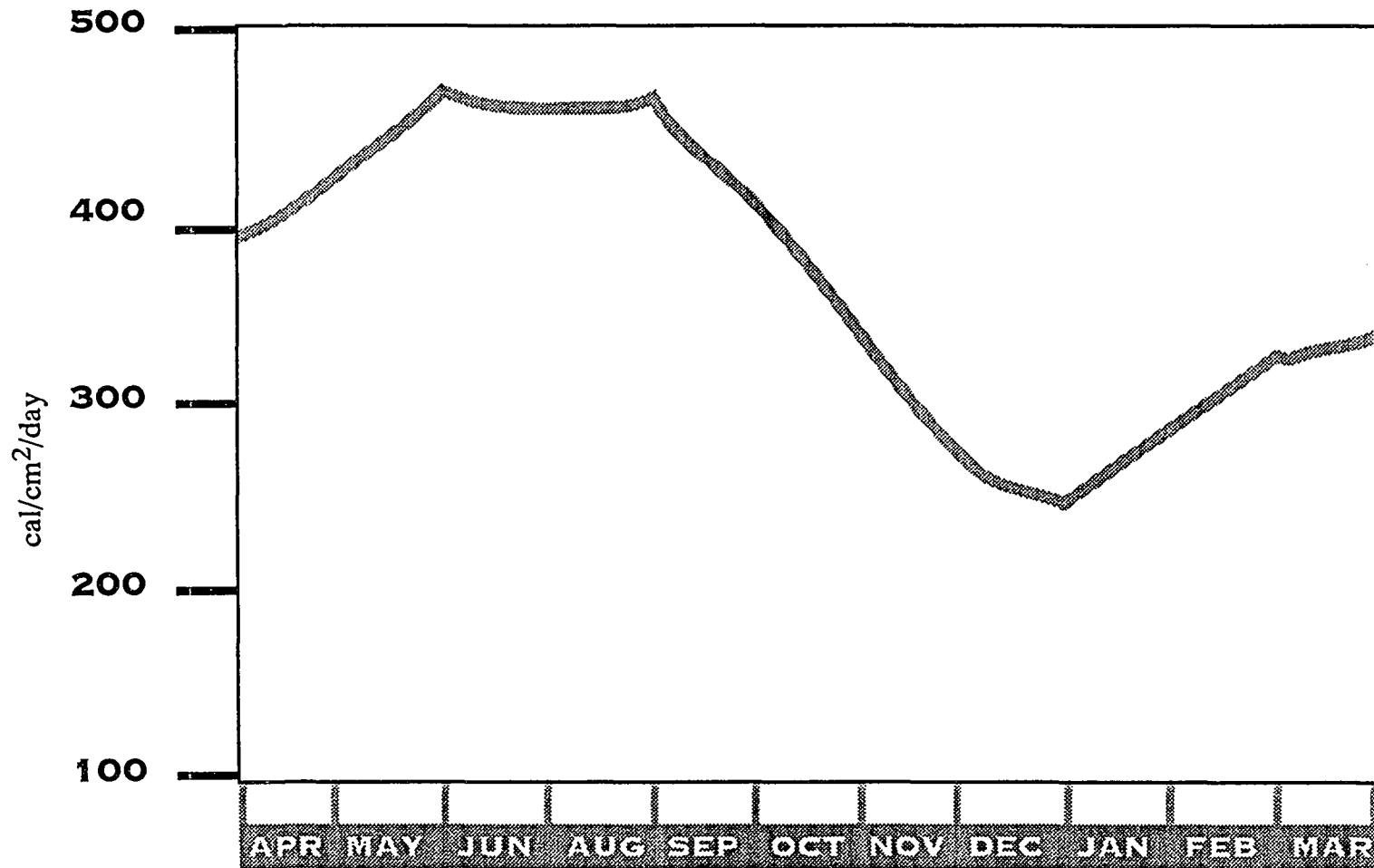
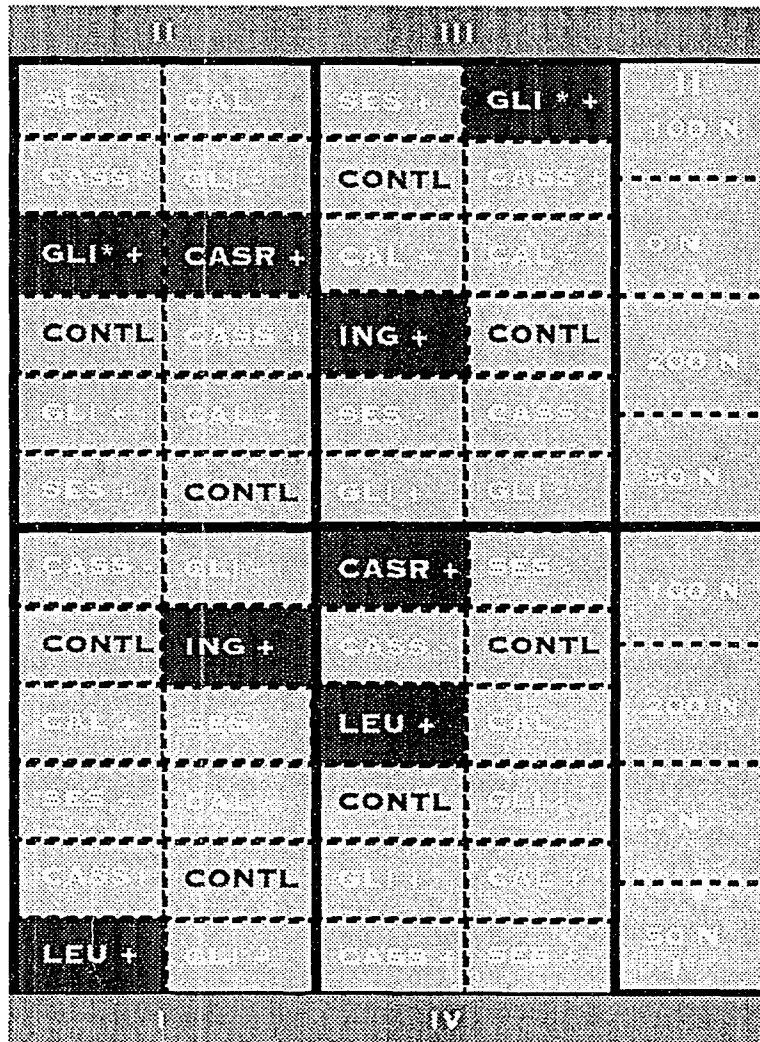


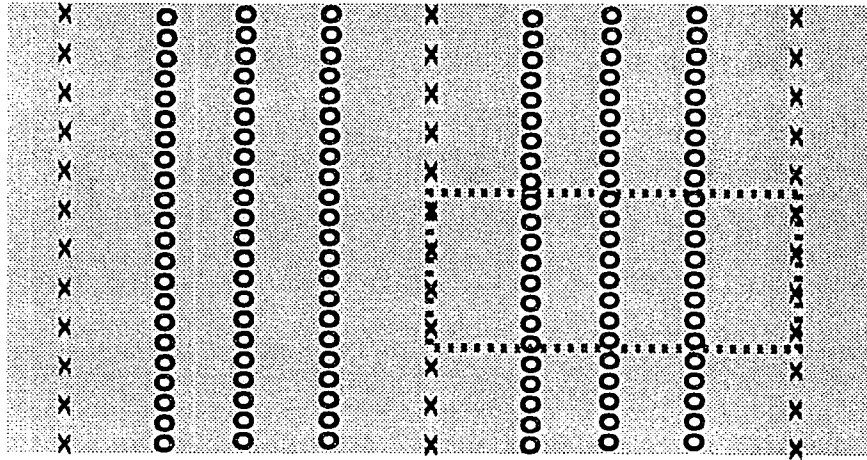
Figure 2.2. Mean monthly solar radiation taken at the Lihue Plantation Station #1061.3 (Lat. 22°3'; Long. 59°24'; 504 ft.); mean of 13 years data (1962-1975).



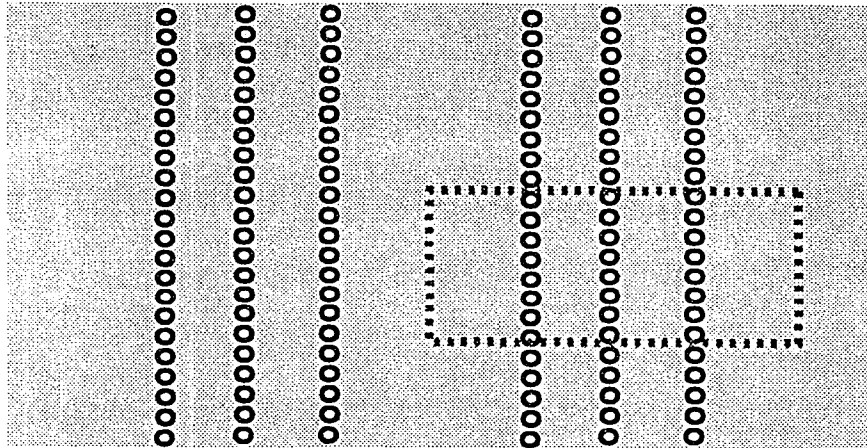
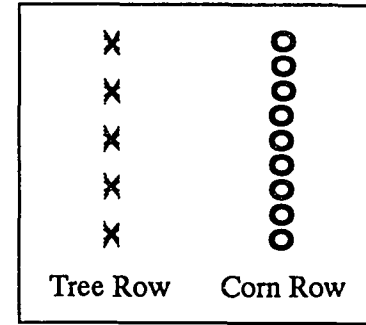
## LEGEND

- CAL Calliandra calothyrsus  
 GLI Gliricidia sepium  
     Samala, Retalhulea seed source  
 CASS Cassia siamea  
 SES Sesbania sesban  
 CASR Cassia reticulata  
 GLI\* Gliricidia sepium  
     Seed orchard seed source  
 ING Inga edulis  
 LEU Leucaena leucocephala
- + TREE PRUNING ADDED  
 - TREE PRUNING REMOVED

Figure 2.3. Diagram of experimental design.



A



B

Figure 2.4. Diagram of plots and subplots in experimental design. A. Alley cropping treatments. B. Control plot treatments.

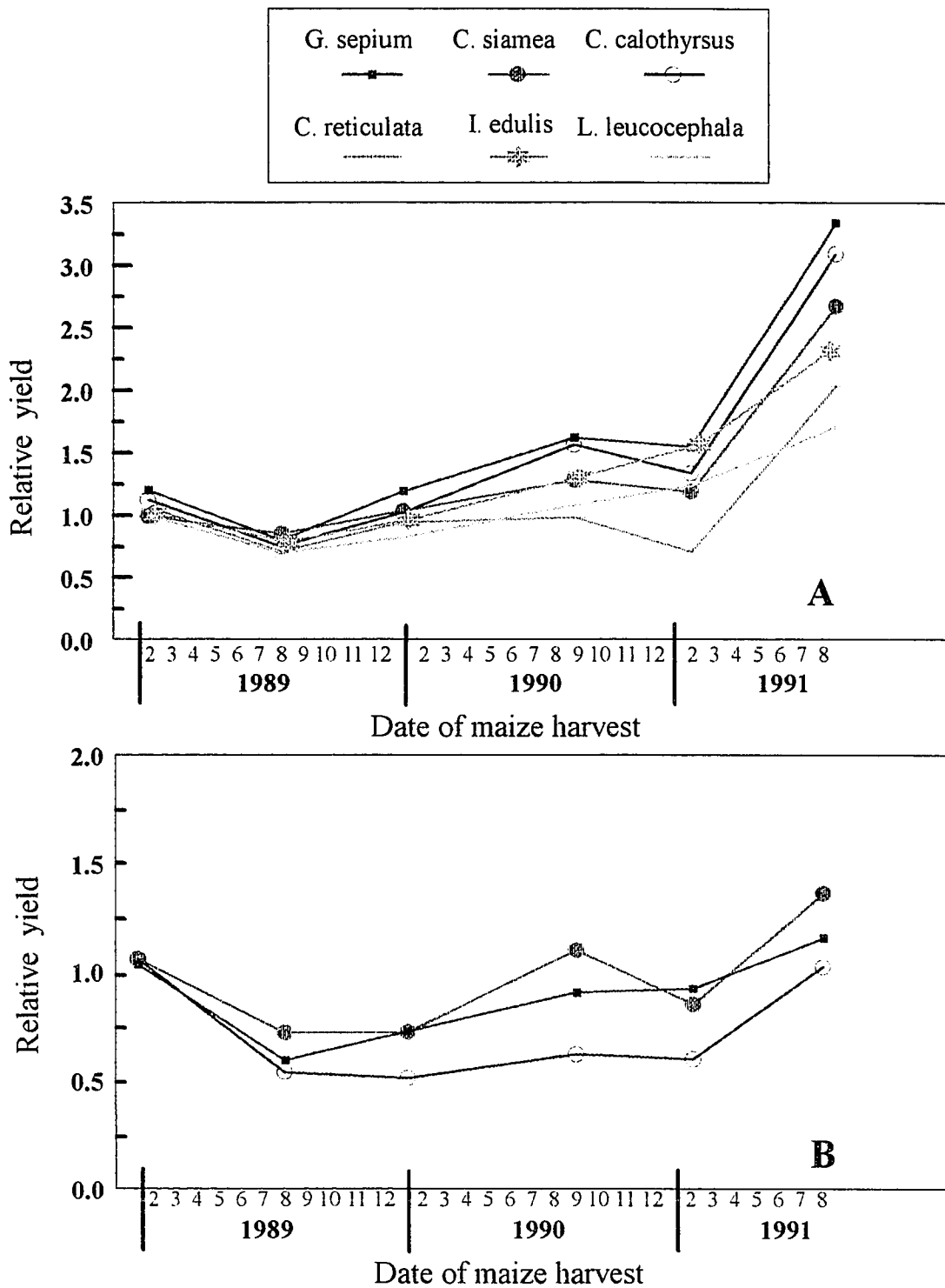


Figure 2.5 Relative yield ratio (alley cropping/control plot). A. Tree prunings applied. B. Tree prunings removed.

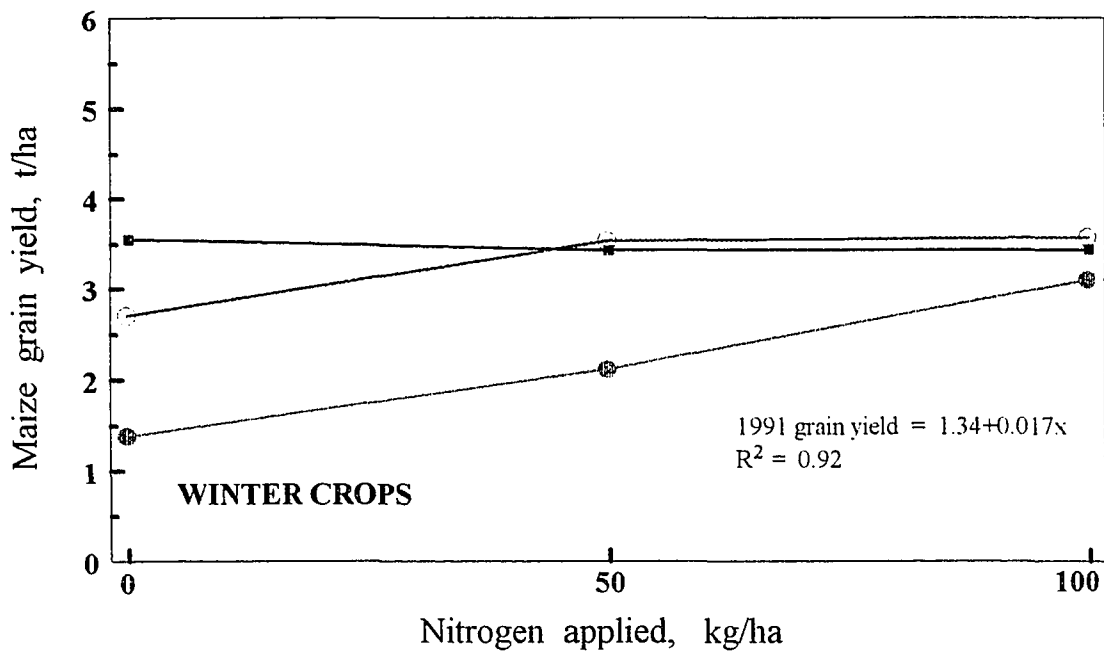
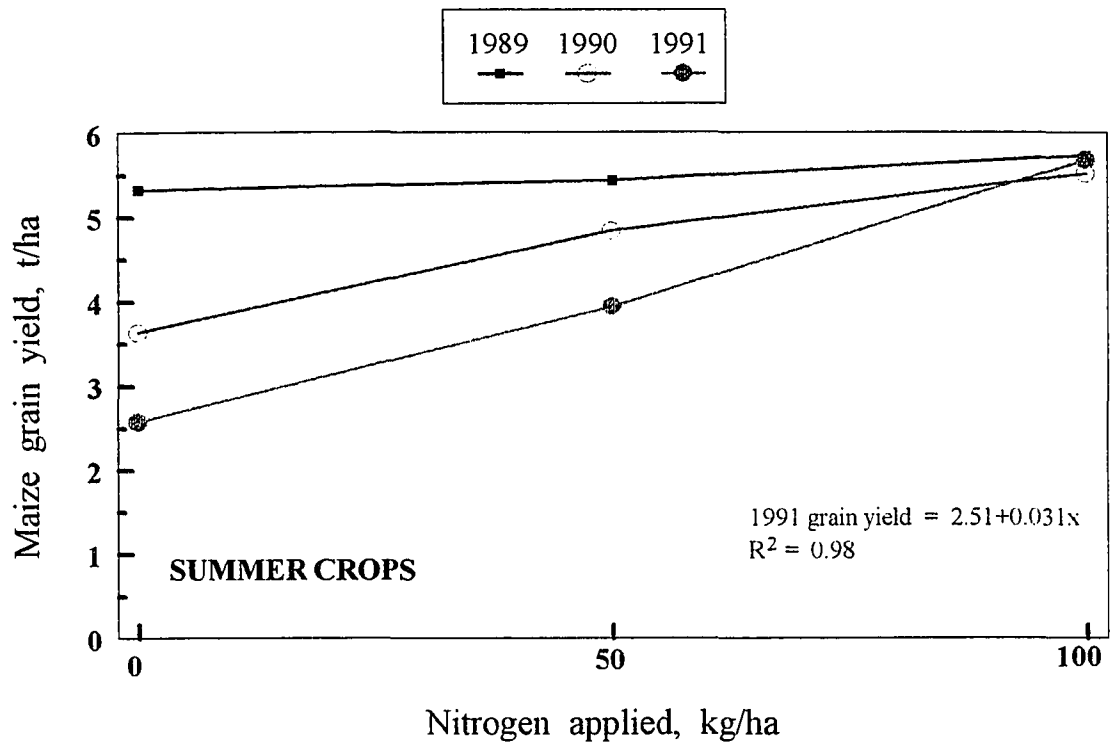


Figure 2.6 Relationship between maize grain yield (t/ha at 15% moisture) and nitrogen applied.

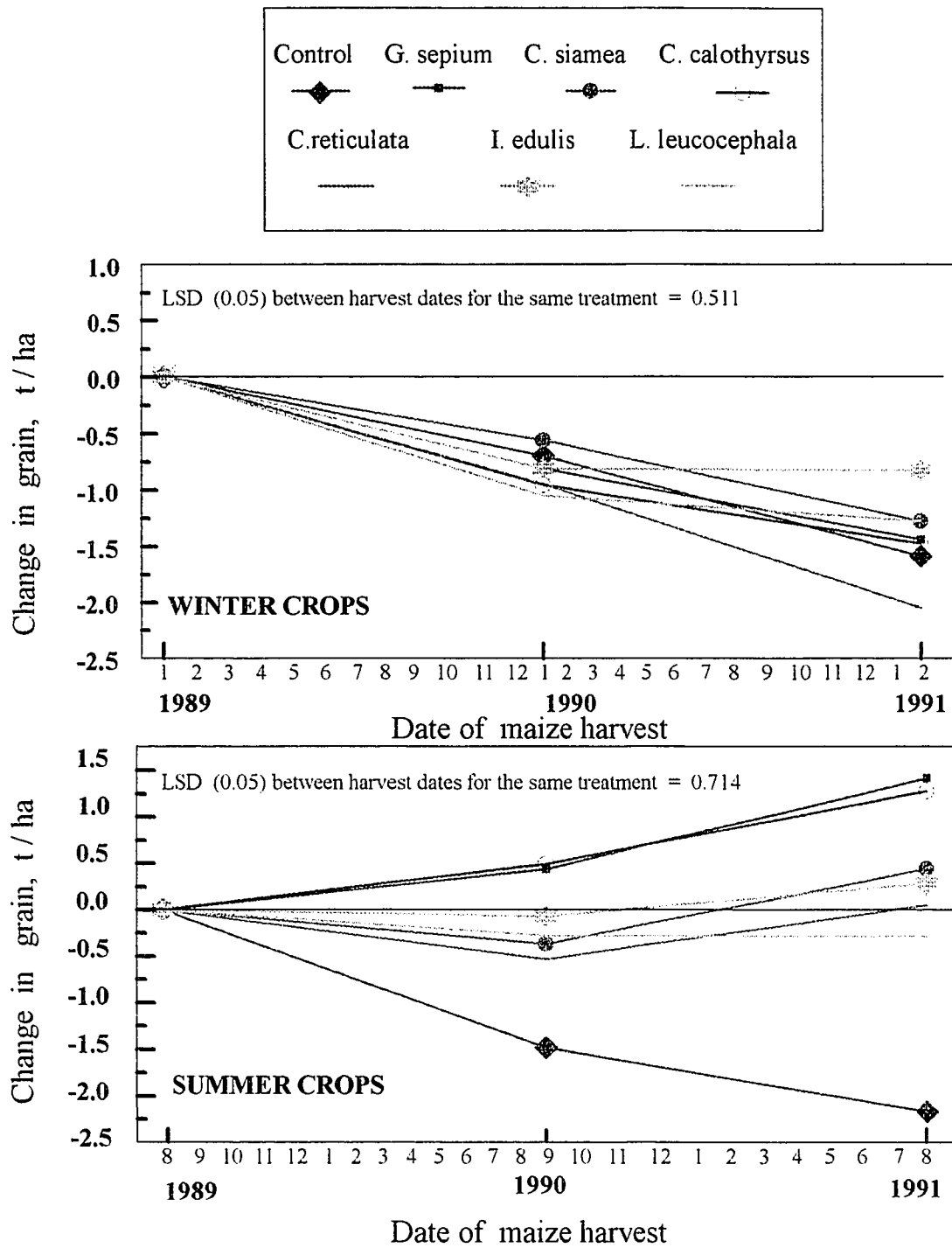


Figure 2.7 Comparison of the trend in maize grain yield over time between the alley cropped plots with tree prunings applied and the control plot.

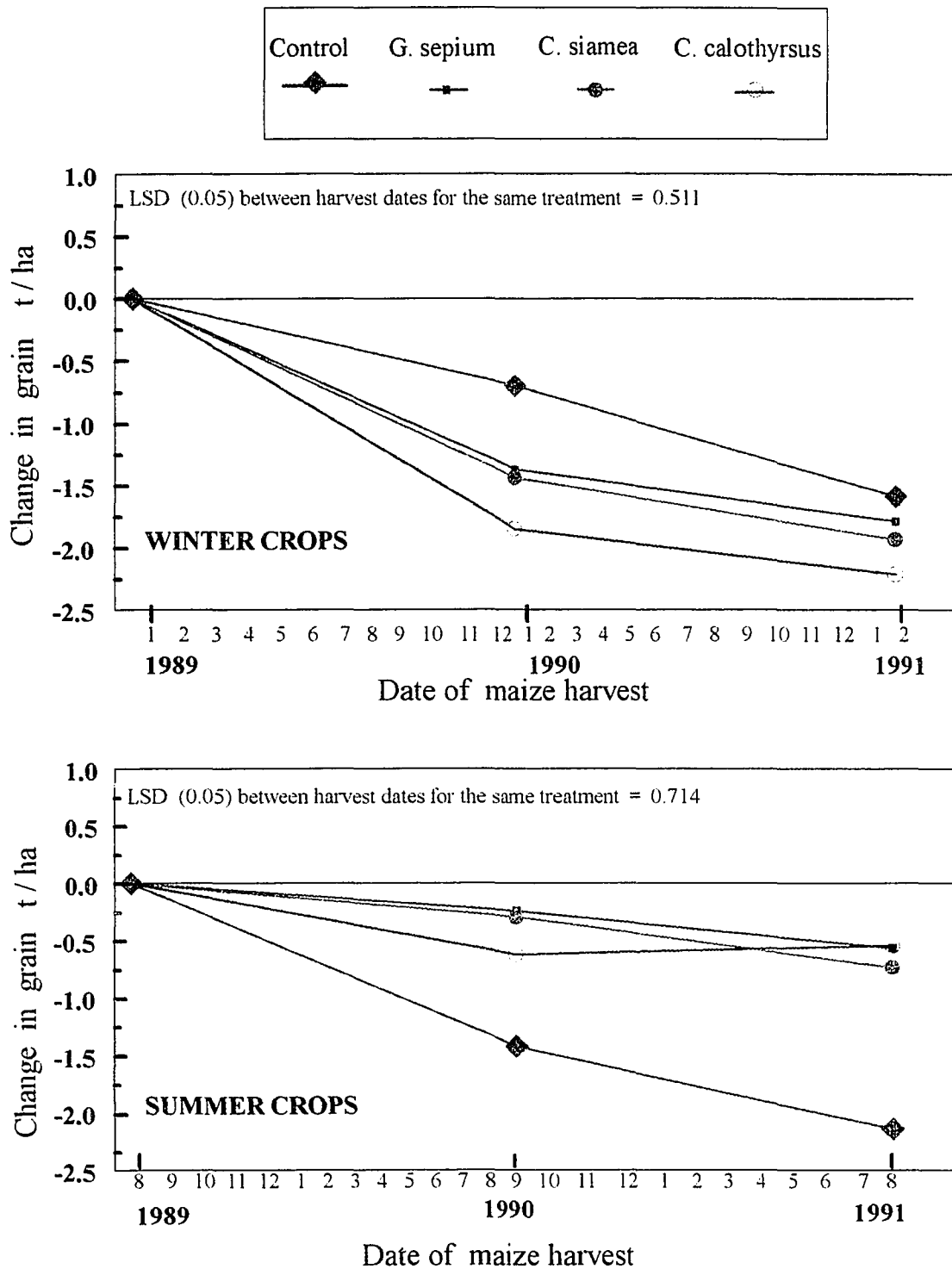


Figure 2.8 Comparison of the trend in maize grain yield over time between the alley cropped plots with tree prunings removed and the control plot.

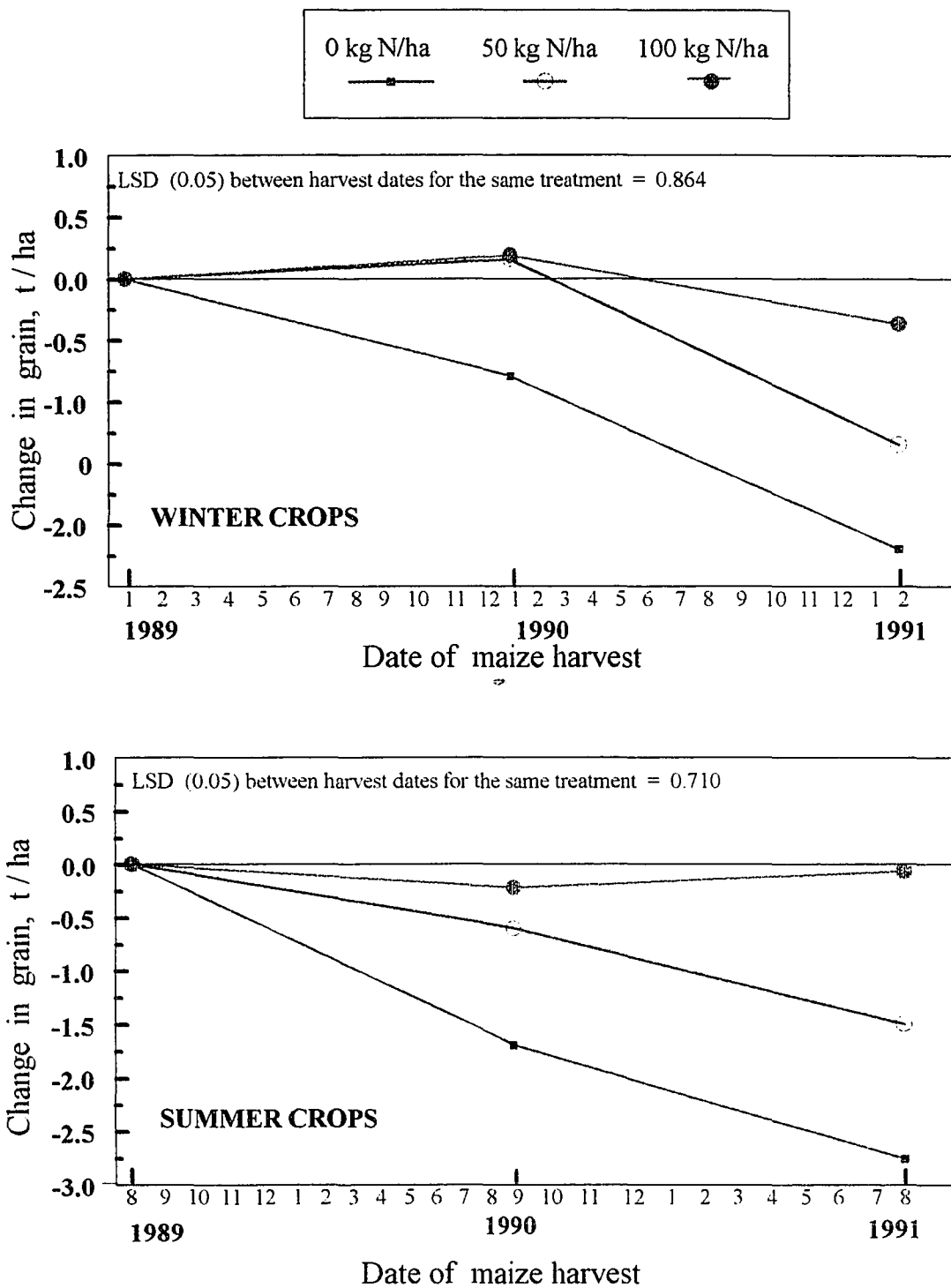


Figure 2.9 Trends in maize grain yield over time for the nitrogen fertilizer experiment.

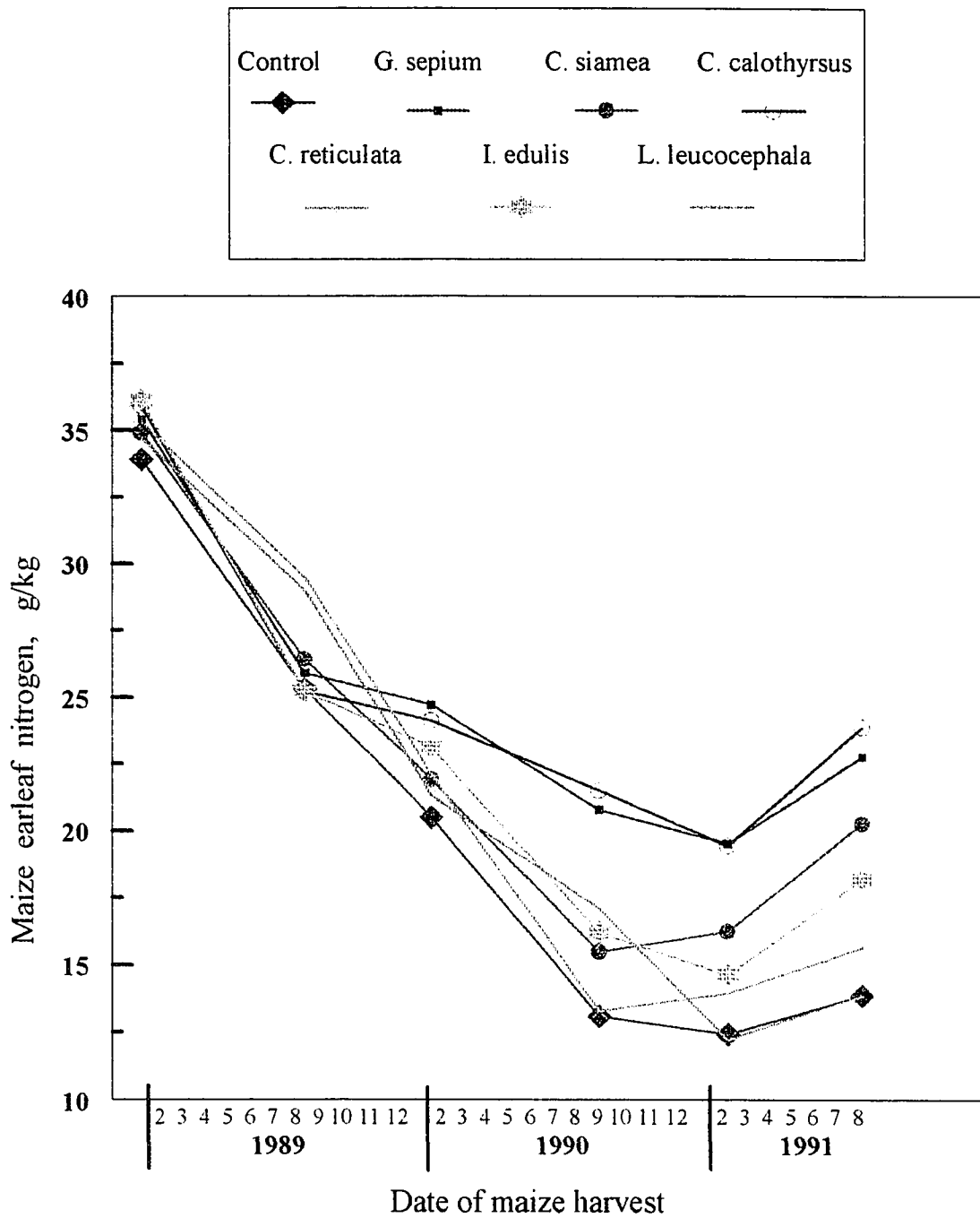


Figure 2.10 Comparison of maize earleaf nitrogen concentrations in the alley cropped plots with tree prunings applied and the control plot. LSD (0.05) values between treatments at each harvest date are given in Table A2.2.

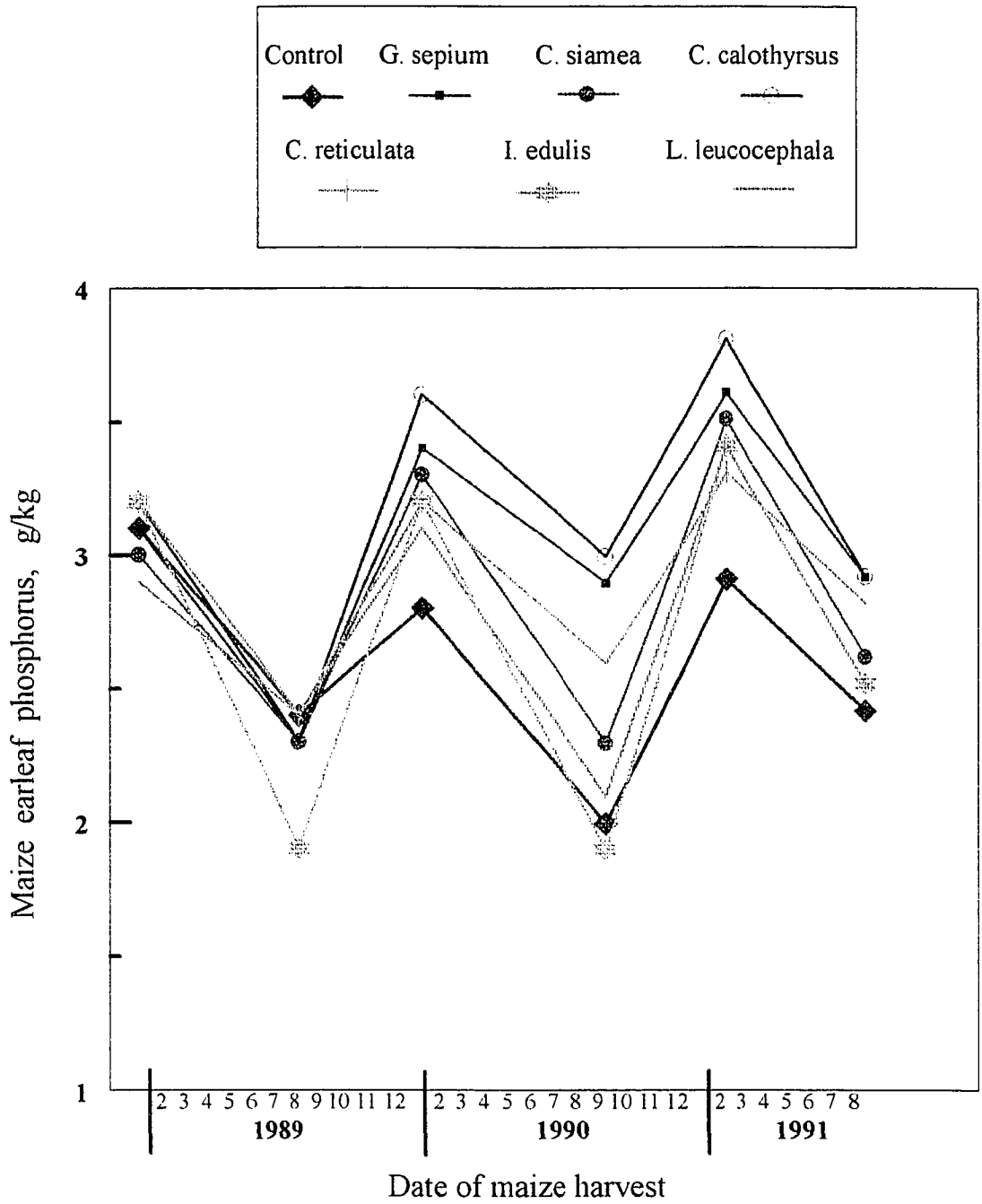


Figure 2.11 Comparison of maize earleaf phosphorus concentrations in the alley cropped plots with tree prunings applied and the control plot. LSD (0.05) values between treatments at each harvest date are given in Table A2.3.

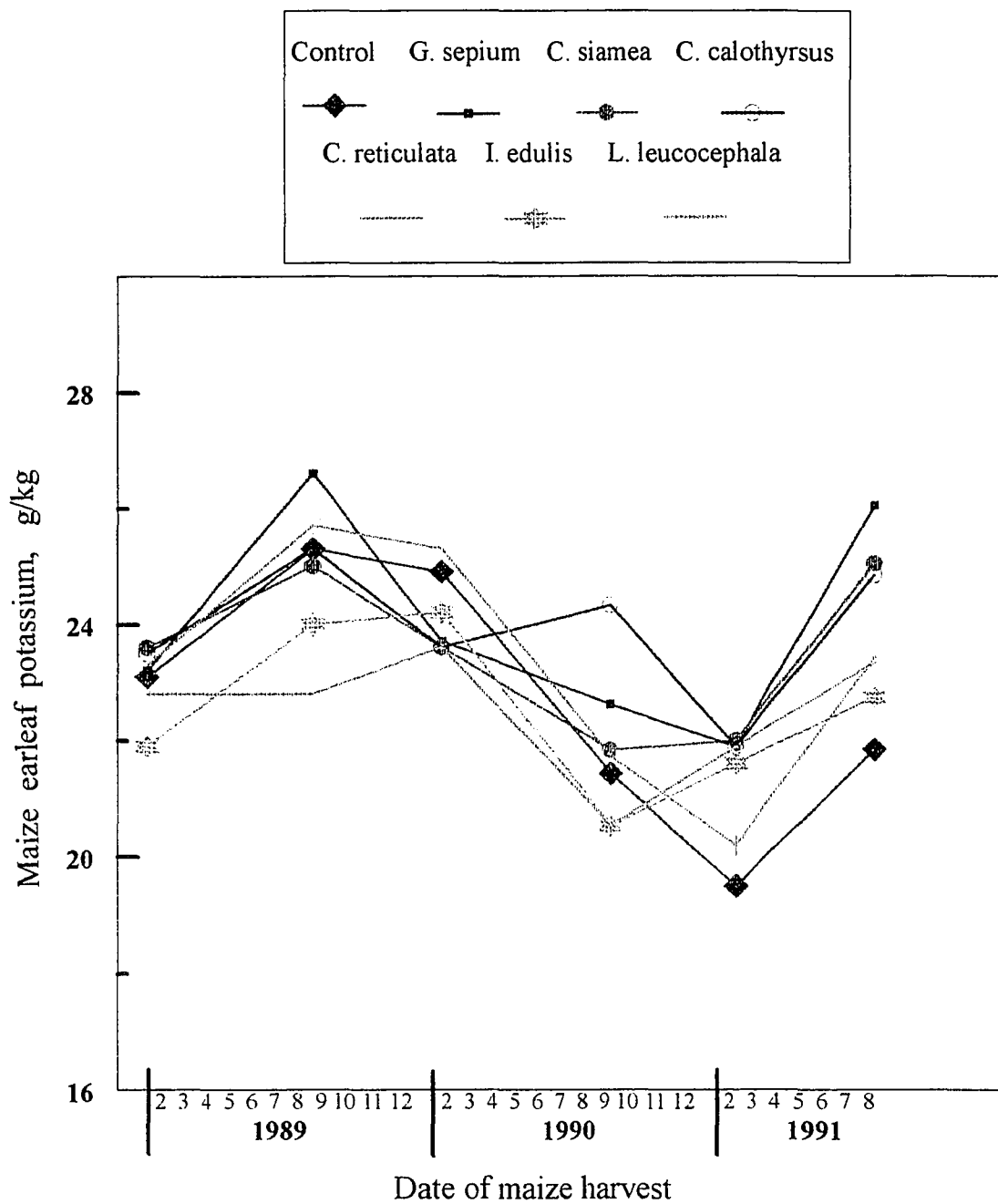


Figure 2.12 Comparison of maize earleaf potassium concentrations in the alley cropped plots with tree prunings applied and the control plot. LSD (0.05) values between treatments at each harvest date are given in Table A2.4.

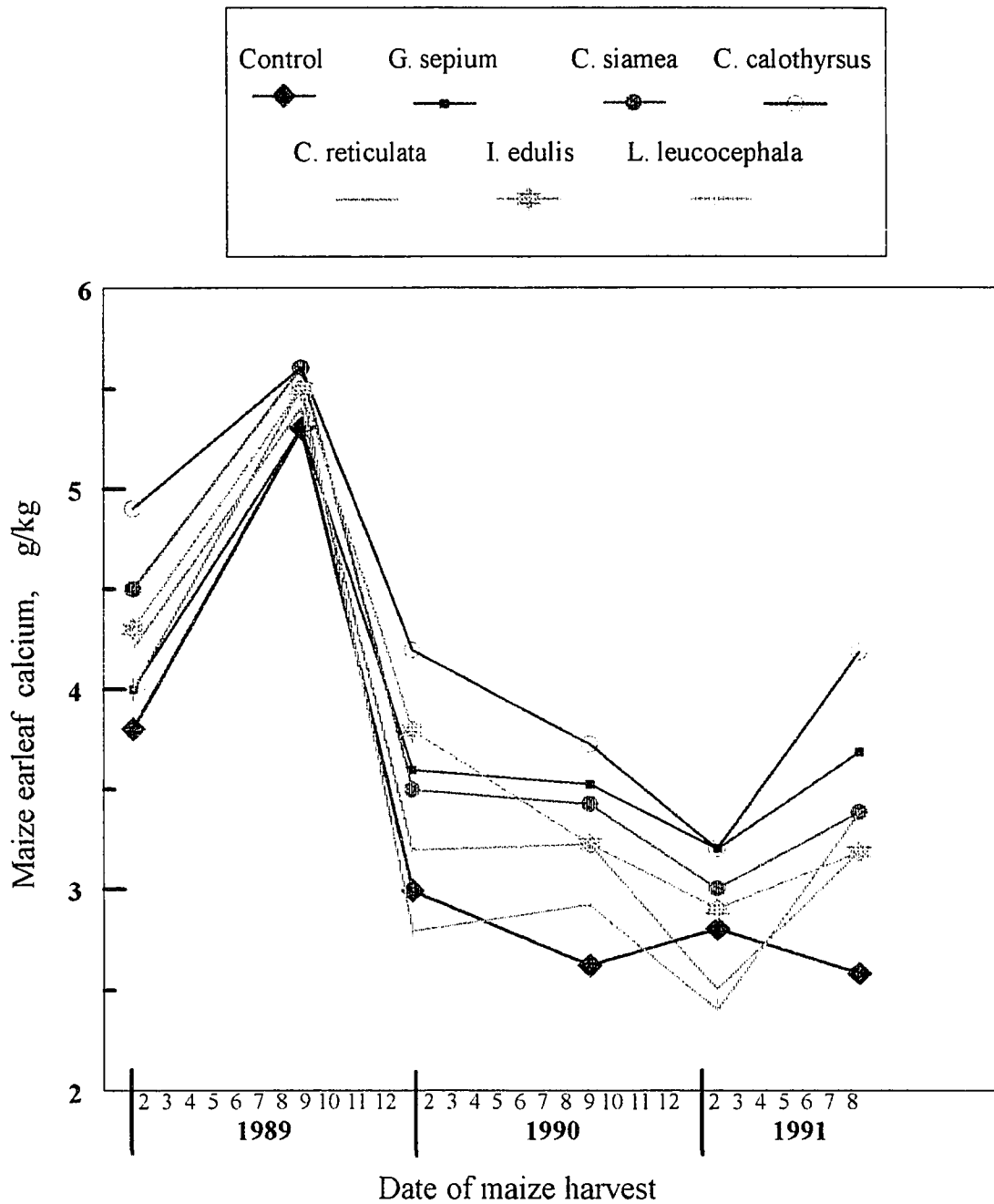


Figure 2.13 Comparison of maize earleaf calcium concentrations in the alley cropped plots with tree prunings applied and the control plot. LSD (0.05) values between treatments at each harvest date are given in Table A2.5.

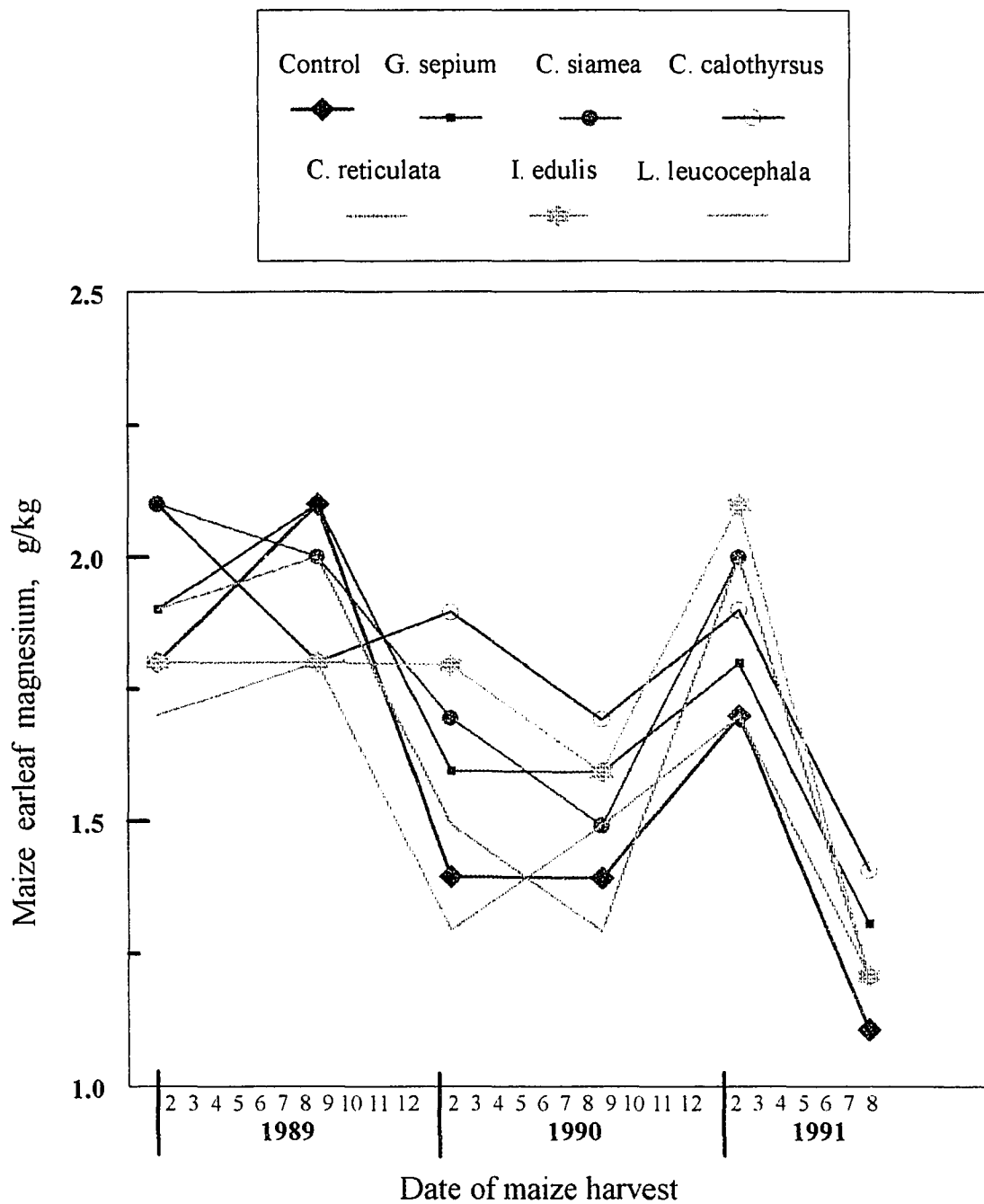


Figure 2.14 Comparison of maize earleaf magnesium concentrations in the alley cropped plots with tree prunings applied and the control plot. LSD (0.05) values between treatments at each harvest date are given in Table A2.6.

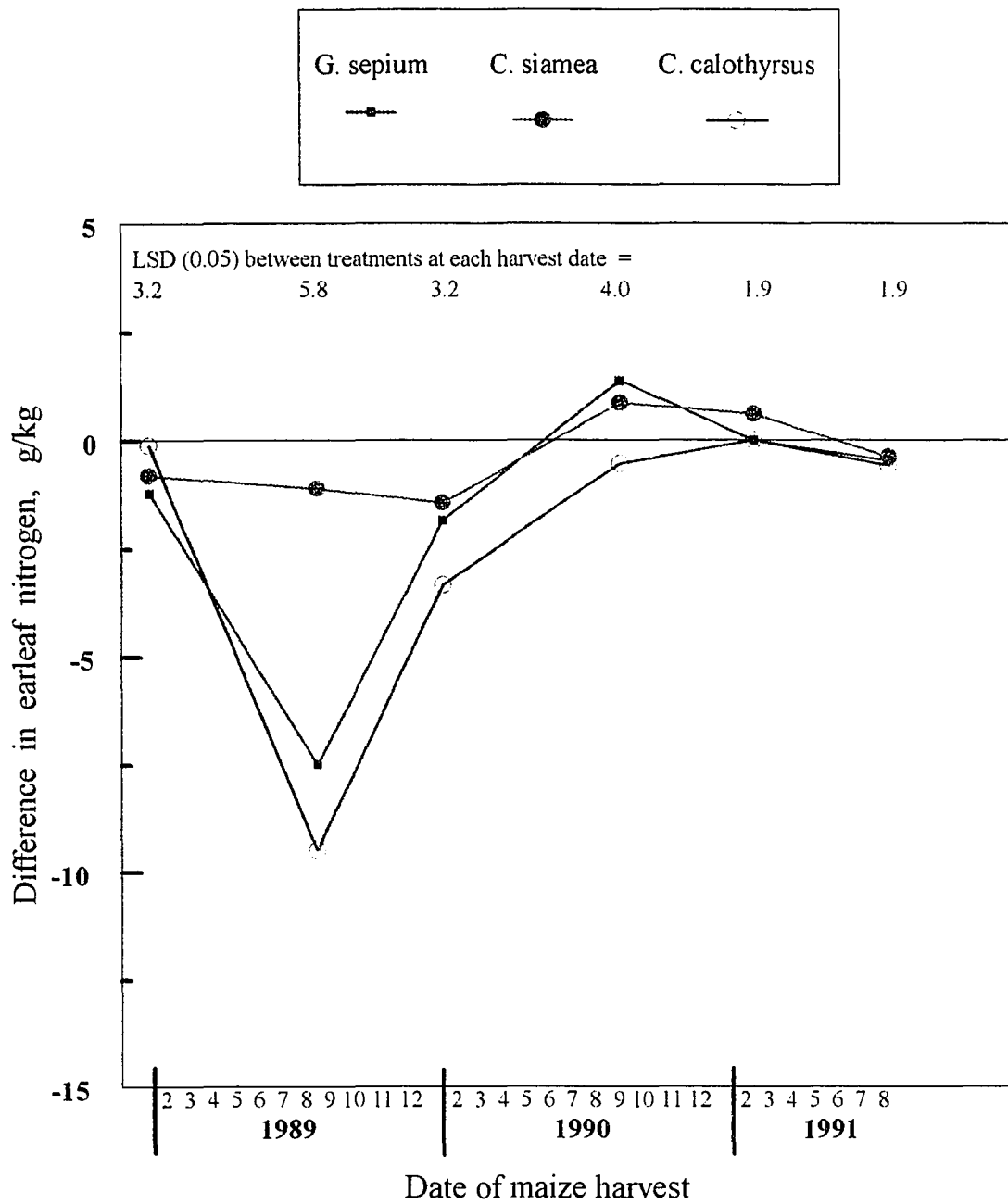


Figure 2.15 Comparison of maize earleaf nitrogen concentrations in the alley cropped plots with tree prunings removed and the control plot.

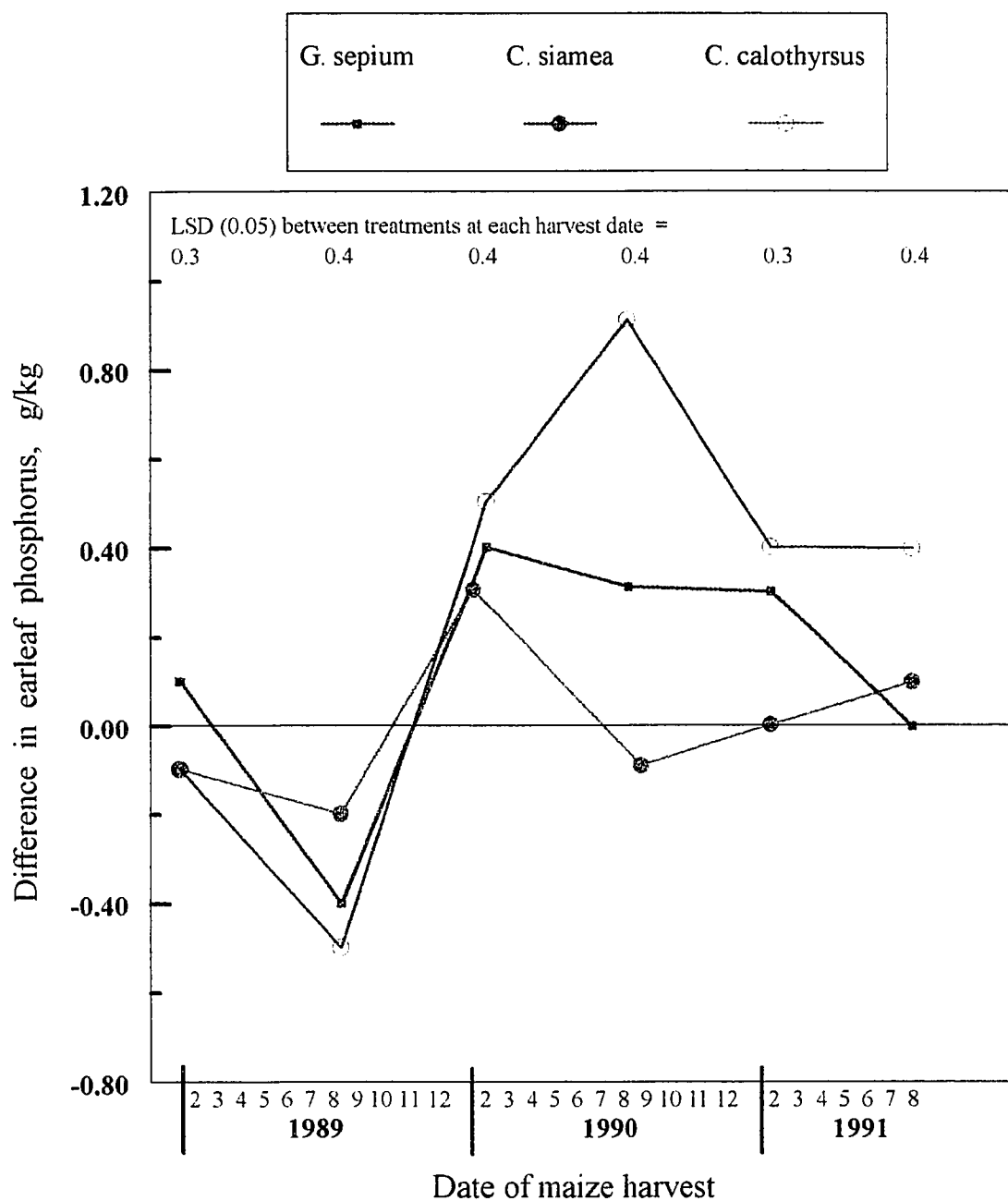


Figure 2.16 Comparison of maize earleaf phosphorus concentrations in the alley cropped plots with tree prunings removed and the control plot.

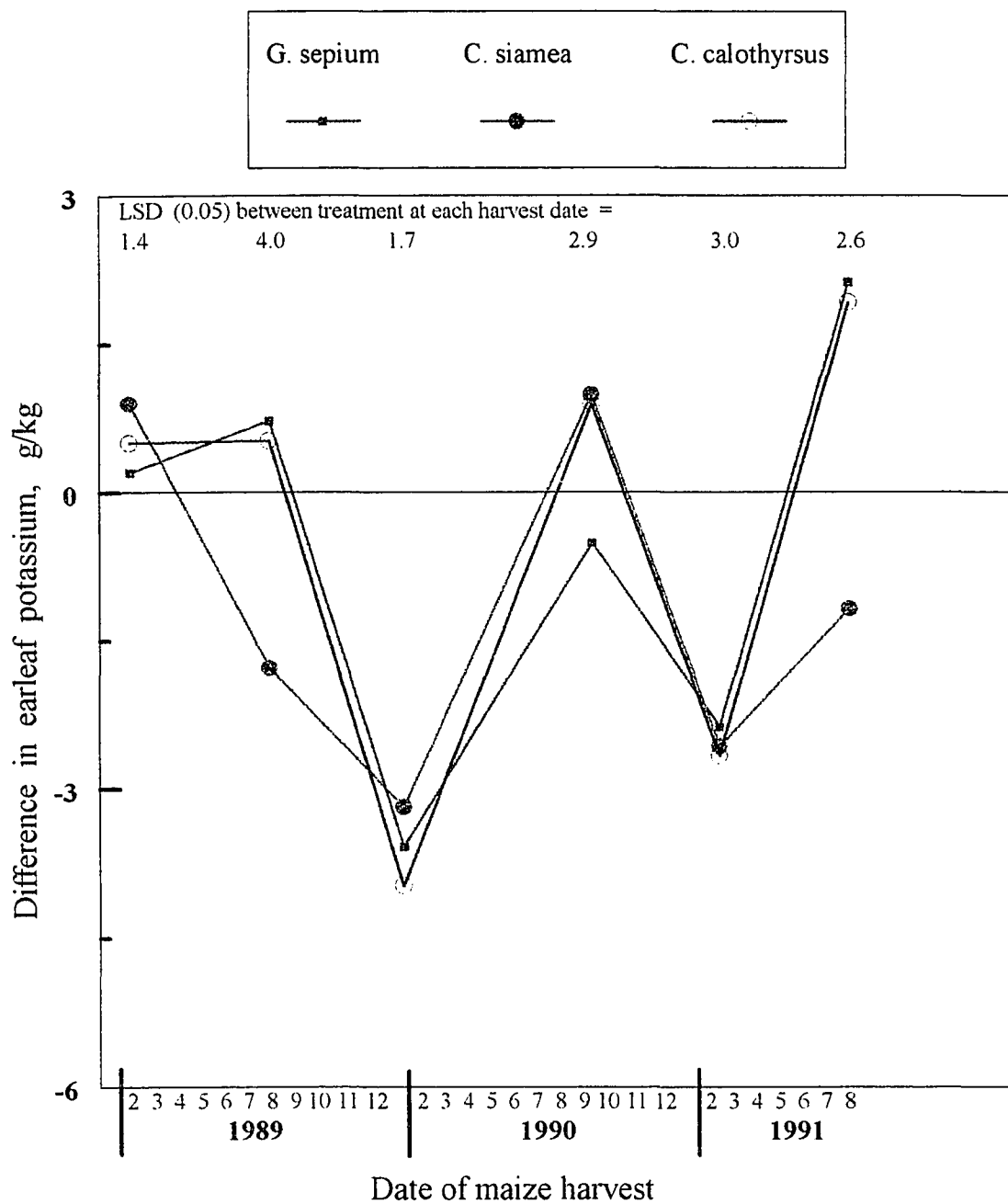


Figure 2.17 Comparison of maize earleaf potassium concentrations in the alley cropped plots with tree prunings removed and the control plot.

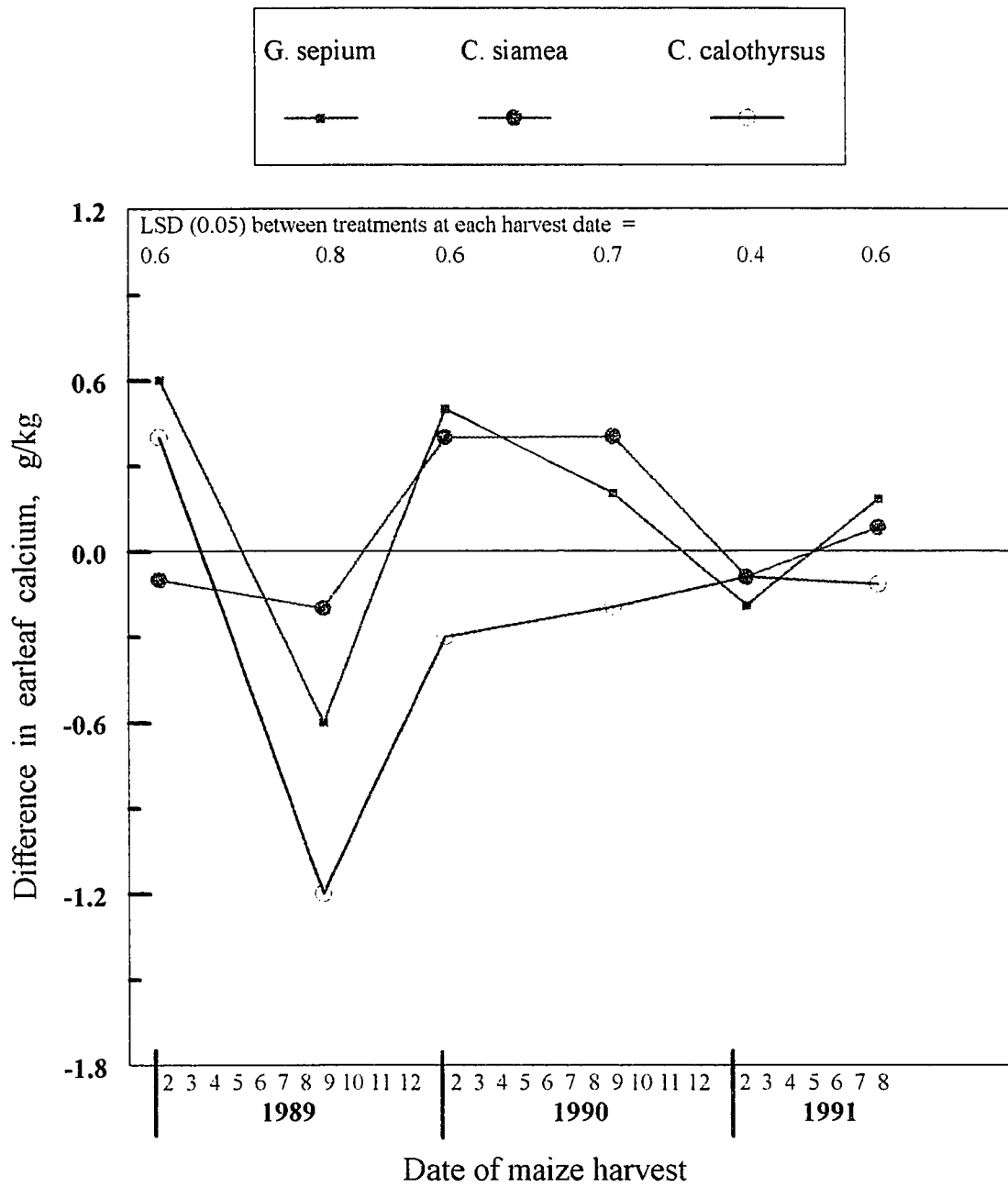


Figure 2.18 Comparison of maize earleaf calcium concentrations in the alley cropped plots with tree prunings removed and the control plot.

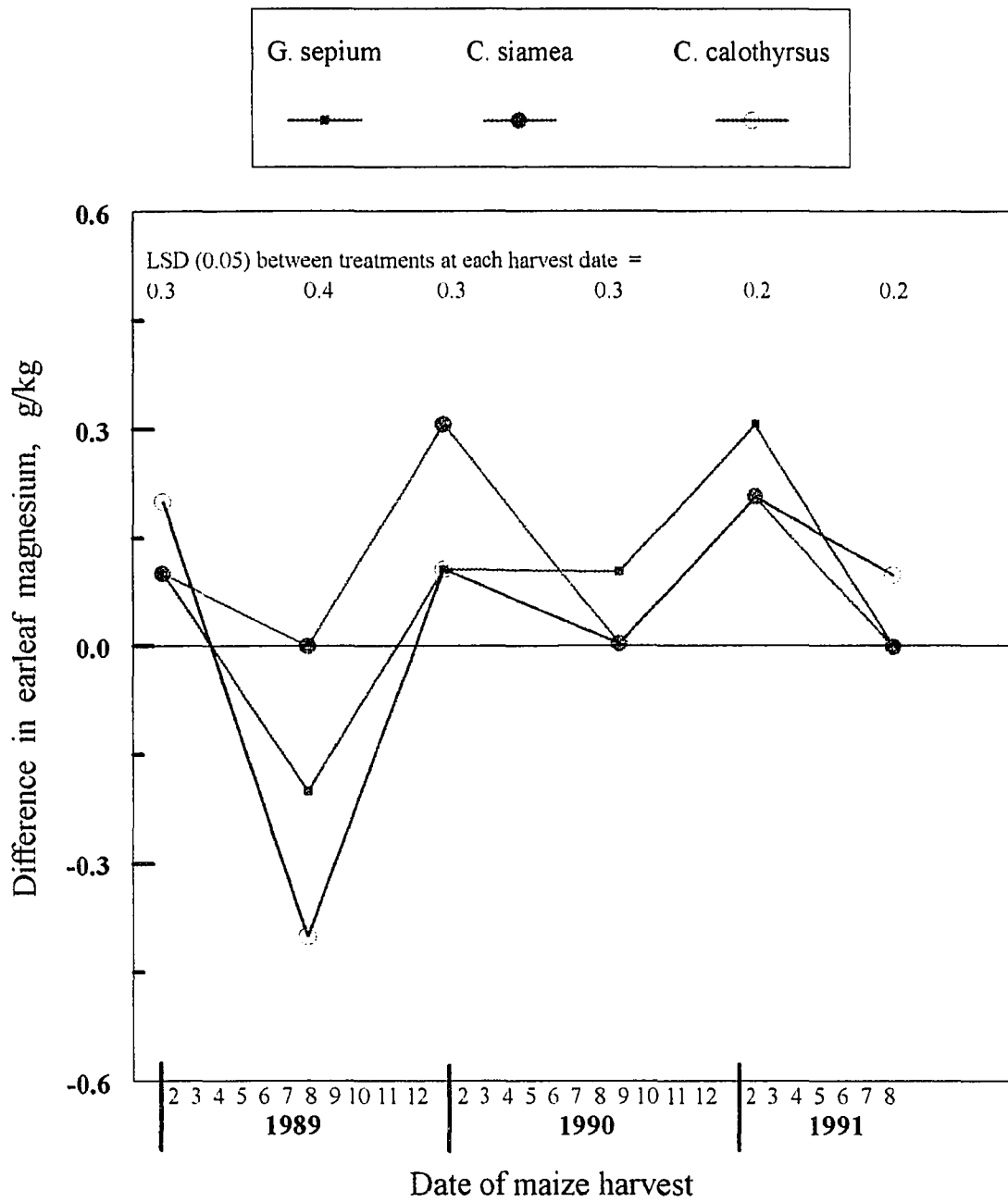


Figure 2.19 Comparison of maize earleaf magnesium concentrations in the alley cropped plots with tree prunings removed and the control plot.

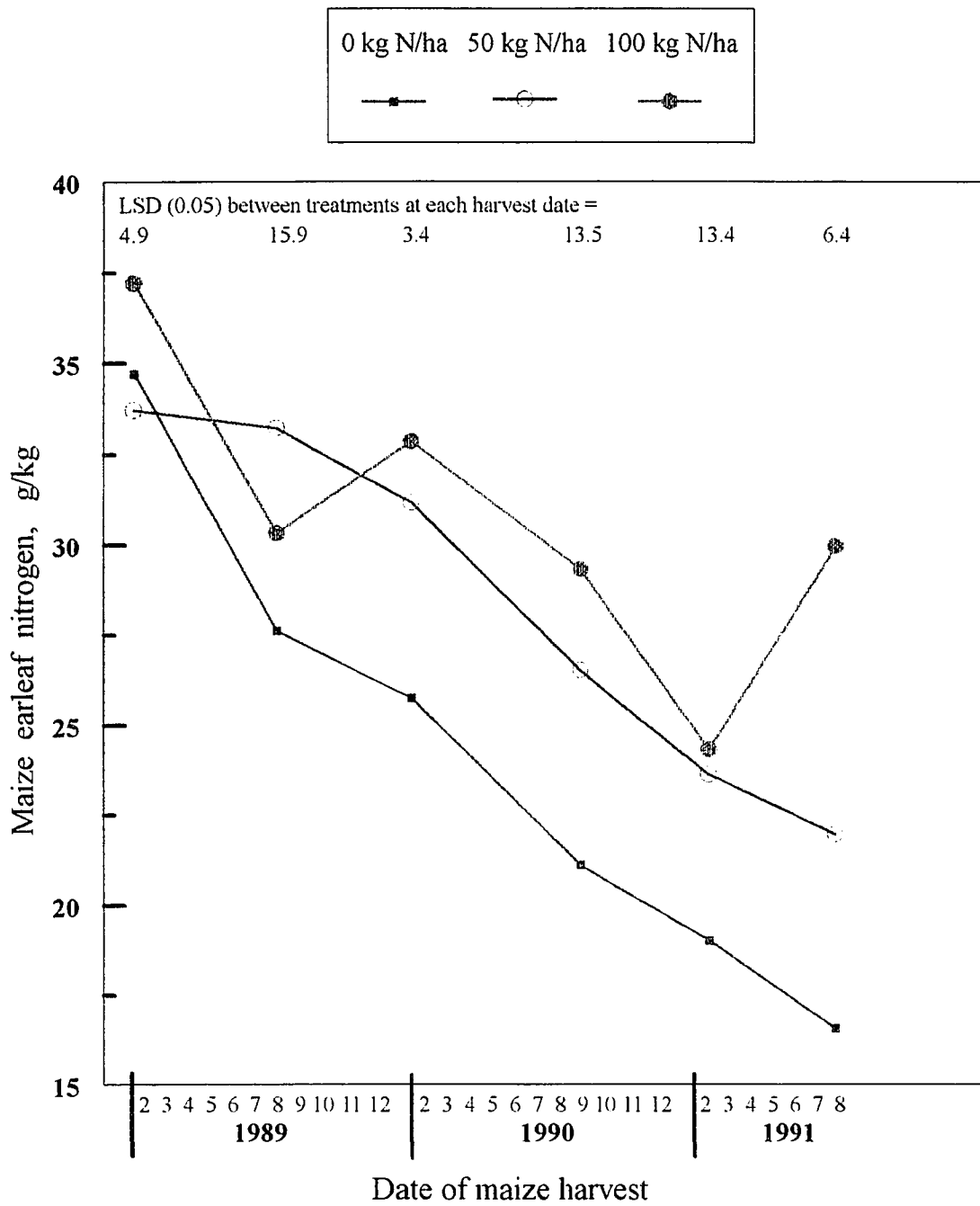


Figure 2.20 Maize earleaf nitrogen concentrations in the nitrogen fertilized plots.

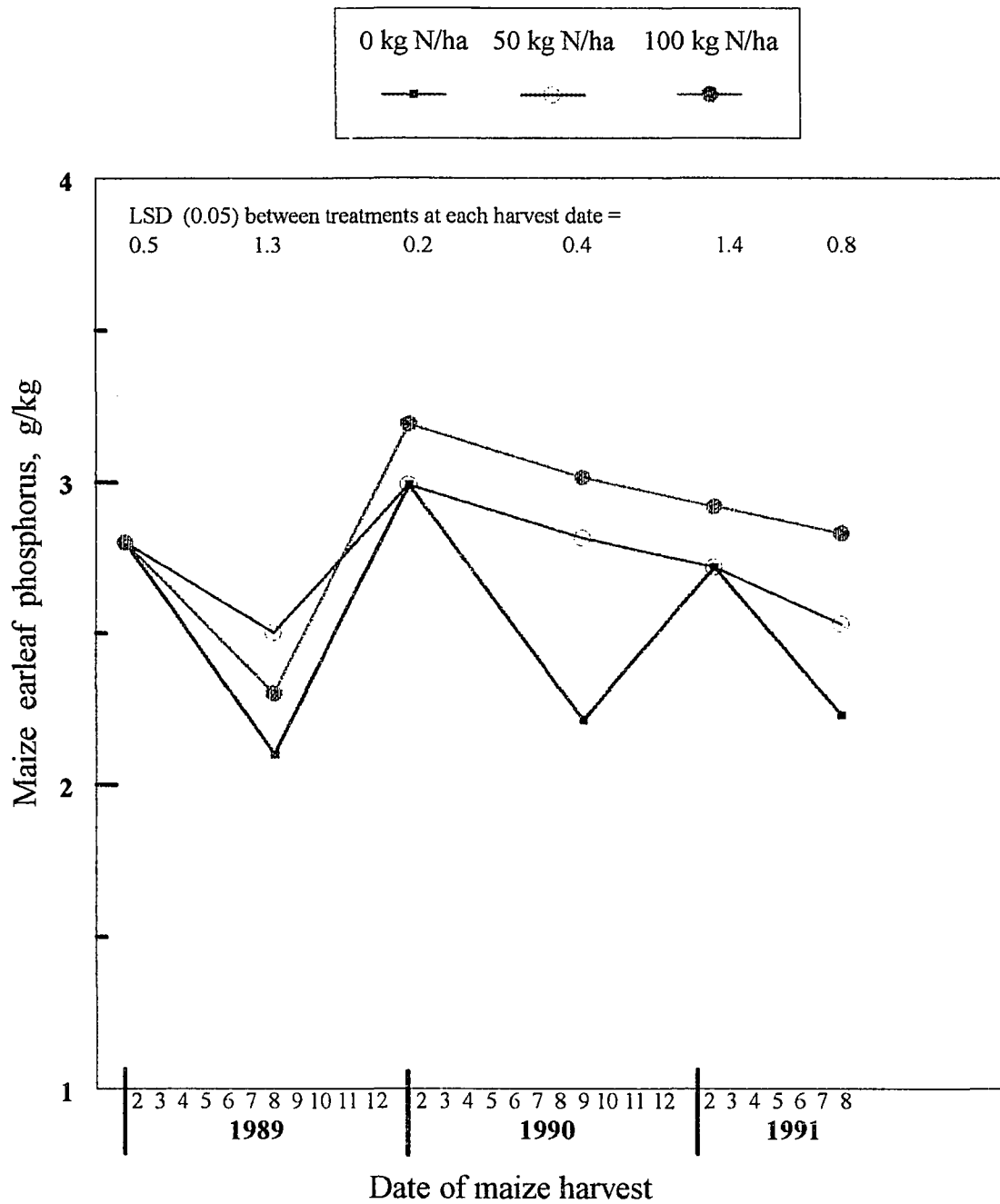


Figure 2.21 Maize earleaf phosphorus concentrations in the nitrogen fertilized plots.

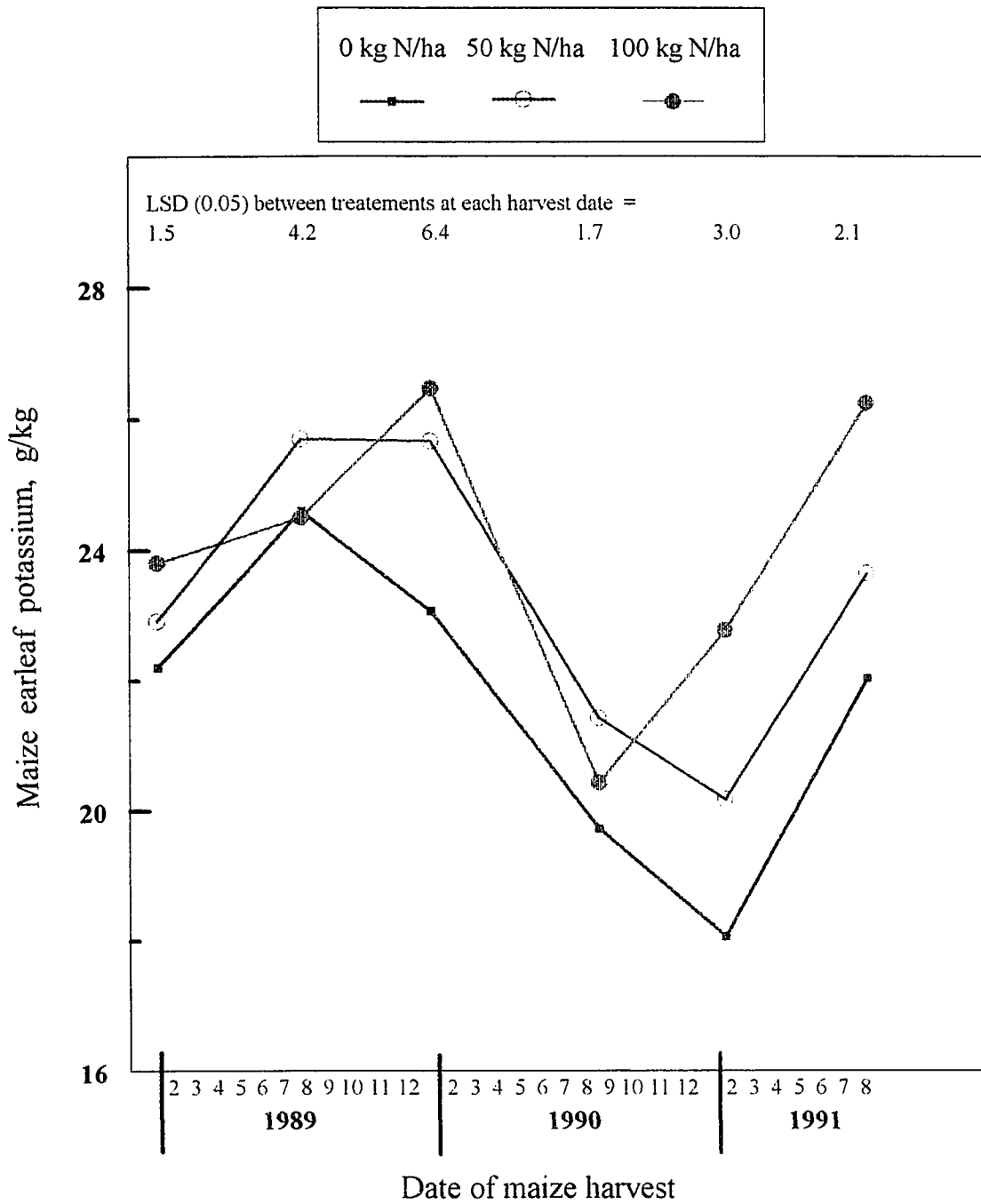


Figure 2.22 Maize earleaf potassium concentrations in the nitrogen fertilized plots.

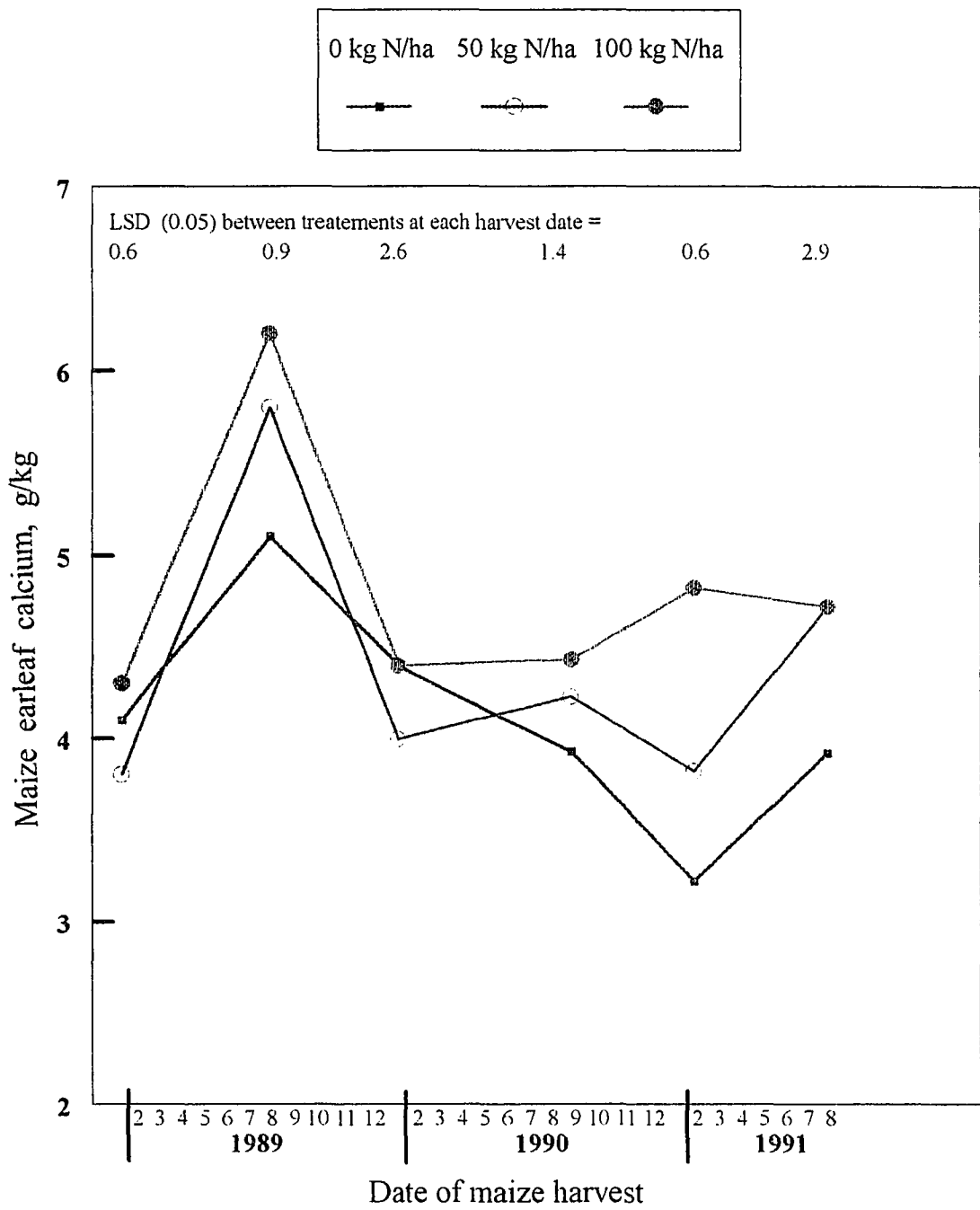


Figure 2.23 Maize earleaf calcium concentrations in the nitrogen fertilized plots.

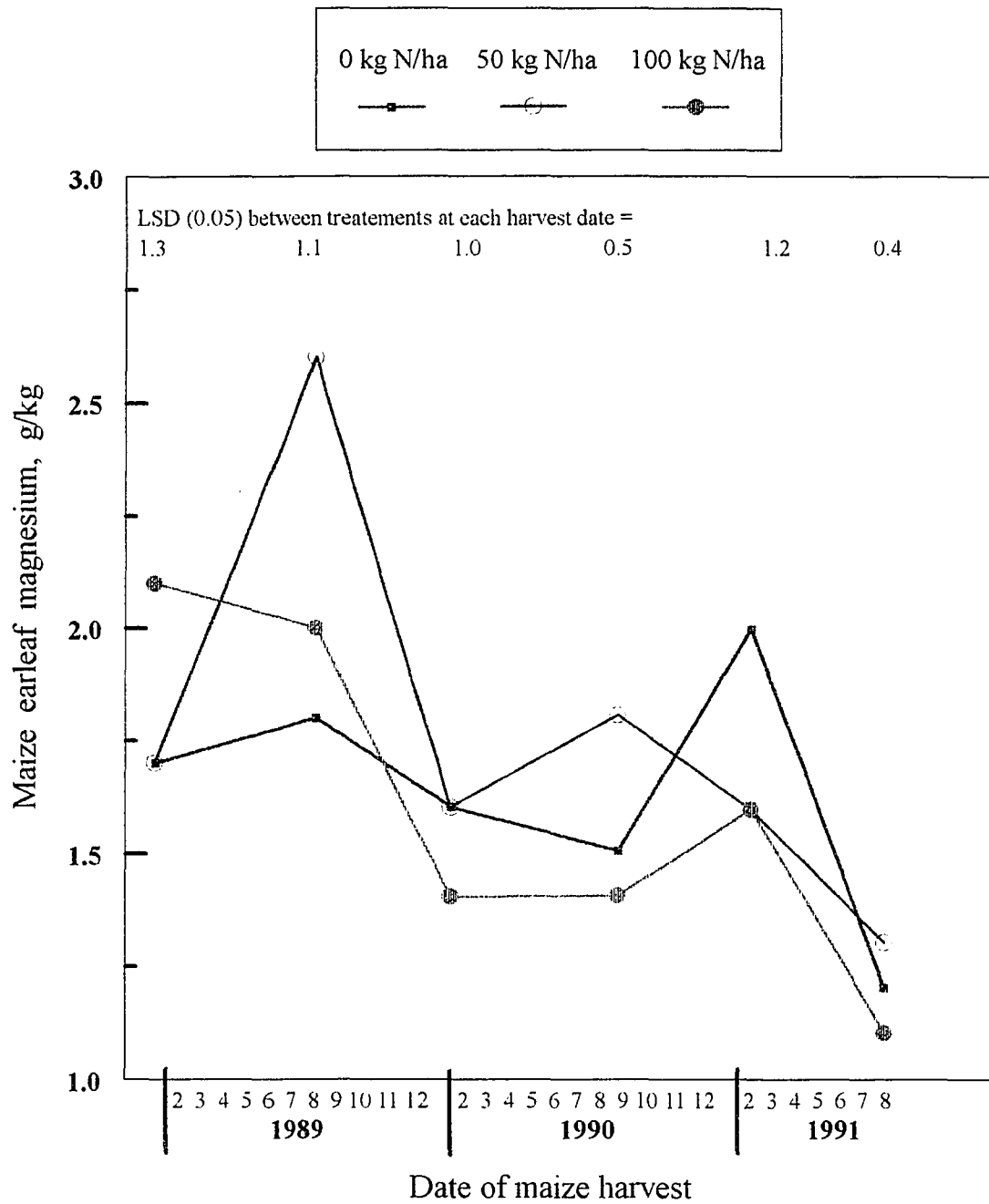


Figure 2.24 Maize earleaf magnesium concentrations in the nitrogen fertilized plots.

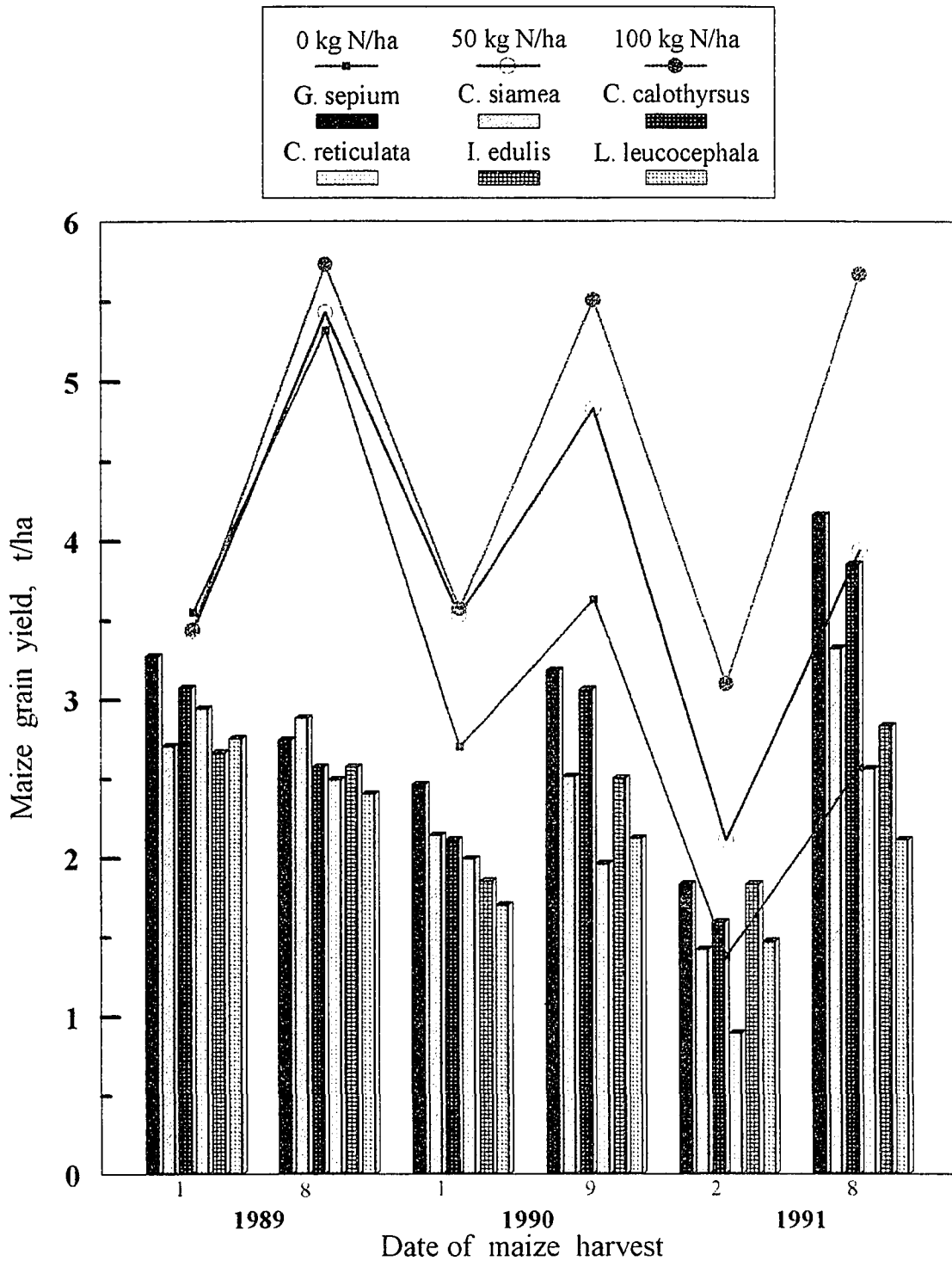


Figure 2.25 Comparison of maize grain yield between the alley cropped plots with tree prunings applied and the inorganic nitrogen fertilized plots.

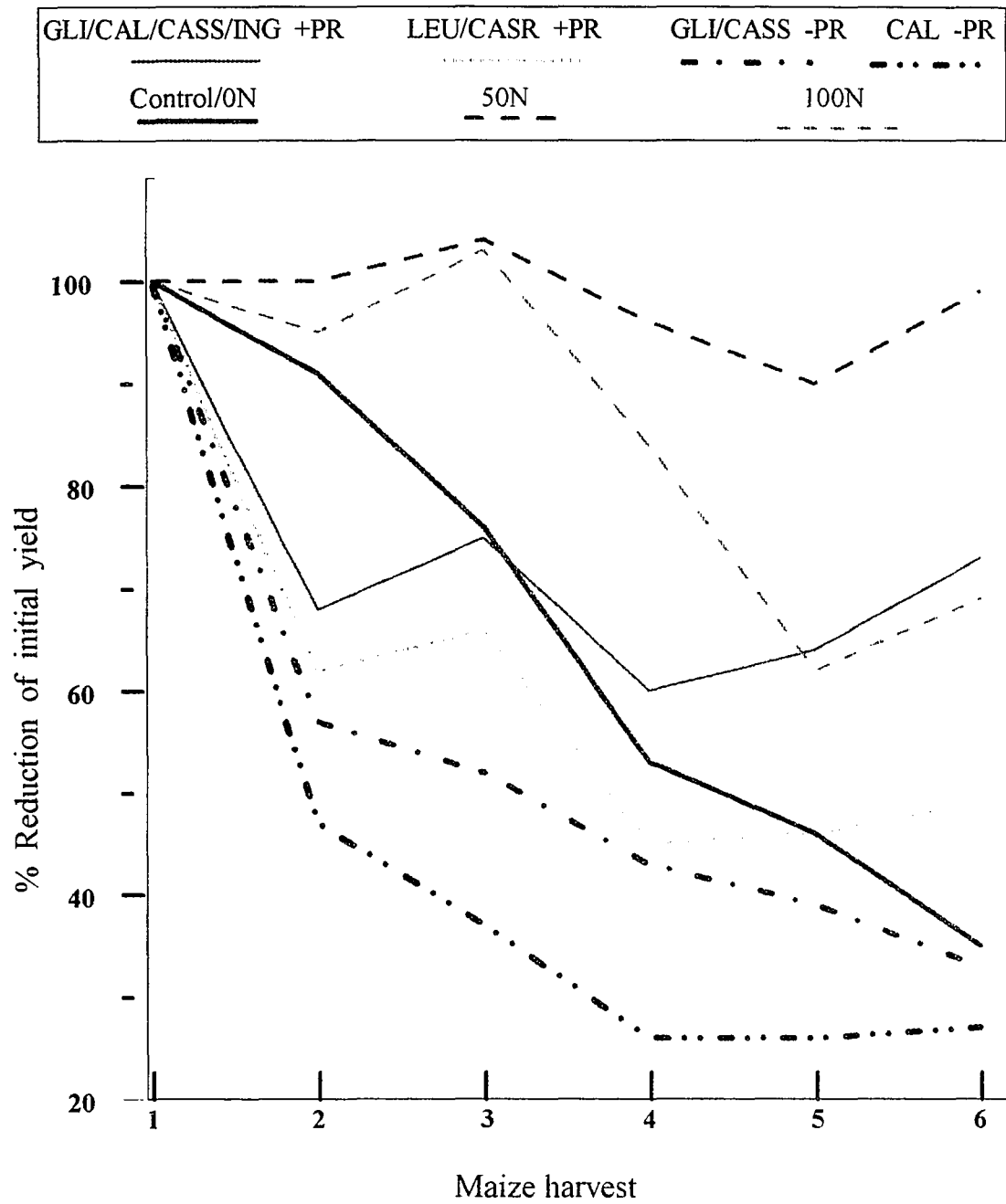


Figure 2.26 Schematic diagram of the trend in maize grain yield over time.

## APPENDIX

Table A2.1. Plant analysis nutrient values for maize earleaf samples.

ELEMENT	NUTRIENT LEVELS		
	Deficient	Low	Sufficient
		- g/kg -	
N	< 24.5	24.6 - 27.5	27.6 - 35.0
P	< 1.5	1.6 - 2.4	2.5 - 4.0
K	< 12.5	12.6 - 17.0	17.1 - 25.0
Ca	< 1.0	1.1 - 2.0	2.1 - 5.0
Mg	< 1.0	1.1 - 2.0	2.1 - 4.0

Source: Jones, J.B. Jr. and H.V. Eck. 1973. Plant analysis as an aid in fertilizing corn and grain sorghum. *In* Soil Testing and Plant Analysis (Walsh, L.M. and J.D. Beaton, Eds.). Soil Science Soc. Am., Madison, Wisconsin.

Table A2.2. Nitrogen concentration of maize earleaf samples as influenced by species and tree pruning management, in g/kg.

TREATMENT	MAIZE HARVEST					
	Winter 1/89	Summer 8/89	Winter 1/90	Summer 9/90	Winter 2/91	Summer 8/91
	- g/kg -					
CONTROL	33.9	25.3	20.5	13.1	12.4	13.7
APPLIED <sup>a</sup> :						
<i>G. sepium</i> <sup>b</sup>	35.4	25.9	24.7	20.8	19.5	22.6
<i>G. sepium</i> <sup>c</sup>	34.1	31.1	27.3	22.4	19.3	25.2
<i>C. calothyrsus</i>	35.9	25.2	24.1	21.5	19.4	23.7
<i>C. siamea</i>	34.9	26.4	21.9	15.5	16.2	20.1
<i>I. edulis</i>	36.1	25.2	23.1	16.2	14.6	18.0
<i>L. leucocephala</i>	34.7	29.0	21.3	17.1	12.2	13.7
<i>C. reticulata</i>	35.3	29.5	22.1	13.3	13.9	15.5
<i>S. sesban</i>	35.0	30.7	--	--	--	--
REMOVED <sup>d</sup> :						
<i>C. siamea</i>	33.1	24.2	19.1	13.9	13.0	13.2
<i>G. sepium</i> <sup>b</sup>	35.7	17.8	18.7	14.4	12.4	13.1
<i>C. calothyrsus</i>	33.8	15.8	17.2	12.5	12.4	13.0
<i>S. sesban</i>	32.7	22.7	--	--	--	--
LSD <sub>0.05</sub> between:						
4 rep trts	3.2	5.8	3.2	4.0	1.9	1.9
2 rep trts	4.5	8.2	4.5	5.7	2.7	2.7
4 & 2 rep trts	3.9	7.1	3.9	4.9	2.3	2.3
0 kg N/ha	34.7	27.6	25.6	20.9	18.9	16.6
50 kg N/ha	33.7	33.2	31.0	26.3	23.5	22.0
100 kg N/ha	37.2	30.3	32.7	29.1	24.2	30.0
LSD <sub>0.05</sub>	4.9	15.9	3.4	13.5	13.4	6.4

<sup>a</sup>tree prunings applied, <sup>b</sup>Samala, Retalhulea seed source, <sup>c</sup>seed orchard seed source, <sup>d</sup>tree prunings removed

Table A2.3. Phosphorus concentration of maize earleaf samples as influenced by species and tree pruning management, in g/kg.

TREATMENT	MAIZE HARVEST					
	Winter 1/89	Summer 8/89	Winter 1/90	Summer 9/90	Winter 2/91	Summer 8/91
	- g/kg -					
CONTROL	3.1	2.4	2.8	2.0	2.9	2.4
APPLIED <sup>a</sup> :						
<i>G. sepium</i> <sup>b</sup>	3.1	2.3	3.4	2.9	3.6	2.9
<i>G. sepium</i> <sup>c</sup>	2.9	2.2	3.2	2.6	3.7	2.5
<i>C. calothyrsus</i>	3.2	2.3	3.6	3.0	3.8	2.9
<i>C. siamea</i>	3.0	2.3	3.3	2.3	3.5	2.6
<i>I. edulis</i>	3.2	1.9	3.2	1.9	3.4	2.5
<i>L. leucocephala</i>	2.9	2.4	3.1	2.1	3.4	2.5
<i>C. reticulata</i>	3.2	2.4	3.2	2.6	3.3	2.8
<i>S. sesban</i>	3.2	2.1	--	--	--	--
REMOVED <sup>d</sup> :						
<i>C. siamea</i>	3.0	2.2	3.1	1.9	2.9	2.5
<i>G. sepium</i> <sup>b</sup>	3.2	2.0	3.2	2.3	3.2	2.4
<i>C. calothyrsus</i>	3.0	1.9	3.3	2.9	3.3	2.8
<i>S. sesban</i>	2.9	2.0	--	--	--	--
LSD <sub>0.05</sub> between:						
4 rep trts	0.3	0.4	0.4	0.4	0.3	0.4
2 rep trts	0.5	0.5	0.6	0.6	0.4	0.6
4 & 2 rep trts	0.4	0.5	0.5	0.6	0.4	0.5
0 kg N/ha	2.8	2.1	3.0	2.2	2.7	2.2
50 kg N/ha	2.8	2.5	3.0	2.8	2.7	2.5
100 kg N/ha	2.8	2.3	3.2	3.0	2.9	2.8
LSD <sub>0.05</sub>	0.5	1.3	0.2	0.4	1.4	0.8

<sup>a</sup>tree prunings applied, <sup>b</sup>Samala, Retalhulea seed source, <sup>c</sup>seed orchard seed source, <sup>d</sup>tree prunings removed.

Table A2.4. Potassium concentration of maize earleaf samples as influenced by species and tree pruning management, in g/kg.

TREATMENT	MAIZE HARVEST					
	Winter 1/89	Summer 8/89	Winter 1/90	Summer 9/90	Winter 2/91	Summer 8/91
	- g/kg -					
CONTROL	23.1	25.3	24.9	21.4	19.5	21.8
APPLIED <sup>a</sup> :						
<i>G. sepium</i> <sup>b</sup>	23.2	26.6	23.7	22.6	21.9	26.0
<i>G. sepium</i> <sup>c</sup>	23.0	22.3	25.0	21.2	24.7	23.5
<i>C. calothyrsus</i>	23.5	25.3	23.6	24.3	21.9	24.8
<i>C. siamea</i>	23.6	25.0	23.6	21.8	22.0	25.0
<i>I. edulis</i>	21.9	24.0	24.2	20.5	21.6	22.7
<i>L. leucocephala</i>	22.8	22.8	23.6	20.5	21.9	23.3
<i>C. reticulata</i>	23.3	25.7	25.3	21.7	20.2	23.4
<i>S. sesban</i>	23.8	28.0	--	--	--	--
REMOVED <sup>d</sup> :						
<i>C. siamea</i>	24.0	23.5	21.8	22.4	17.0	23.0
<i>G. sepium</i> <sup>b</sup>	23.3	26.0	21.4	20.9	17.2	23.9
<i>C. calothyrsus</i>	23.6	25.8	21.0	21.4	16.9	23.7
<i>S. sesban</i>	24.2	27.8	--	--	--	--
LSD <sub>0.05</sub> between:						
4 rep trts	1.4	4.0	1.7	2.9	3.0	2.6
2 rep trts	2.0	5.7	2.5	3.9	4.2	3.6
4 & 2 rep trts	1.7	4.9	2.1	3.4	3.7	3.1
0 kg N/ha	22.2	24.5	23.0	19.7	18.0	22.2
50 kg N/ha	22.9	25.6	25.6	21.4	20.1	23.8
100 kg N/ha	23.8	24.4	26.4	20.4	22.7	26.4
LSD <sub>0.05</sub>	1.5	4.2	6.4	1.7	3.0	2.1

<sup>a</sup>tree prunings applied, <sup>b</sup>Samala, Retalhulea seed source, <sup>c</sup>seed orchard seed source, <sup>d</sup>tree prunings removed

Table A2.5. Calcium concentration of maize earleaf samples as influenced by species and tree pruning management, in g/kg.

TREATMENT	MAIZE HARVEST					
	Winter 1/89	Summer 8/89	Winter 1/90	Summer 9/90	Winter 2/91	Summer 8/91
	- g/kg -					
CONTROL	3.8	5.3	3.0	2.6	2.8	2.6
APPLIED <sup>a</sup> :						
<i>G. sepium</i> <sup>b</sup>	4.0	5.3	3.6	3.5	3.2	3.7
<i>G. sepium</i> <sup>c</sup>	4.0	5.2	3.7	3.7	3.2	3.6
<i>C. calothyrsus</i>	4.9	5.6	4.2	3.7	3.2	4.2
<i>C. siamea</i>	4.5	5.6	3.5	3.4	3.0	3.4
<i>I. edulis</i>	4.3	5.5	3.8	3.2	2.9	3.2
<i>L. leucocephala</i>	4.2	5.4	3.2	3.2	2.5	3.2
<i>C. reticulata</i>	4.0	5.5	2.8	2.9	2.4	3.4
<i>S. sesban</i>	4.2	5.2	--	--	--	----
REMOVED <sup>d</sup> :						
<i>C. siamea</i>	3.7	5.1	3.4	3.0	2.7	2.7
<i>G. sepium</i> <sup>b</sup>	4.4	4.7	3.5	2.8	2.6	2.8
<i>C. calothyrsus</i>	4.2	4.1	3.3	2.8	2.7	2.7
<i>S. sesban</i>	3.6	5.0	--	--	--	
LSD <sub>0.05</sub> between:						
4 rep trts	0.6	0.8	0.6	0.7	0.4	0.6
2 rep trts	0.9	1.2	0.8	1.0	0.6	0.8
4 & 2 rep trts	0.8	1.0	0.8	0.8	0.5	0.7
0 kg N/ha	4.1	5.1	4.4	3.9	3.2	3.9
50 kg N/ha	3.8	5.8	4.0	4.2	3.8	4.7
100 kg N/ha	4.3	6.2	4.4	4.4	4.8	4.7
LSD <sub>0.05</sub>	0.6	0.9	2.6	1.4	0.6	2.9

<sup>a</sup>tree prunings applied, <sup>b</sup>Samala, Retalhulea seed source, <sup>c</sup>seed orchard seed source, <sup>d</sup>tree prunings removed

Table A2.6. Magnesium concentration of maize earleaf samples as influenced by species and tree pruning management, in g/kg.

TREATMENT	MAIZE HARVEST					
	Winter 1/89	Summer 8/89	Winter 1/90	Summer 9/90	Winter 2/91	Summer 8/91
	- g/kg -					
CONTROL	1.8	2.1	1.4	1.4	1.7	1.1
APPLIED <sup>a</sup> :						
<i>G. sepium</i> <sup>b</sup>	1.9	2.1	1.6	1.6	1.8	1.3
<i>G. sepium</i> <sup>c</sup>	2.0	2.2	1.8	1.6	1.8	1.3
<i>C. calothyrsus</i>	2.1	1.8	1.9	1.7	1.9	1.4
<i>C. siamea</i>	2.1	2.0	1.7	1.5	2.0	1.2
<i>I. edulis</i>	1.8	1.8	1.8	1.6	2.1	1.2
<i>L. leucocephala</i>	1.9	2.0	1.5	1.3	2.0	1.2
<i>C. reticulata</i>	1.7	1.8	1.3	1.5	1.7	1.2
<i>S. sesban</i>	2.1	2.1	--	--	--	--
REMOVED <sup>d</sup> :						
<i>C. siamea</i>	1.9	2.1	1.7	1.4	1.9	1.1
<i>G. sepium</i> <sup>b</sup>	1.9	1.9	1.5	1.5	2.0	1.1
<i>C. calothyrsus</i>	2.0	1.7	1.5	1.4	1.9	1.2
<i>S. sesban</i>	1.7	2.0	--	--	--	--
LSD <sub>0.05</sub> between:						
4 rep trts	0.3	0.4	0.3	0.3	0.2	0.2
2 rep trts	0.4	0.6	0.4	0.5	0.4	0.3
4 & 2 rep trts	0.3	0.6	0.3	0.4	0.3	0.3
0 kg N/ha	1.7	1.8	1.6	1.5	2.0	1.2
50 kg N/ha	1.7	2.6	1.6	1.8	1.6	1.3
100 kg N/ha	2.1	2.0	1.4	1.4	1.6	1.1
LSD <sub>0.05</sub>	1.3	1.1	1.0	0.5	1.2	0.4

<sup>a</sup>tree prunings applied, <sup>b</sup>Samala, Retalhulea seed source, <sup>c</sup>seed orchard seed source, <sup>d</sup>tree prunings removed.

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### CHAPTER 3

#### NITROGEN YIELD AND APPARENT NITROGEN RECOVERY BY MAIZE FROM SIX WOODY LEGUMES IN ALLEY CROPPING SYSTEMS

A key to the success of alley cropping is the appropriate selection of tree species. One criterion is to produce tree prunings with sufficient quantities of nitrogen to supply the needs of associated crops. Various tree and shrub species have been evaluated for use in alley cropping systems with an emphasis on measuring the quantity of nitrogen in tree prunings. A wide range of annual nitrogen yields have been reported, from 25 to 413 kg/ha, depending on tree species, spacing, pruning regime, and site conditions (Hawkins et al. 1990, Kang et al. 1990, Szott et al. 1991).

The nitrogen recovery from tree prunings applied in alley cropping systems by associated crops has received less attention. Recent research has shown that only a small proportion, less than 10 percent, of the nitrogen applied via tree prunings in alley cropping systems was recovered by the associated maize crop (Haggar 1990, Mulongoy and van der Meersch 1988). In contrast, recovery of fertilizer nitrogen by maize ranged from 32 to 65 percent in an extensive nitrogen-fertilization study conducted by Fox and colleagues (1974) at five sites in Puerto Rico. Nitrogen recovery from leguminous green manures applied to monocropped maize has been reported to be lower, similar, or higher than fertilizer nitrogen. Evensen (1984) reported a 33 percent nitrogen recovery from *L. leucocephala* leaves by maize, compared to 61 percent from N-urea fertilizer. In

an experiment conducted on the same site, Chaudhary (1984) reported a 28 percent nitrogen recovery from *L. leucocephala* tree prunings by maize, compared to 44 percent from N-urea fertilizer. Bouldin and colleagues (1991) evaluated seven leguminous green manures as a source of nitrogen for maize and found nitrogen recovery by maize to range from 35 to 82 percent, compared to 57 percent from N-urea fertilizer.

Nitrogen transfer from tree prunings to maize in alley cropping systems is the net result of a number of interacting plant and soil processes. Factors affecting nitrogen recovery include the 1) amount of available soil nitrogen for crop growth, 2) nitrogen release pattern of tree prunings and synchronization with crop uptake, 3) competition between trees and crops, and 4) nitrogen loss by leaching, denitrification, and volatilization.

The release of nitrogen from tree prunings differs considerably among tree species (Table 3.1). Leaf chemistry (nitrogen, lignin, polyphenols) and tissue type (leaves, twigs, wood) affect the rate of nitrogen release (Palm and Sanchez 1991, Frankenberger and Abdelmagid 1985, Oglesby and Fownes 1992). Competition between trees and crops in alley cropping systems has been documented in a number of studies. Crop yields have been reported to be significantly reduced in crop rows adjacent to tree rows compared to crop rows in the middle of the alleys and attributed to competition (Kang et al. 1981, Evensen 1989, Rosecrance et al. 1992, Haggard and Beer 1993, Salazar et al. 1993).

The objective of this study was to evaluate various woody legumes as a nitrogen source for maize production in alley cropping systems. The specific objectives were to 1) quantify dry matter and nitrogen yields of tree prunings, 2) measure maize nitrogen uptake, 3) estimate apparent nitrogen recovery from tree prunings by the associated maize crop, and 4) compare apparent nitrogen recovery by maize of tree prunings to N-urea fertilizer.

## **METHODS**

### **Site Description**

The alley cropping experiment was conducted at the University of Hawaii Wailua Agricultural Experiment Station located on the Island of Kauai (22° 04' N, 159° 24' W) at an elevation of 150 m. Mean annual precipitation is 2489 mm, with mean monthly precipitation seldom less than 100 mm. Temperatures range from an average monthly minimum of 20.0° C to an average monthly maximum of 25.5° C, with an absolute daily minimum and maximum of 12° C and 35° C, respectively. Average daily solar radiation ranges from approximately 250 to 500 cal/cm<sup>2</sup>, with the higher values occurring between May and September. The soil is derived from basic igneous rock mixed with volcanic ash, classified as a clayey, ferritic, isothermic Typic Gibbsihumox with a gravelly, silty, clay texture (Ikawa et al. 1985). Organic carbon and total nitrogen are high, 3.59 percent and 0.247 percent, respectively. The soil is low in bases and phosphorus: 2.0 cmol<sub>c</sub> Ca/kg,

0.34 cmol<sub>c</sub> Mg/kg, 0.17 cmol<sub>c</sub> K/kg, and < 0.03 mg P/kg (modified Truog method), with a pH of 4.5. The site was under grass fallow for six to eight years.

### **Experimental Design**

The experimental design for the alley cropping trial was a randomized incomplete block. Four treatments were replicated in four blocks (*C.siamea*, *C. calothyrsus*, *G. sepium*, and a treeless control), with three additional treatments replicated twice (*C. reticulata*, *I. edulis*, and *L. leucocephala* (K636)). Trees were planted at a spacing of 3.0 x 0.5 m. Each plot consists of three rows of trees six meters in length, resulting in a plot size of 9 x 6 m.

A nitrogen response experiment of monocropped maize was established in the same field with nitrogen fertilizer (urea) application rates of 0, 50, and 100 kg/ha broadcast at each maize planting. A randomized complete block design with two replications was used.

### **Tree and Crop Management**

Four-month-old, nursery-grown seedlings were transplanted in the field in March 1988. Two maize crops were planted per year, a summer crop (April to August) and a winter crop (September to January), with the first crop planted September 1988. The trees were cut twice per crop cycle, at maize planting and approximately 65 days after maize planting when tree heights reached 1.5 to 2.0 m. The trees were first cut at approximately 0.60 m above ground level. The

pruning height of the trees increased at each harvest, reaching approximately 0.90 m above ground level after twelve tree harvests. Tree biomass was separated into fuelwood (stems > 0.01 to 0.02 m in diameter) and green manure components. At maize planting, green manure was incorporated into the soil to a 0.25 m depth. Green manure was applied to the soil surface at the second tree cutting.

Three rows of maize (Pioneer Hi-Bred International Co. singlecross hybrid X304C) were planted in the alleys. At the first cropping season, maize was planted at a spacing of 0.75 x 0.25 m. At the second and subsequent cropping seasons, maize rows were spaced 0.90 m from tree rows and 0.60 m between maize rows with a 0.25-m within-row spacing to reduce potential competition between trees and crops. In the control plot, maize was planted at the same spacing and density as the alley cropped plots, not replacing tree species with maize plants but simply eliminating the tree species. In the sole-cropped nitrogen response experiment, maize was always planted at a spacing of 0.75 x 0.25 m. At each maize planting, 100 kg P/ha as treble superphosphate and 100 kg K/ha as muriate of potash was broadcast on all plots in both experiments. Crop residues were removed from the field in all plots after harvest.

### **Data Collection**

Biomass yield of tree prunings and the amount of nitrogen in tree prunings and maize (stover and grain) were determined at each tree and maize harvest. Trees were harvested from a 2-m length segment of the middle tree row in each

plot, at each tree cutting. Tree prunings were separated into wood and green manure components and weighed. For the first harvest, stems larger than 0.02 m in basal diameter were defined as wood, with the remaining defined as green manure. For the second and subsequent tree harvests, stems larger than 0.01 m in basal diameter were defined as wood. A subsample (3 to 4 branches) was taken of the green manure component and separated into leaf and twig components. Wood, twig, and leaf subsamples were weighed, dried to a constant weight at 70° C, and weighed again for moisture content determination and leaf:twig ratio. Ground subsamples of wood, twigs, and leaves were analyzed for percent nitrogen using a LECO 600 C-H-N Elemental Analyzer. Maize was harvested from a 2 x 3 m area adjacent to the middle row of each plot, with maize grain and stover yield calculations based on the actual area harvested. Grain and stover yields were determined following the methods described by the Benchmark Soils Project (1982). Subsamples of grain and stover were oven dried at 70° C, ground, and analyzed for percent nitrogen using a LECO 600 C-H-N Elemental Analyzer.

### **Data Analysis**

Percent apparent nitrogen recovery in the maize crop was determined by the difference method in which total nitrogen recovered in the plots with nitrogen applied (tree prunings or inorganic fertilizer) minus total nitrogen recovered in the control-plot maize is divided by the quantity of applied nitrogen. This method

assumes that uptake of soil nitrogen by a crop supplied with nitrogen is the same as that of a crop not supplied with nitrogen, with the difference in total nitrogen uptake attributed to the nitrogen applied. There are, however, a number of problems associated with the underlying assumption of the difference method. A crop supplied with nitrogen can produce a larger root system, enabling it to exploit a larger volume of soil than a crop not supplied with nitrogen, resulting in an underestimate of soil nitrogen uptake and an overestimate of apparent nitrogen recovery. Numerous investigators have published evidence of the so-called priming effect, or stimulating effect of nitrogen fertilizers on uptake of soil nitrogen (Allison 1966, Westerman and Kurtz 1973, Hauck and Bremner 1976). In some cases, uptake of soil nitrogen is increased two or threefold by addition of fertilizer, resulting in an underestimate of soil nitrogen uptake and an overestimate of apparent nitrogen recovery. In addition to these problems, apparent nitrogen recovery in cropping systems with repeated additions of nitrogen will include residual nitrogen and will result in an overestimate of apparent nitrogen recovery for a specific cropping period. The use of isotopically labeled nitrogen provides the most accurate measure of plant uptake of soil nitrogen, but its use is limited because of high cost.

Treatment means and standard errors of means were calculated for all sampling times and factors. Differences between treatment means for all variables were determined using analysis of variance techniques (General Linear Model procedure in Statistical Analysis System) and compared using LSD.

## RESULTS

### Amount of Tree Prunings Applied to Maize Crops

The amount of tree prunings applied to the maize crops was greatest for *C. calothyrsus*, averaging 4.0 t DW/ha per maize crop and increasing substantially over time (Figure 3.1, Table A3.1). *C. reticulata* and *G. sepium* produced similar amounts of tree prunings, averaging 3.3 and 3.1 t DW/ha per maize crop, respectively. *C. siamea*, *I. edulis*, and *L. leucocephala* produced the lowest amount of tree prunings, averaging 2.4, 1.8, and 1.5 t DW/ha per maize crop, respectively.

### Amount of Nitrogen Applied via Tree Prunings

The amount of nitrogen applied to the maize crop via tree prunings ranged from an average of 115 kg N/ha per maize crop for *C. calothyrsus* to an average of 42 kg N/ha per maize crop for *I. edulis* (Figure 3.2, Table A3.2). Tree prunings of *G. sepium* and *C. reticulata* contained similar amounts of nitrogen in five of the six maize crops, averaging 85 and 75 kg N/ha per maize crop, respectively. *C. siamea*, *L. leucocephala*, and *I. edulis* tree prunings contained an average of 50, 47, and 42 kg N/ha per maize crop, respectively. The trend in nitrogen applied via tree prunings over the six cropping periods varied among tree species. The amount of nitrogen applied via tree prunings increased over time for *C. calothyrsus*, *C. siamea*, and *I. edulis*. In contrast, the amount of nitrogen in tree prunings for *G. sepium*, *C. reticulata*, and *L. leucocephala* decreased initially and remained relatively constant thereafter.

## Maize Nitrogen Uptake

For the first maize harvest, maize nitrogen uptake was similar among alley cropping treatments (Table 3.2). Differences in maize nitrogen uptake among alley cropping treatments began at the second harvest. The ranking of tree species at each maize harvest was similar. In general, the greatest maize nitrogen uptake was observed with the tree species *G. sepium*, followed by *C. calothyrsus*, *C. siamea*, *I. edulis*, *L. leucocephala*, and *C. reticulata*.

At the first maize harvest, there was no significant difference in maize nitrogen uptake between the control plot and the alley cropped plots (Table 3.2). At the second maize harvest, maize nitrogen uptake in the control plot was greater than in the *I. edulis*, *L. leucocephala*, and *C. reticulata* alley cropped plots. Greater maize nitrogen uptake in the alley cropped plots compared to the control plot began at the third harvest with *G. sepium*, at the fourth harvest with *C. calothyrsus*, at the fifth harvest with *I. edulis*, and at the sixth harvest with *C. siamea* and *C. reticulata*. Maize nitrogen uptake in the *L. leucocephala* alley-cropped plots was similar to the control plot at the third maize harvest and thereafter.

Maize nitrogen uptake was similar between treatments in the nitrogen fertilization experiment at the first and second harvest (Table 3.3). Differences between treatments occurred at the third harvest and thereafter, with higher maize nitrogen uptake in the 50 kg N/ha and 100 kg N/ha treatments than the no-fertilized treatment.

Maize nitrogen uptake was greater in the 0 N kg/ha treatment in the monocropping experiment compared to the control plot in the alley cropping experiment, as a result of the area occupied by the trees which reduced the area for maize cultivation in the alley cropping experiment.

#### **Apparent Nitrogen Recovery by Maize**

At each maize harvest, the apparent nitrogen recovery was calculated only when maize nitrogen uptake in the alley cropped and nitrogen fertilized plots was significantly greater than the control plots. At every maize harvest, apparent nitrogen recovery was roughly two times higher for *G. sepium* than *C. calothyrsus* (Table 3.4). During the summer cropping seasons, apparent nitrogen recovery increased over time in the *G. sepium* and *C. calothyrsus* plots, with the magnitude of increase greatest for *G. sepium*. At the final cropping period, apparent nitrogen recovery was greatest for *G. sepium* and *C. siamea*, followed by *I. edulis*, *C. reticulata*, and *C. calothyrsus*.

In the nitrogen fertilized plots, apparent nitrogen recovery averaged 41 percent during the winter cropping seasons (Table 3.5). During the summer cropping season, apparent nitrogen recovery averaged 34 and 60 in the 50 kg N/ha and 100 kg N/ha treatments, respectively. Apparent nitrogen recovery did not increase significantly over time during the summer cropping seasons, as in the alley cropped plots.

## DISCUSSION

In most cases, the amount of nitrogen applied via tree prunings was higher than the amount taken up by the associated maize crop. The ratio between tree-pruning nitrogen applied and maize nitrogen uptake averaged 2.00 for *C. calothyrsus*, 1.84 for *C. reticulata*, 1.30 for *G. sepium*, 1.03 for *L. leucocephala*, 0.87 for *C. siamea*, and 0.81 for *I. edulis*. *L. leucocephala* grew extremely poorly at this site, primarily as a result of continuous damage by the leucaena psyllid (*Heteropsylla cubana*).

Despite the large amounts of nitrogen applied via tree prunings, the apparent nitrogen recovery by the associated maize crop was low until the sixth cropping season, except in the case of *G. sepium*. In contrast, the apparent nitrogen recovery from nitrogen fertilizer was high beginning at the third cropping season. Apparent nitrogen recovery was considerably greater, up to 3.6 times greater, in the nitrogen fertilized plots than in the alley cropped plots with the difference between the two decreasing over time. The decrease in the difference of apparent nitrogen recovery between the nitrogen fertilized plots and the alley cropped plots was a result of increased apparent nitrogen recovery in the alley cropped plots over time. The availability of residual nitrogen from repeated tree pruning additions was probably the reason for the increased apparent nitrogen recovery in the alley cropping plots. Bouldin and colleagues (1991) found apparent nitrogen recovery of residual nitrogen from leguminous green manure applications to be 4 to 9 percent of the applied nitrogen or 17 to 28 percent of

residual N utilized. Fox and colleagues (1974) reported very little residual effect of applied nitrogen fertilizer in maize systems from a study conducted at five sites in Puerto Rico.

If a considerable amount of nitrogen was applied in the alley cropping systems, why is it not available to the associated crop? It is likely that in the first cropping season a sufficient amount of soil nitrogen was mineralized for maize production. In the subsequent maize crops, competition between trees and crops and unsynchronized nitrogen availability and crop demand contributed to low apparent nitrogen recovery.

Competition between trees and crops for light and/or nutrients in alley cropping systems has been demonstrated by reduced crop yields near the tree rows (Kang et al. 1981, Evensen 1989, Haggard and Beer 1993, Salazar et al. 1993). It is most likely that maize nitrogen uptake was limited by light competition in the alley cropped plots, resulting in higher apparent nitrogen recovery by urea fertilizer in the monocropped plots. Competition between trees and crops for nitrogen could also contribute to low apparent nitrogen recovery, particularly in the alley cropped plots with non-nitrogen fixing trees (*C. reticulata* and *C. siamea*) and the fastest growing species (*C. calothyrsus*).

A study using soil and tree prunings from this experiment found cumulative percent nitrogen mineralized in 28 days to be 65, 55, 42, 29, 19, and 17 percent for *G. sepium*, *C. reticulata*, *L. leucocephala*, *C. siamea*, *C. calothyrsus*, and *I. edulis*, respectively (Oglesby and Fownes 1992). The greatest nitrogen demand for

maize occurs between 30 and 75 days after planting (Aldrich et al. 1978, Yamoah et al. 1986, Haggard 1990). Tree prunings were applied twice per maize crop, at maize planting and 65 days after maize planting. Unsynchronized nitrogen availability and crop demand occurred with both fast and slower decomposing tree prunings. At the first tree pruning application, nitrogen was presumably released from the faster decomposing tree prunings (*G. sepium* and *C. reticulata*) before the peak in crop demand. The greater apparent nitrogen recovery by maize in the *G. sepium* alley cropped plot could be a result of synchronized nitrogen release from the second tree pruning application and crop demand. Competition for nitrogen between maize and the non-nitrogen fixing tree species *C. reticulata* could explain the low apparent nitrogen recovery observed.

In summary, the data presented indicates that apparent nitrogen recovery was initially higher for nitrogen fertilizer in monocropping than for tree prunings in alley cropping systems. Apparent nitrogen recovery from tree prunings in alley cropping systems, however, increased over time. By the sixth cropping period, apparent nitrogen recovery by maize from tree prunings and nitrogen fertilizer were similar. Apparent nitrogen recovery by maize from tree prunings was highest for *G. sepium*, followed by *C. siamea*, *I. edulis*, *C. reticulata*, and *C. calothyrsus*.

It is clear that information is needed on how best to maximize nitrogen transfer from trees to maize in an alley cropping system. While the work reported here provides insight into the net effect of a number of interacting plant and soil

processes, more specific research to reduce competition between trees and crops, synchronize nitrogen release from tree prunings with crop demand, and understand residual effects of repeated applications of woody legume green manure would improve our ability to manage nitrogen and make more of it available to crops.

Table 3.1. Comparison of nitrogen released by the mulch of various tree species used in alley cropping.

TREE SPECIES	N RELEASED <sup>a</sup>	MATERIAL	METHOD	AUTHOR
	- % -			
<i>Gliricidia sepium</i>	65	leaves	open frame	Budelman 1988
<i>Gliricidia sepium</i>	65	leaves + twigs	incubation	Oglesby & Fownes 1992
<i>Gliricidia sepium</i>	50	leaves	mesh bags	Yamoah et.al. 1986
<i>Gliricidia sepium</i>	34	leaves	incubation	Constantinides 1992
<i>Gliricidia sepium</i>	32	leaves + twigs	incubation	Constantinides 1992
<i>Leucaena leucocephala</i>	60	leaves	incubation	Constantinides 1992
<i>Leucaena leucocephala</i>	42	leaves + twigs	incubation	Oglesby & Fownes 1992
<i>Leucaena leucocephala</i>	36	leaves	open frame	Budelman 1988
<i>Cassia reticulata</i>	55	leaves + twigs	incubation	Oglesby & Fownes 1992
<i>Sesbania sesban</i>	41	leaves	incubation	Constantinides 1992
<i>Sesbania sesban</i>	31	leaves + twigs	incubation	Oglesby & Fownes 1992
<i>Cassia siamea</i>	42	leaves	incubation	Constantinides 1992
<i>Cassia siamea</i>	35	leaves	mesh bags	Yamoah et.al. 1986
<i>Cassia siamea</i>	29	leaves + twigs	incubation	Oglesby & Fownes 1992
<i>Flemingia macrophylla</i>	26	leaves	open frames	Budelman 1988
<i>Flemingia macrophylla</i>	20	leaves	mesh bags	Yamoah et.al. 1986
<i>Calliandra calothyrsus</i>	30	leaves	incubation	Constantinides 1992
<i>Calliandra calothyrsus</i>	27	leaves + twigs	incubation	Constantinides 1992
<i>Calliandra calothyrsus</i>	19	leaves + twigs	incubation	Oglesby & Fownes 1992
<i>Inga edulis</i>	28	leaves	incubation	Constantinides 1992
<i>Inga edulis</i>	17	leaves + twigs	incubation	Oglesby & Fownes 1992

<sup>a</sup> Percent of original nitrogen released in 28 days

Table 3.2. Comparison of maize nitrogen uptake among various tree species in alley cropping systems.

TREATMENT	MAIZE CROP					
	Winter 1/89	Summer 8/89	Winter 1/90	Summer 9/90	Winter 2/91	Summer 8/91
	-kg/ha-					
CONTROL	56.8	64.8	38.6	40.0	21.5	40.5
<i>G. sepium</i>	78.3	62.6	57.8	62.9	39.0	105.7
<i>C. calothyrsus</i>	71.1	56.2	43.4	61.8	32.0	94.5
<i>C. siamea</i>	55.7	67.0	47.6	51.2	28.3	92.2
<i>I. edulis</i>	62.8	52.0	37.4	58.8	34.5	71.1
<i>L. leucocephala</i>	67.4	48.4	36.6	44.9	27.1	57.6
<i>C. reticulata</i>	67.3	43.7	44.6	36.1	17.9	66.8
LSD <sub>0.05</sub> between:						
4 rep trts	26.9	9.2	13.2	17.9	7.7	18.1
2 rep trts	38.1	13.0	18.7	25.4	10.9	25.7
4 & 2 rep trts	33.0	11.2	16.2	22.0	9.4	22.2

Table 3.3. Comparison of maize nitrogen uptake between nitrogen fertilized treatments in the sole cropping experiment.

TREATMENT	MAIZE CROP					
	Winter 1/89	Summer 8/89	Winter 1/90	Summer 9/90	Winter 2/91	Summer 8/91
	- kg/ha -					
0 kg N/ha	72.7	128.2	54.3	72.6	25.9	69.6
50 kg N/ha	71.1	137.7	78.8	91.6	41.5	84.4
100 kg N/ha	71.5	147.1	100.1	128.6	63.6	134.2
LSD <sub>0.05</sub>	14.5	19.0	12.0	16.3	13.9	14.2

Table 3.4. Comparison of percent nitrogen recovered from tree prunings by associated maize in alley cropping systems.

TREATMENT	MAIZE CROP			
	Winter	1990 Summer	Winter	1991 Summer
	- % N recovery <sup>a</sup> -			
<i>G. sepium</i>	24.2(6.3) <sup>b</sup>	25.8(8.8)	32.1(6.1)	67.7(7.5)
<i>C. calothyrsus</i>	-- <sup>c</sup>	15.3(5.3)	11.4(0.2)	32.2(6.1)
<i>C. siamea</i>	--	--	--	54.9(8.9)
<i>I. edulis</i>	--	--	32.9(7.1)	39.8(8.1)
<i>C. reticulata</i>	--	--	--	39.6(10.9)

<sup>a</sup> percent recovery = (maize N uptake<sub>prunings applied</sub> - maize N uptake<sub>control</sub>)/N applied

<sup>b</sup> parenthesis enclose one standard error of the mean

<sup>c</sup> data omitted if maize N uptake was not significantly greater than the control plot

Table 3.5. Comparison of percent nitrogen recovered from inorganic nitrogen fertilizer (urea) maize in sole cropping systems.

TREATMENT	MAIZE CROP			
	Winter	1990 Summer	Winter	1991 Summer
	- % N recovery <sup>a</sup> -			
50 kg N/ha	48.8(3.4) <sup>b</sup>	37.9(3.6)	31.4(1.2)	29.5(2.2)
100 kg N/ha	45.9(4.1)	55.9(12.2)	37.8(5.4)	64.6(6.7)

<sup>a</sup> percent recovery = (maize N uptake<sub>fert. trts.</sub> - maize N uptake<sub>no fert.</sub>)/N applied

<sup>b</sup> parenthesis enclose one standard error of the mean

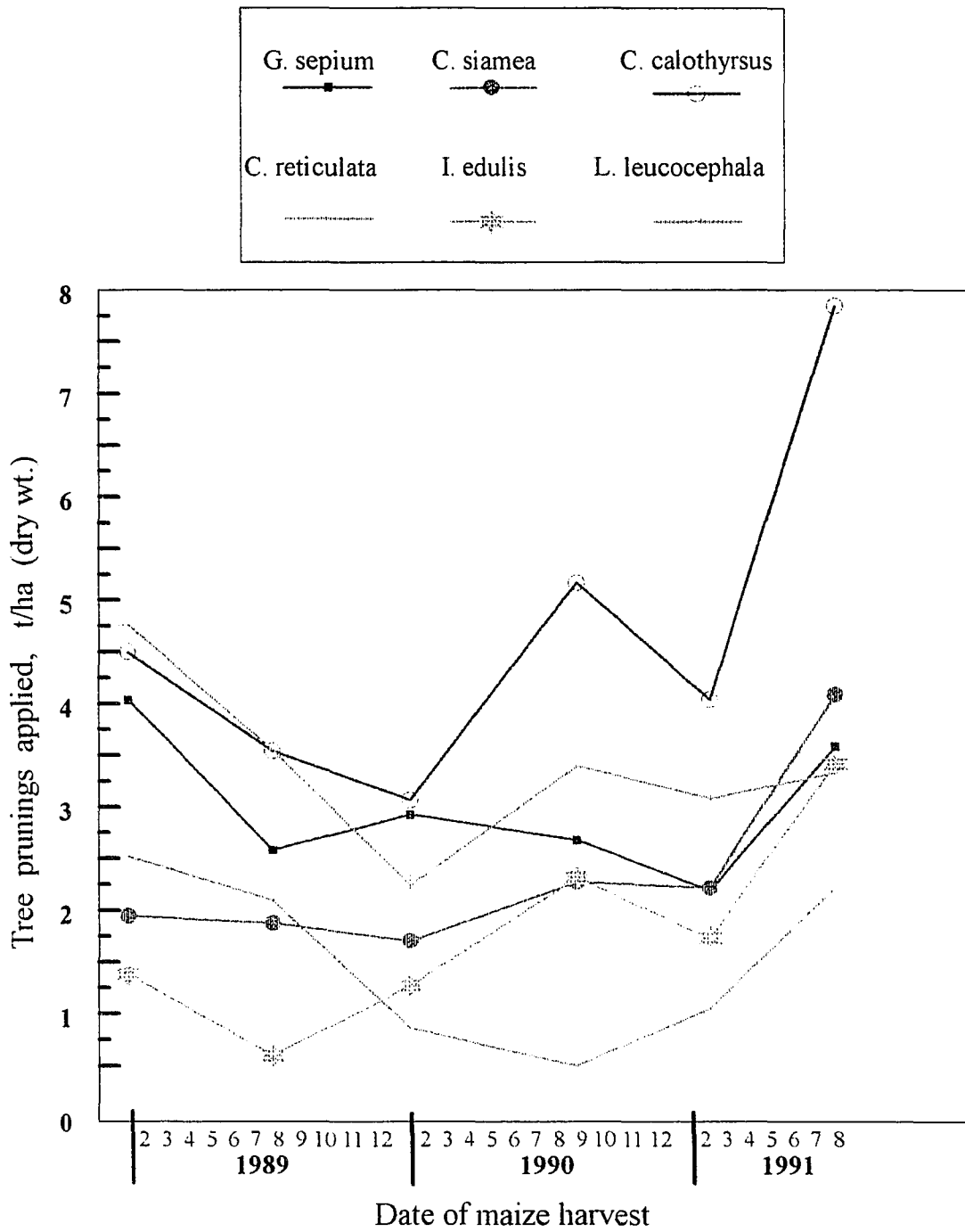


Figure 3.1 Comparison of the amount of tree pruning applied in alley cropping systems, in t/ha (dry wt.) per crop cycle.

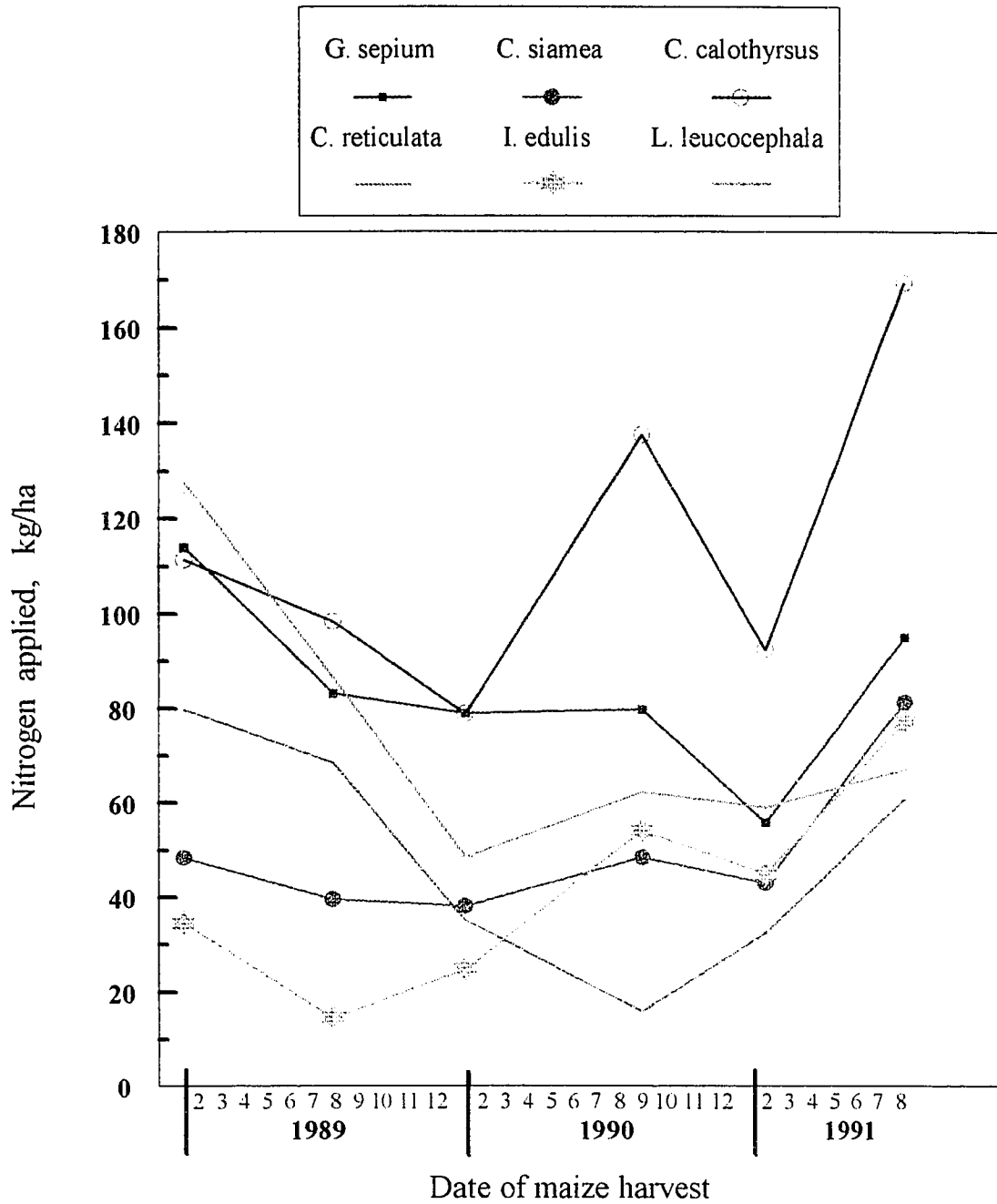


Figure 3.2 Comparison of the amount of nitrogen applied via tree prunings in alley cropping systems, in kg N/ha per crop cycle.

## APPENDIX

Table A3.1. Amount of tree prunings applied at each tree cutting.

CROP	SPECIES	TREE PRUNINGS APPLIED		
		at maize planting	at 65 days after planting	Total
		- kg DW/ha -		
1/89	<i>C. Calothyrsus</i>	2912 (266) <sup>a</sup>	1586 (58)	4498 a
	<i>G. sepium</i>	2061 (221)	1973 (274)	4034 a
	<i>C. reticulata</i>	2970 (42)	1787 (15)	4757 a
	<i>L. leucocephala</i>	1555 (208)	965 (182)	2520 b
	<i>C. siamea</i>	998 (45)	944 (91)	1942 bc
	<i>I. edulis</i>	580 (45)	794 (52)	1374 c
8/89	<i>C. calothyrsus</i>	2165 (202)	1414 (77)	3579 a
	<i>G. sepium</i>	1183 (144)	1440 (162)	2623 b
	<i>C. reticulata</i>	2256 (338)	1336 (200)	3592 a
	<i>L. leucocephala</i>	982 (170)	1154 (14)	2136 b
	<i>C. siamea</i>	1288 (126)	624 (114)	1912 b
	<i>I. edulis</i>	635 (50)	0	636 c
1/90	<i>C. calothyrsus</i>	1807 (178)	1256 (137)	3063 ab
	<i>G. sepium</i>	1756 (320)	1167 (67)	2923 bc
	<i>C. reticulata</i>	821 (100)	1416 (52)	2237 cd
	<i>L. leucocephala</i>	454 (168)	404 (190)	858 f
	<i>C. siamea</i>	830 (118)	870 (102)	1700 de
	<i>I. edulis</i>	741 (97)	524 (98)	1265 ef

(continued)

Table A3.1. (Continued) Amount of tree prunings applied at each tree cutting.

CROP	SPECIES	TREE PRUNINGS APPLIED		
		at maize planting	at 65 days after planting	Total
		- kg DW/ha -		
9/90	<i>C. calothyrsus</i>	2728 (235)	2425 (261)	5153 a
	<i>G. sepium</i>	530 (38)	2136 (210)	2666 bc
	<i>C. reticulata</i>	1745 (108)	1636 (380)	3381 b
	<i>L. leucocephala</i>	324 (116)	165 (24)	489 d
	<i>C. siamea</i>	917 (107)	1339 (117)	2256 c
	<i>I. edulis</i>	1405 (32)	894 (143)	2299 c
2/91	<i>C. calothyrsus</i>	2522 (87)	1581 (281)	4103 a
	<i>G. sepium</i>	1554 (128)	700 (36)	2254 c
	<i>C. reticulata</i>	1335 (114)	1809 (87)	3144 b
	<i>L. leucocephala</i>	477 (225)	632 (65)	1109 d
	<i>C. siamea</i>	1348 (137)	928 (102)	2276 c
	<i>I. edulis</i>	847 (118)	942 (22)	1789 cd
8/91	<i>C. calothyrsus</i>	4930 (405)	2853 (179)	7783 a
	<i>G. sepium</i>	1337 (207)	2182 (242)	3519 bc
	<i>C. reticulata</i>	1754 (137)	1512 (310)	3266 bc
	<i>L. leucocephala</i>	890 (448)	1258 (429)	2149 c
	<i>C. siamea</i>	2023 (215)	1996 (160)	4019 b
	<i>I. edulis</i>	1873 (295)	1476 (111)	3349 bc

<sup>a</sup> parenthesis enclose one standard error of the mean

Means followed by the same letter within each cropping period are not significantly different at 5% probability level by LSD test.

Table A3.2. Amount of nitrogen applied via tree prunings at each tree cutting.

CROP	SPECIES	NITROGEN APPLIED VIA TREE PRUNINGS		
		at maize planting	at 65 days after planting	Total
- kg DW/ha -				
1/89	<i>C. calothyrsus</i>	63.20 (5.76) <sup>a</sup>	48.02 (3.11)	111.21 a
	<i>G. sepium</i>	55.85 (5.98)	57.97 (9.46)	113.82 a
	<i>C. reticulata</i>	83.47 (1.17)	43.98 (2.34)	127.45 a
	<i>L. leucocephala</i>	47.29 (6.37)	32.12 (4.71)	79.70 b
	<i>C. siamea</i>	23.95 (1.07)	24.29 (2.03)	48.24 c
	<i>I. edulis</i>	13.92 (1.08)	20.48 (0.26)	34.40 c
8/89	<i>C. calothyrsus</i>	57.46 (3.05)	41.85 (3.08)	99.30 a
	<i>G. sepium</i>	36.56 (4.88)	47.57 (8.96)	84.13 ab
	<i>C. reticulata</i>	45.75 (1.65)	41.64 (3.02)	87.40 ab
	<i>L. leucocephala</i>	31.95 (6.21)	27.45 (5.07)	69.40 bc
	<i>C. siamea</i>	27.26 (3.46)	13.20 (1.94)	40.46 cb
	<i>I. edulis</i>	15.40 (0.92)	0	15.40 d
1/90	<i>C. calothyrsus</i>	44.66 (4.85)	34.11 (4.37)	78.78 a
	<i>G. sepium</i>	39.00 (8.06)	39.91 (2.38)	78.90 a
	<i>C. reticulata</i>	14.92 (1.01)	33.48 (2.66)	48.40 b
	<i>L. leucocephala</i>	12.02 (4.86)	12.86 (6.39)	34.88 bc
	<i>C. siamea</i>	15.98 (2.80)	22.05 (3.24)	24.65 c
	<i>I. edulis</i>	11.92 (0.65)	12.73 (2.04)	24.65 c

(continued)

Table A3.2. (Continued) Amount of nitrogen applied via tree prunings at each tree cutting.

CROP	SPECIES	NITROGEN APPLIED VIA TREE PRUNINGS		
		at maize planting	at 65 days after planting	Total
		- kg/ha -		
9/90	<i>C. calothyrsus</i>	69.30 (5.90)	69.29 (7.57)	138.58 a
	<i>G. sepium</i>	17.14 (1.24)	63.66 (8.28)	80.80 b
	<i>C. reticulata</i>	33.44 (2.34)	29.76 (4.51)	63.20 bc
	<i>L. leucocephala</i>	10.62 (4.08)	6.24 (1.24)	16.86 d
	<i>C. siamea</i>	22.14 (2.75)	27.30 (2.52)	49.45 c
	<i>I. edulis</i>	35.18 (3.04)	19.93 (2.28)	55.12 c
2/91	<i>C. calothyrsus</i>	51.29 (3.20)	41.28 (6.94)	92.57 a
	<i>G. sepium</i>	34.24 (4.13)	21.76 (1.10)	56.01 b
	<i>C. reticulata</i>	19.74 (1.56)	39.50 (1.10)	59.24 b
	<i>L. leucocephala</i>	12.66 (6.36)	19.82 (2.76)	32.48 c
	<i>C. siamea</i>	20.62 (2.88)	22.58 (2.07)	43.21 bc
	<i>I. edulis</i>	18.12 (3.11)	27.08 (0.12)	45.21 bc
8/91	<i>C. calothyrsus</i>	102.08 (8.16)	67.04 (4.21)	169.12 a
	<i>G. sepium</i>	33.46 (4.75)	61.21 (6.77)	94.67 b
	<i>C. reticulata</i>	32.60 (3.46)	34.18 (7.00)	66.78 b
	<i>L. leucocephala</i>	21.98 (12.17)	38.62 (13.18)	60.60 b
	<i>C. siamea</i>	39.29 (7.00)	41.75 (3.36)	81.04 b
	<i>I. edulis</i>	42.47 (2.86)	34.50 (2.60)	76.96 b

<sup>a</sup> parenthesis enclose one standard error of the mean

Means followed by the same letter within each cropping period are not significantly different at 5% probability level by LSD test.

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## CHAPTER 4

### SPATIAL AND TEMPORAL DYNAMICS OF SOIL ORGANIC CARBON AND NITROGEN IN ALLEY CROPPING SYSTEMS

It is often hypothesized that there is considerable potential for soil conservation in agroforestry systems, such as alley cropping, both in the control of erosion and by other means of maintaining soil fertility (Kang et al. 1984, Nair 1984, Young 1989). Suggested mechanisms by which trees can maintain or improve soil fertility are 1) maintenance of soil organic carbon through carbon fixation in photosynthesis and its transfer via tree residues, 2) addition of nitrogen by nitrogen-fixing trees and translocation of nitrogen from soil layers beyond the reach of annual crops, and 3) reduction of nitrogen loss through a combination of adsorption and uptake by trees (Anderson 1986, Young 1989).

The effects of alley cropping on soil carbon and organic nitrogen have been studied at the International Institute of Tropical Agriculture (Kang et al. 1985, Yamoah et al. 1986, Lal 1989, Gichuru and Kang 1989), the Centro Agronomico Tropical de Investigacion y Ensenanza (Kass et al. 1989), and as part of the Tropical Soils Research Program (Salazar 1991). Results are variable, with some authors reporting a decline in soil carbon and organic nitrogen after several years of alley cropping, whereas others have reported increases after one or two cropping cycles (Tables 4.1 and 4.2).

The present study was conducted to test the hypothesis that alley cropping can maintain or increase soil organic carbon and nitrogen, thus contributing to the

knowledge base concerning soil fertility aspects of alley cropping systems. The specific objectives of this study were 1) to measure changes in soil carbon and total soil nitrogen under alley cropping, and 2) to construct a partial nitrogen budget for estimating nitrogen gain/loss of the system.

A second hypothesis tested was that differences in soil organic carbon and nitrogen develop over time between the soil in the cropping area (alleys) and the soil beneath the trees in alley cropping systems. Soil organic carbon and nitrogen are expected to be higher in the soil within the cropping area (alleys) than the soil beneath the trees, as a result of tree prunings applied to the cropping area. In alley cropping systems where tree prunings are removed, soil organic carbon and nitrogen are expected to be higher in the soil beneath the trees compared to the soil within the cropping area (alleys), as a result of increased mineralization of soil organic matter due to cultivation in the cropping area.

## **METHODS**

### **Site Description, Experimental Design, and Management**

Soil carbon and nitrogen were determined on soil samples collected in an alley cropping experiment conducted at the University of Hawaii Wailua Agricultural Experiment Station located on the Island of Kauai (22° 04' N, 159° 24' W) at an elevation of 150 m. Mean annual precipitation is 2489 mm, with mean monthly precipitation seldom less than 100 mm. Temperatures range from an average minimum of 20.0° C to an average maximum of 25.5° C. The soil is

derived from basic igneous rock mixed with volcanic ash, classified as a clayey, ferritic, isothermic Typic Gihbsumox with a gravelly, silty, clay texture (Ikawa et al. 1985). Organic carbon and total nitrogen are both high, 3.59 percent and 0.247 percent, respectively. The soil Ph(H<sub>2</sub>O) is 4.5 and is low in bases and phosphorus; 2.0 cmol<sub>c</sub> Ca/kg, 0.34 cmol<sub>c</sub> Mg/kg, 0.17 cmol<sub>c</sub> K/kg, and < 0.03 mg P/kg (modified Truog method). The site was under grass fallow for six to eight years.

A randomized complete block design with four replications was used to evaluate three tree species (*C. siamea*, *C. calothyrsus*, and *G. sepium*), each with two management practices (tree prunings applied and tree prunings removed), and a control treatment with no tree species and no tree prunings applied. Trees were planted at a spacing of 3.0 x 0.5 m. Each plot consisted of three rows of trees six meters in length, resulting in a plot size of 9 x 6 m.

Nursery-grown tree seedlings were transplanted in the field in March 1988. Two maize crops were planted per year, a summer crop (April to August) and a winter crop (September to January), with the first crop planted in September 1988. The trees were cut twice per crop cycle, at maize planting and approximately 65 days after maize planting when tree heights reached 1.5 to 2.0 m. The trees were first cut at approximately 0.60 m above ground level. The pruning height of the trees was increased at each harvest, reaching approximately 0.90 m above ground level after twelve tree harvests. Tree biomass was separated into fuelwood (stems > 0.01 to 0.02 m in basal diameter) and greenmanure/fodder components. At maize planting, green manure was incorporated into the

soil to a 0.25-m depth with a disc plow. Green manure was applied to the soil surface at the second tree cutting.

Three rows of maize (Pioneer Hi-Bred International Co. singlecross hybrid X304C) were planted in the alleys. At the first cropping season, maize was planted at a spacing of 0.75 x 0.25 m. At the second and subsequent cropping seasons, maize rows were spaced 0.90 m from tree rows and 0.60 m between maize rows with a 0.25-m within-row spacing to reduce potential competition between trees and crops. The control plot was planted at the same spacing and density as the alley cropped plots, not replacing tree species with maize plants but simply eliminating the tree species. At each maize planting, 100 kg P/ha as treble superphosphate and 100 kg K/ha as muriate of potash was broadcast on all plots in both experiments. Crop residues in all plots were removed from the field after harvest.

#### **Data Collection**

Twenty-eight soil samples were taken at two depths (0 to 0.25 and 0.25 to 0.50 m) from the entire experimental area, before establishing the experiment in March 1988. In April 1992, three years after establishment (five cropping cycles and ten tree cuttings), soil samples were collected again. Seven soil samples were collected per plot at two depths (0 to 0.25 and 0.25 to 0.50 m). Composite soil samples of three cores per plot comprised the soil sample for the area occupied by the trees (base of tree to 0.6 m on both sides of the tree row) and of four

cores per plot for the cropping area (1.8-m wide section in the middle of the 3-m width alley). Soil samples were air dried, passed through a 2-mm sieve, and powdered for analysis. Organic carbon and nitrogen were analyzed using a LECO 600 C-H-N Elemental Analyzer. All soil analyses were done at the end of the three years to reduce laboratory errors.

The amount of nitrogen removed in maize (grain and stover) and tree prunings was determined at each maize and tree harvest. Maize was harvested from a 2- x 3-m area adjacent to the middle row of each plot, with yield calculations based on the actual area harvested. Grain and stover yields were determined following the methods described by the Benchmark Soils Project (1982). Tree prunings were harvested from a 2-m length segment of the middle-tree row in each plot. Tree prunings were separated into wood and green manure/fodder components and weighed. For the first harvest, stems larger than 0.02 m in basal diameter were considered wood, with the remaining defined as green manure/fodder. For the second and subsequent tree harvests, stems larger than 0.01 m in basal diameter were defined as wood. A subsample was taken of the green manure/fodder fraction and separated into leaf and twig components. Wood, twig, and leaf subsamples were weighed, dried to a constant weight at 70° C, and weighed again for moisture content determination and leaf:twig ratio. Subsamples of maize grain and stover and tree wood, twigs, and leaves were analyzed for percent nitrogen using a LECO 600 C-H-N Elemental Analyzer.

## Data Analysis

Differences in soil organic carbon and nitrogen between soil in the cropping area and soil beneath the trees were evaluated using a split-plot design with treatments as main plots and location (tree area vs. cropping area) as subplots and compared using LSD. Orthogonal comparisons were made to test management effects: tree prunings applied vs. tree prunings removed.

Differences in soil carbon and nitrogen between initial and final soil sampling dates were determined using the Students t test.

The whole system nitrogen budget was calculated at the end of three years, based on the change in total soil nitrogen, removal of nitrogen in maize (grain and stover) and tree prunings, nitrogen remaining in tree stump, and nitrogen inputs from fertilizer and precipitation. The change in total soil nitrogen was calculated on a plot basis, using the weighted average of soil nitrogen measured in the crop area and the tree area. Nitrogen in precipitation was estimated to be 15 kg/ha/year (Greenland 1977, Jordan 1985).

$$\text{Net N Gain or Loss} = \text{change in soil N} + \text{N removed in maize and prunings} + \text{N in tree stump} - \text{N fertilizer} - \text{N precipitation.}$$

Treatment means were compared using LSD.

## RESULTS

### Soils in Cropping Area vs. Tree Area

In the alley cropping plots with tree prunings applied, soil carbon was higher in soils in the cropping area compared to the tree area only in the *C. calothyrsus* and *G. sepium* plots at a soil depth of 0 to 0.25 m (Table 4.3). In the plots with tree prunings removed, soil carbon levels did not vary among locations. Soil organic nitrogen differed among locations only in the *C. calothyrsus* plot with tree prunings applied, with higher levels found in the cropping area than the tree area at both soil depths (Table 4.4). In the plots with tree prunings removed, soil organic nitrogen levels did not vary among locations.

### Changes in Soil Organic Carbon

Surface soil organic carbon in the cropping area, 0- to 0.25-m depth, increased after three years of continuous maize cultivation in all treatments, ranging from 2.7 to 7.1 g/kg (Table 4.5). The largest gain in organic carbon over time was observed in the alley cropping plots with tree prunings applied. Organic carbon increased the most in the plots with *C. calothyrsus*, followed by *G. sepium* and *C. siamea*. An increase in surface soil organic carbon was also observed in the tree area in all treatments, ranging from 2.7 to 4.0 g/kg with no significant difference among treatments. Soil organic carbon in the *C. siamea* treatment with tree prunings applied was not significantly different than the treatments with tree prunings removed or the control treatment. There was no difference in soil

organic carbon between the alley cropping treatments with tree prunings removed and the control treatment.

Subsoil organic carbon in the cropping area (0.25 to 0.50 m) increased in the *C. calothyrsus* and *G. sepium* alley cropping plots with tree prunings applied and in the control plot. In all other treatments, subsoil organic carbon in the cropping area did not change after three years of maize cultivation. Subsoil organic carbon in the tree area also increased in the *C. calothyrsus* and *G. sepium* alley cropping plots with tree prunings applied.

#### **Changes in Soil Organic Nitrogen**

Surface soil organic nitrogen in the cropping area, 0- to 0.25-m depth, increased in the *C. calothyrsus* plot with tree prunings applied after three years of continuous maize cultivation (Table 4.6). In the *G. sepium* and *C. siamea* plots with tree prunings applied and in the control plot, surface soil organic nitrogen in the cropping area did not change after three years of continuous maize cultivation. In the alley cropping plots with tree prunings removed, surface organic nitrogen in the cropping area declined significantly with no significant difference among treatments. Surface soil organic nitrogen in the tree area did not change after three years of continuous maize cultivation in all plots, except for a slight decrease in the *C. siamea* plot with tree prunings removed. Subsoil organic nitrogen in the cropping and tree area (0.25 to 0.50 m) declined considerably in all treatments.

### **System Nitrogen Budget**

After three years of maize cultivation, a net loss of nitrogen (0- to 0.50-m soil depth) occurred in all alley cropping plots with tree prunings applied and in the control plot (Table 4.7). The amount of nitrogen lost was significantly less in the *C. calothyrsus* plot compared to the other treatments.

## **DISCUSSION**

### **Soil Organic Carbon and Nitrogen Changes**

Continuous cultivation of maize for five cropping periods resulted in an overall increase in soil organic carbon in all treatments. The relative rate of increase was most notable in the alley cropping plots with *G. sepium* and *C. calothyrsus* tree prunings applied. The increase in surface soil carbon in the control and alley cropping plots with tree prunings removed indicates that root residues can provide a measurable input to soil carbon. Gichuru and Kang (1989) and Yamoah et al. (1986) reported increases of soil carbon in maize alley-cropping systems when tree prunings were removed from the field, although Yamoah et al. (1986) found no increase in the control treatment.

The increase in soil organic carbon is most likely a measure of increasing below-ground litter pools, rather than soil organic matter. It is difficult to conclude whether the increase in soil organic carbon over time is increasing soil organic matter and soil fertility. Below-ground litter pools and soil organic matter, together with turnover rates, need to be estimated separately before

conclusions on the effect of alley cropping on soil fertility and nutrient availability can be evaluated.

Alley cropping with tree prunings applied maintained or increased surface soil organic nitrogen (0- to 0.25-m depth) after five cropping periods, but the decrease in subsoil organic nitrogen (0.25- to 0.50-m depth) resulted in an overall decline, except in the *C. calothyrsus* plot. Kass and colleagues (1989) also reported no change in surface soil organic nitrogen (0- to 0.20-m depth) and a decline in subsoil organic nitrogen (0.20- to 0.40-m depth) after six years of alley cropping. Removing tree prunings in alley cropping system resulted in a decline in surface and subsoil organic nitrogen after three years, suggesting that the contribution of tree roots and nodules to soil organic nitrogen relative to that of green manure is negligible.

Only in the alley cropping plot with *C. calothyrsus* was soil organic nitrogen maintained (0- to 0.50-m depth) after three years of alley cropping. The maintenance of soil nitrogen in the *C. calothyrsus* plot compared to the loss of soil nitrogen in the *G. sepium* and *C. siamea* plots is most likely a result of 1) more nitrogen applied via tree prunings, 2) slower nitrogen release from tree prunings, and 3) the incorporation of nitrogen into relatively more stable organic forms. In general, organic inputs of low quality, high in lignin or polyphenolics, lead to a more rapid formation of stable forms of organic matter than organic materials of high quality (Martin and Haider 1980, Stott et al. 1983, Kelly and Stevenson 1987). Polyphenolic compounds are also well known as modifiers of the rate of

decomposition (Swift et al. 1979). The amino acid and other biologically active forms of nitrogen undergo reaction with polyphenols to form stable polymers, which are eventually built into the complex stable organic matter with attendant reduction in biological and chemical reactivity (Broadbent 1984). High quality inputs, in turn, are associated with increased labile nitrogen which can result in large losses of nitrogen, if not synchronized with plant uptake. Soluble polyphenolic contents of *C. calothyrsus* leaves are considerably higher, more than double, than those found in *G. sepium* and *C. siamea* (Oglesby 1990, Oglesby and Fownes 1992, Constantinides 1992).

The data presented supports the hypothesis that the addition of tree prunings in alley cropping systems can increase levels of soil organic carbon over time. The addition of tree prunings resulted in higher soil organic carbon levels within the cropping area than the area occupied by the trees. If only the surface soil (0- to 0.25-m depth) is considered, the data also supports the hypothesis that soil organic nitrogen can be maintained or increased in alley cropping systems when tree prunings are used as green manure. However, when considering a soil depth of 0 to 0.50 m, the hypothesis is not always true. Soil organic nitrogen was not always found to be higher in the soil within the cropping area compared to the tree area.

The increase in soil carbon but not soil nitrogen supports the assumption of an increasing below-ground litter pool, rather than an increase in soil organic matter. A portion of this below-ground litter pool contains live roots and

undecomposed materials. Live roots have a C:N ratio between 45 and 90, resulting in a greater buildup of soil carbon relative to soil nitrogen.

### **Partial System Nitrogen Budget**

A near zero net nitrogen balance observed in the *C. calothyrsus* alley cropped plot with tree prunings applied suggests that there was either a greater nitrogen input or a reduced nitrogen output, compared to the other treatments. A greater nitrogen input would indicate the benefits from nitrogen fixation and/or the ability of trees to transfer soil nitrogen from deeper soil horizons. Although nitrogen fixation was not measured, the nitrogen fixing trees were nodulated and presumably fixing nitrogen. Changes in soil nitrogen below 0.50 m in depth were not measured, and, therefore, conclusions as to whether trees transfer soil nitrogen from deeper soil horizons cannot be made. Nitrogen was, however, transferred from the tree area to the cropping area. A reduced output could also have occurred and explained by the slower mineralization of *C. calothyrsus* tree prunings relative to the *G. sepium* and *C. siamea*.

A substantial amount of nitrogen was lost or unaccounted for in all other treatments, with no statistical difference in the amount of loss found among treatments. Estimated net nitrogen loss ranged from 909 to 1563 kg N/ha during the three years of maize cultivation, indicating that total nitrogen mineralization exceeded plant uptake by a substantial margin. Nitrogen uptake in maize accounted for less than 20 percent of the total soil organic nitrogen lost. Oglesby

(1990) and Constantinides (1992) measured nitrogen mineralization in soil collected from this experiment and reported mineralization rates (0- to 0.25-m soil depth) in the range of 3 to 5 percent per year of total soil organic nitrogen, with the upper range reflecting the influence of repeated additions of tree prunings. Nitrogen mineralization (0- to 0.25-m soil depth), therefore, ranged from 200 to 370 kg N/ha/year. Leaching is suspected as the main avenue of nitrogen loss, because of high rainfall and low nutrient uptake during the winter cropping periods. Nitrate leaching is often the most important channel of nitrogen loss from agricultural fields (Haynes 1986). Unfortunately, no direct evidence exists of when nitrogen losses occurred during the three years of alley cropping.

Substantial nitrogen losses in tropical agricultural fields have been documented in a number of studies. A review by Bartholomew (1977) of soil nitrogen changes during cropping after fallowing in tropical regions shows a decrease in surface soil nitrogen (0- to 0.30-m depth) between 100 and 700 kg N/ha/year in the first two to three years of cropping. Fox and colleagues (1974) reported losses of 167 to 258 kg/ha of soil nitrate in the top 0.75 m of soil after four or five maize crops in Puerto Rico. Burle and colleagues (1992) measured decreasing soil inorganic nitrogen in surface soil horizons (0 to 0.15 m) and accumulation in lower soil horizons (below 0.60 m) after three maize crops fertilized with green manures.

In the process of conceptualizing agroforestry, the hypothesis that agroforestry systems promote efficient nutrient cycling compared to agricultural

systems has been strongly implied (Nair 1984, Sanchez 1987, Young 1989). This hypothesis is primarily based on studies of natural forest ecosystems in the humid tropics where the potential of nutrient loss is high, but the actual loss of nutrients is low (Jordon 1985). This study does not confirm this hypothesis, but rather shows that alley cropping systems function more like agricultural systems than natural forest ecosystems in terms of nitrogen cycling.

What emerges from the data presented on the system nitrogen budget is that practices to reduce nitrogen losses would substantially improve alley cropping systems established on newly cleared lands. Much work needs to be done to determine the processes which contribute to the fate of nitrogen in alley cropping systems. Direct evidence on the effects of nitrogen fixation, translocation of nitrogen from deeper soil horizons, timing and placement of organic inputs, and organic input quantity and quality in regulating nitrogen in alley cropping systems warrants further study.

Table 4.1. Effect of alley cropping on surface soil carbon (0 to 0.15/0.20 m).

	CARBON (g/kg)			TREE SPECIES	APPLIED <sup>a</sup> CROPS <sup>b</sup>		SOIL TYPE	AUTHOR
	initial	final	change					
113	23.7	6.0	-17.7	<i>G. sepium</i>	--	8	Oxic Paleustalf	Lal, 1989
	23.7	10.0	-13.7	<i>L. leucocephala</i>	--	8	Oxic Paleustalf	Lal, 1989
	35.0	32.0	-3.0	<i>G. sepium</i>	55	12	Typic Humitropept	Kass et al., 1989
	18.1	15.8	-2.3	<i>F. macrophylla</i>	19	2	Oxic Paleustalf	Yamoah et al., 1986
	34.6	35.2	+0.6	<i>E. poeppigiana</i>	44	12	Typic Humitropept	Kass et al., 1989
	9.8	10.7	+0.9	<i>L. leucocephala</i>	35	12	Oxic Paleustalf	Kang et al., 1985
	16.2	17.9	+1.7	<i>G. sepium</i>	12	2	Oxic Paleustalf	Yamoah et al., 1986
	11.1	13.0	+1.9	<i>G. sepium</i>	9	9	Typic Paleudult	Salazar, 1991
	11.1	13.0	+1.9	<i>I. edulis</i>	13	9	Typic Paleudult	Salazar, 1991
	11.1	13.0	+3.0	<i>C. reticulata</i>	17	9	Typic Paleudult	Salazar, 1991
	15.6	18.8	+3.2	<i>C. calothyrsus</i>	12	4	Oxic Paleustalf	Gichuru&Kang, 1989
	16.2	23.2	+7.0	<i>C. siamea</i>	25	2	Oxic Paleustalf	Yamoah et al., 1986

<sup>a</sup>Total tree prunings applied in tons (dry weight), <sup>b</sup>Number of crops harvested

Table 4.2. Effect of alley cropping on surface soil organic nitrogen (0 to 0.15/0.20 m).

NITROGEN (g/kg)			TREE SPECIES	APPLIED <sup>a</sup> CROPS <sup>b</sup>		SOIL TYPE	AUTHOR
initial	final	change					
3.97	1.03	-2.94	<i>L. leucocephala</i>	--	8	Oxic Paleustalf	Lal, 1989
2.42	1.11	-1.31	<i>G. sepium</i>	--	8	Oxic Paleustalf	Lal, 1989
3.0	2.8	-0.2	<i>E. poeppigiana</i>	44	12	Typic Humitropept	Kass et al., 1989
2.9	2.8	-0.1	<i>G. sepium</i>	55	12	Typic Humitropept	Kass et al., 1989
1.5	1.5	0	<i>C. calothyrsus</i>	12	4	Oxic Paleustalf	Girchuru & Kang, 1989
2.47	2.48	+0.01	<i>G. sepium</i>	12	2	Oxic Paleustalf	Yamoah et al., 1986
0.8	0.9	+0.1	<i>G. sepium</i>	9	9	Typic Paleudult	Salazar, 1991
0.8	0.9	+0.1	<i>I. edulis</i>	13	9	Typic Paleudult	Salazar, 1991
0.8	0.9	+0.1	<i>C. reticulata</i>	17	9	Typic Paleudult	Salazar, 1991
2.58	2.81	+0.23	<i>F. macrophylla</i>	19	2	Oxic Paleustalf	Yamoah et al., 1986
2.07	3.44	+1.37	<i>C. siamea</i>	25	2	Oxic Paleustalf	Yamoah et al., 1986

<sup>a</sup>Total tree prunings applied in tons (dry weight), <sup>b</sup>Number of crops harvested

Table 4.3. Effect of tree pruning management and sample location on soil organic carbon after three years of alley cropping.

	0 to 0.25 M SOIL DEPTH		0.25 to 0.50 M SOIL DEPTH	
	Crop area <sup>a</sup>	Tree area <sup>b</sup>	Crop area	Tree area
	- g/kg -		- g/kg -	
APPLIED <sup>c</sup>	41.2	39.4 **	37.3	37.5 ns
<i>C. calothyrsus</i>	43.1	40.0 ***	38.8	38.0 ns
<i>G. sepium</i>	41.0	39.5 *	37.3	37.8 ns
<i>C. siamea</i>	39.5	38.7 ns	35.9	36.7 ns
REMOVED <sup>d</sup>	38.9	39.6 ns	36.1	37.0 ns
<i>C. calothyrsus</i>	39.2	40.3 ns	35.8	36.9 ns
<i>G. sepium</i>	38.9	39.8 ns	36.5	37.2 ns
<i>C. siamea</i>	38.7	38.7 ns	35.9	36.7 ns

LSD<sub>.05</sub> between areas for the same treatment:

0 to 0.25 m	1.2
0.25 to 0.50 m	1.6

<sup>a</sup>Crop area = 1.8 m wide section in the middle of a 3 m width alley

<sup>b</sup>Tree area = base of tree to 0.6 m on both sides of tree row

<sup>c</sup>Mean of treatments with tree prunings applied

<sup>d</sup>Mean of treatments with tree prunings removed

\*, \*\*, \*\*\* significant at .05, .01, and .001 by LSD test

ns non-significant

Table 4.4. Effect of tree pruning management and sample location on soil organic nitrogen after three years of alley cropping.

	0 to 0.25 M SOIL DEPTH			0.25 to 0.50 M SOIL DEPTH		
	Crop area <sup>a</sup>	Tree area <sup>b</sup>		Crop area	Tree area	
	- g/kg -			- g/kg -		
APPLIED <sup>c</sup>	2.46	2.34	ns	2.16	2.14	ns
<i>C. calothyrsus</i>	2.71	2.47	**	2.30	2.12	*
<i>G. sepium</i>	2.31	2.26	ns	2.08	2.19	ns
<i>C. siamea</i>	2.36	2.29	ns	2.11	2.12	ns
REMOVED <sup>d</sup>	2.20	2.30	ns	2.10	2.12	ns
<i>C. calothyrsus</i>	2.21	2.28	ns	1.98	2.06	ns
<i>G. sepium</i>	2.20	2.35	ns	2.21	2.09	ns
<i>C. siamea</i>	2.18	2.26	ns	2.11	2.22	ns
LSD <sub>.05</sub> between areas for the same treatment:						
	0.25 m	0.27				
	0.25 to 0.50 m	0.18				

<sup>a</sup>Crop area = 1.8 m wide section in the middle of a 3 m width alley

<sup>b</sup>Tree area = base of tree to 0.6 m on both sides of tree row

<sup>c</sup>Mean of treatments with tree prunings applied

<sup>d</sup>Mean of treatments with tree prunings removed

\*, \*\*, \*\*\* significant at .05, .01, and .001 by LSD test

ns non-significant

Table 4.5. Changes in soil organic carbon in the crop area after three years of alley cropping.

MANAGEMENT	SPECIES	DEPTH	ORGANIC C	CHANGE <sup>a</sup>
		0 to 2.5 m	- g/kg -	
CONTROL			39.2 (0.3) <sup>b</sup> c	+3.2 ***
APPLIED	<i>C. siamea</i>		39.5 (0.6) bc	+3.5 ***
	<i>G. sepium</i>		41.0 (0.6) b	+5.0 ***
	<i>C. calothyrsus</i>		43.1 (0.7) a	+7.1 ***
REMOVED	<i>C. siamea</i>		38.7 (0.5) c	+2.7 **
	<i>G. sepium</i>		38.9 (0.9) c	+2.9 *
	<i>C. calothyrsus</i>		39.2 (0.3) c	+3.2 ***
LSD <sub>.05</sub> between treatments at the final sampling date = 1.7				
		0.25 to 0.50 m		
CONTROL			37.5 (0.5) b	+1.8 *
APPLIED	<i>C. siamea</i>		35.9 (0.7) b	+0.2 ns
	<i>G. sepium</i>		37.3 (0.2) ab	+1.6 **
	<i>C. calothyrsus</i>		38.8 (0.7) a	+3.1 ***
REMOVED	<i>C. siamea</i>		35.9 (1.2) b	+0.2 ns
	<i>G. sepium</i>		36.5 (1.0) b	+0.8 ns
	<i>C. calothyrsus</i>		35.8 (0.8) b	+0.1 ns
LSD <sub>.05</sub> between treatments at the final sampling date = 2.1				

<sup>a</sup>Initial soil carbon levels 0 to 2.5 m: 36.0 (0.3), 0.25 to 0.50 m: 35.7 (0.1)

\*, \*\*, \*\*\* significant difference at .05, .01, and .001 between initial (n=28) and final (n=4) sampling dates, by Students t test.

ns non-significant

<sup>b</sup>Standard error in parentheses

Means followed by the same letter in each column are not significantly different at 5% probability level by LSD test.

Table 4.6. Changes in soil organic nitrogen levels in the crop area after three years of alley cropping.

MANAGEMENT	SPECIES	DEPTH	ORGANIC C	CHANGE <sup>a</sup>
		0 to 0.25 m		- g/kg -
CONTROL			2.28 (0.04) <sup>b</sup> bc	-0.11 ns
APPLIED	<i>C. siamea</i>		2.36 (0.09) b	-0.03 ns
	<i>G. sepium</i>		2.31 (0.05) bc	-0.08 ns
	<i>C. calothyrsus</i>		2.71 (0.06) a	+0.32 ***
REMOVED	<i>C. siamea</i>		2.18 (0.08) c	-0.21 *
	<i>G. sepium</i>		2.20 (0.07) bc	-0.19 *
	<i>C. calothyrsus</i>		2.21 (0.01) bc	-0.18 **
LSD <sub>.05</sub> between treatments at the final sampling date = 0.17				
		0.25 to 0.50 m		
CONTROL			2.02 (0.11) bc	-0.52 ***
APPLIED	<i>C. siamea</i>		2.10 (0.09) abc	-0.44 ***
	<i>G. sepium</i>		2.08 (0.09) abc	-0.46 ***
	<i>C. calothyrsus</i>		2.30 (0.07) a	-0.24 **
REMOVED	<i>C. siamea</i>		2.11 (0.09) abc	-0.43 ***
	<i>G. sepium</i>		2.21 (0.09) ab	-0.33 **
	<i>C. calothyrsus</i>		1.98 (0.06) c	-0.56 ***
LSD <sub>.05</sub> between treatments at the final sampling date = 0.23				

<sup>1</sup>Initial soil carbon levels 0 to 0.25 m: 2.39 (0.03), 0.25 to 0.50 m: 2.54 (0.01)

\*, \*\*, \*\*\* significant difference at .5, .01, and .001 between initial (n=28) and final (n=4) sampling dates, by Students t test.

ns non-significant

<sup>2</sup>Standard error in parentheses

Means followed by the same letter in each column are not significantly different at 5% probability level by LSD test.

Table 4.7. Estimated nitrogen budget of alley cropping systems and sole cropping control (0 to 0.50 m depth).

	APPLIED			REMOVED			CONTROL
	CAS <sup>a</sup>	GLI <sup>b</sup>	CAL <sup>c</sup>	CAS <sup>a</sup>	GLI <sup>b</sup>	CAL <sup>c</sup>	Monocrop
	- kg/ha -						
Soil nitrogen	-1346	-1422	-237	-1545	-1411	-1868	-1740
Fertilizer	6	36	36	6	36	36	0
Precipitation*	45	45	45	45	45	45	45
Corn Harvest	250	301	265	215	189	161	222
Tree Harvest	0	0	0	253	374	672	0
Fuelwood	2	15	21	3	13	21	0
Tree Stump	7	9	15	6	10	16	0
Net Gain or Loss	-1138	-1178	-20	-1118	-906	-1079	-1563
LSD <sub>.05</sub>	664						

<sup>a</sup>CAL=*C. calothyrsus*, <sup>b</sup>GLI=*G. sepium*, <sup>c</sup>CAS=*C. siamea*

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## CHAPTER 5

### SUMMARY OF CONCLUSIONS

#### MAIZE PRODUCTIVITY

Maize yield response to alley cropping with tree prunings applied ranged from no response for the first crop to a negative response for the second crop, followed by a positive response beginning in the fourth crop (Table 2.2). A positive response to alley cropping occurred during the latter cropping periods, in part, as a result of declining yields in the control plot. In most cases, greater maize yields were observed in the alley cropped plots with tree prunings applied than in the control plot at the latter cropping periods. However, total maize yield for the six crops was significantly higher with only three of the six tree species tested. Total maize yield for the six crops was roughly 1.3 times greater in the *G. sepium*, *C. calothyrsus*, and *C. siamea* alley cropped plots than the control. In the *C. reticulata*, *I. edulis*, and *L. leucocephala* plots, total maize yield for the six crops was similar to the control.

Maize yields with two of the six tree species whose tree prunings were applied eventually attained similar levels to those obtained with 50 kg N/ha applied, suggesting that the crop yield benefits of alley cropping accrue over time (Figure 2.25). However, the application of 50 and 100 kg/ha of inorganic nitrogen per crop produced much greater total maize yields for the six crops than alley cropping with tree prunings applied. Total maize yield for the six crops in the monocropping treatment with 50 kg N/ha applied was 1.3 to 1.8 times greater

than in the alley cropping treatments, and 1.5 to 2.2 times greater in the 100 kg N/ha monocropping treatment than the alley cropping treatments.

## **MAIZE YIELD SUSTAINABILITY**

Maize yields remained relatively constant for two cropping periods and declined steadily thereafter in the alley cropping control plot and in the monocropping plot with no inorganic nitrogen applied, as is typical in shifting agricultural systems. Maize yields in the alley cropping plots were not maintained over time, but rather declined initially and remained relatively constant thereafter (Figure 2.26). In some of the alley cropped plots, maize yields appeared to be increasing slightly by the sixth cropping period. The application of 50 kg N/ha per maize crop was not sufficient to maintain maize yields for more than four cropping periods. Only in the monocropping plots with an application of 100 kg N/ha per maize crop were maize yields maintained for six cropping periods. Nitrogen appears to be the limiting nutrient for maize production in both experiments, as indicated by 1) the positive response to applied inorganic nitrogen, 2) the decline in maize earleaf nitrogen from sufficient to deficient levels over time, and 3) the positive correlation between grain yield and maize earleaf nitrogen concentrations. During the six cropping periods, maize earleaf phosphorus, potassium, and calcium were in the sufficiency range in all treatments. Maize earleaf calcium and magnesium concentrations declined over time in all alley cropping treatments, with only Mg levels dropping below

sufficiency range. It is possible that other nutrients or the balance among nutrients may have contributed to reduced yields over time.

#### **NITROGEN APPLIED VIA TREE PRUNINGS AND APPARENT NITROGEN RECOVERY BY MAIZE**

The amount of nitrogen applied via tree prunings ranged from an average of 42 to 115 kg N/ha per maize crop (Figure 3.2). In most cases, the amount of nitrogen applied via tree prunings was higher than the amount taken up by the associated maize crop. The ratio between tree pruning nitrogen applied and maize nitrogen uptake averaged 2.00 for *C. calothyrsus*, 1.84 for *C. reticulata*, 1.30 for *G. sepium*, 1.03 for *L. leucocephala*, 0.87 for *C. siamea*, and 0.81 for *I. edulis*.

Despite the large amounts of nitrogen applied via tree prunings, the apparent nitrogen recovery from tree prunings by the associated maize crop was low, compared to the apparent nitrogen recovery by maize from inorganic nitrogen fertilizer (Tables 3.4 and 3.5). Apparent nitrogen recovery by maize was initially considerably greater, up to 3.6 times greater, in the nitrogen fertilized plots than in the alley cropped plots. However, the difference in apparent nitrogen recovery by maize between tree pruning nitrogen and inorganic nitrogen fertilizer decreased over time, as a result of increasing apparent nitrogen recovery by maize from tree pruning nitrogen. The availability of residual nitrogen from repeated tree pruning additions was probably the reason for the increased apparent nitrogen recovery by maize from tree pruning nitrogen in the alley cropping plots.

## CHANGES IN SOIL ORGANIC CARBON AND NITROGEN

An increase in surface soil organic carbon (0 to 0.25 m) after five continuous maize crops was observed in the control plot and alley cropped plots when either tree prunings were applied or removed (Table 4.5). The amount of increase in soil organic carbon over time was similar for most treatments, with the exception of a greater increase in the *G. sepium* and *C. calothyrsus* alley cropped plots with tree prunings applied. It is difficult, however, to conclude whether the increase in soil organic carbon over time is increasing soil organic matter and soil fertility. The increase in soil organic carbon is most likely a measure of increasing below-ground litter pools, rather than soil organic matter. Below-ground litter pools and soil organic matter, together with turnover rates, need to be estimated separately before conclusions on the effect of alley cropping on soil fertility and nutrient availability can be evaluated.

The addition of tree prunings in alley cropping systems did maintain or increase surface soil organic nitrogen (0 to 0.25 m) after five cropping periods, whereas monocropping (control plot) and removing tree prunings in alley cropping systems decreased surface soil organic nitrogen (Table 4.6). However, maize earleaf nitrogen and maize yields in the sixth cropping season were not correlated with the amount of total soil organic nitrogen. The substantial increase in total soil organic nitrogen in the *C. calothyrsus* plot did not result in higher maize earleaf nitrogen or higher maize yield. Possible reasons for this are 1) competition between trees and maize, and 2) nitrogen accumulation in the slow or

passive soil organic nitrogen pools, rather than the labile pool. Total soil organic nitrogen does not appear to be the best indicator for nitrogen availability to associated crops in alley cropping systems.

#### **NITROGEN BUDGET FOR SOIL-CROP SYSTEM**

After three years of maize cultivation, a substantial negative net nitrogen balance (0 to 0.50 m soil depth) occurred in all alley cropping plots and in the control plot, with the exception of the *C. calothyrsus* plot with tree prunings applied (Table 4.7). The near-zero net nitrogen balance observed in the *C. calothyrsus* alley cropped plot with tree prunings applied suggests that there was either a greater nitrogen input or a reduced nitrogen output, compared to the other treatments. A greater nitrogen input would indicate the benefits from nitrogen fixation and/or the ability of trees to transfer soil nitrogen from deeper soil horizons. A reduced output could have occurred, and explained by the slower mineralization of *C. calothyrsus* tree prunings relative to the *G. sepium* and *C. siamea*. A larger net negative nitrogen balance could have occurred than was observed in the other alley cropped plots, if nitrogen was added to the system by nitrogen fixation and/or transferred from deeper soil horizons by tree roots. The nitrogen fixing trees were nodulated, and presumably fixing.

The observation that a large amount of nitrogen is mineralized following land clearing and that a substantial amount of this nitrogen moves rapidly through the soil profile in the humid tropics is not new. However, in the process of

conceptualizing agroforestry, the hypothesis that agroforestry systems promote efficient nutrient cycling compared to agricultural systems has been strongly implied. This study does not confirm this hypothesis, but rather shows that alley cropping systems function more like agricultural systems than natural forest ecosystems in terms of nitrogen cycling.

There are various reasons why alley cropping may not promote a closed nitrogen cycle: 1) the nitrogen release from tree prunings and the uptake of nitrogen by maize are not synchronized, 2) tree roots are disturbed by cultivation preventing the establishment of a dense mat to prevent leaching, and 3) the use of easily or rapidly mineralized organic inputs may promote leaching.

In summary, alley cropping with tree prunings applied did prevent the continuous decline in maize yields often found in shifting agricultural systems. Taking into consideration that shifting agricultural systems are still the dominant land-use system in vast areas of the tropics and that sources of nitrogen fertilizer are limited and costly, alley cropping offers an obvious alternative. While the work reported here provides a basis for managing nitrogen in alley cropping systems, there are several areas in which more information is needed. Quantifying the amount of nitrogen lost by leaching, including temporal fluctuations in leaching losses, would improve our ability to manage soil nitrogen and make more of it available to crops. Management practices to reduce competition between trees and crops by evaluating other spatial arrangements of trees and crops could substantially improve alley cropping systems. The

importance of nutrient competition from trees relative to reduced nutrient uptake due to light competition has yet to be addressed in alley cropping studies.

Understanding residual nitrogen effects of repeated application of woody legume green manure will no doubt contribute to the knowledge of the long-term benefits of alley cropping.