UNIVERSITY OF COSTA RICA
Graduate Studies System

MULCHES FROM TWO TROPICAL TREE SPECIES *Erythrina poeppigiana* (Walpers) O.F. COOK AND *Gmelina arborea* Rox. AS NITROGEN SOURCES IN THE PRODUCTION OF MAIZE (*Zea mays* L.)

Thesis presented for the consideration of the Commission of the Joint Graduate Studies Program in Agricultural Studies and Natural Resources of the University of Costa Rica and the Centro Agronómico Tropical de Investigación y Enseñanza to qualify for the title of

Magister Scientiae

by

Mary Megan Quinlan

Centro Agronómico Tropical de Investigación y Enseñanza
Crop Production Department
Turrialba, Costa Rica

1984

DEDICATION

To my mother, Betty

my sister, Catherine

and the memory of my father, Wayne Quinlan,

I dedicate this work as a token of my love

and appreciation for their constant support

and encouragement during these years of study.

ACKNOWLEDGEMENTS

I want to thank my main professor, Dr. Donald Kass, and committee members Dr. Carlos Burgos, Dr. Julio Henao, and Dr. Joseph Saunders for their patient guidance in the work and writing of this thesis. Thanks also goes to a number of other CATIE professionals who collaborated in this project, particularly to Dr. Margaret Smith. Financial support from the International Rotary Foundation for 1982, from IICA for 1983 and from IFAD for laboratory and computer costs, has been greatly appreciated.

I wish to express appreciation as well for the following: to all of the CATIE staff, especially in the Graduate Office, for their help in orienting me in a foreign country; to Amyel Locatelli for secretarial work; to the La Montaña staff for help in the field work; to the Soil Laboratory staff for cooperation in analysis and to Walter Bermúdez, Mario Jiménez and Gregorio Fuentes for their extensive assistance in all phases of the study.

All of my classmates deserve recognition for their invaluable help in improving my Spanish and with course materials. Most of all I want to thank Eleonor Vargas and Gerard Raessens for their honest friendships which strengthen me. And to Jorge Espinoza I want to express the great value of his loving encouragement in striving for the best future.

BIOGRAPHY

The author was born and raised in Oklahoma City, Oklahoma, United States, finishing her secondary studies there in 1977. In 1981 she graduated with a Bachelor's degree in Botany and Zoology from Duke University, Durham, North Carolina, and then returned to Oklahoma to manage a private organic farm. In March, 1982 she began graduate studies in the Crop Production Department at the Tropical Agricultural Research and Training Center (CATIE), in Turrialba, Costa Rica. The title of Magister Scientiae was awarded to her in December of 1984.

This thesis has been accepted by the Commission of the Joint Graduate Studies Program in Agricultural Sciences and Natural Resources of the University of Costa Rica and the Centro Agronómico Tropical de Investigación y Enseñanza in partial fulfillment of the requirements for the degree of

Magister Scientiae

Donald Kass, Ph.D. — Advising Professor

Carlos Burgos, Ph.D. — Committee Member

Julio Henao, Ph.D. — Committee Member

Joseph Saunders, Ph.D. — Committee Member

Director, Graduate Studies Program in Agricultural Sciences and Natural Resources UCR/CATIE

Dean, Graduate Studies Program of the University of Costa Rica

Mary M. Quinlan
Candidate

CONTENTS

MULCHES FROM TWO TROPICAL TREE SPECIES ERYTHRINA POEPPIGIANA (WALPERS) O.F. COOK AND GMELINA ARBOREA ROX. AS NITROGEN SOURCES IN THE PRODUCTION OF MAIZE (ZEA MAYS L.)

SUMMARY

An evaluation of prunings from the nitrogen-fixing *Erythrina poeppigiana* (Leguminosae), and the fast-growing *Gmelina arborea* (Verbenaceae) for use as mulches was carried out in the humid tropical site of Turrialba, Costa Rica using Tuxpeño C-7 variety maize as an indicator crop. The maize was planted at a density of 55,500 plants/ha in a randomized complete block design with four replicates. Treatment differences were restricted to different sources (mineral or mulch) and levels of applied nitrogen. Other management practices, including fertilization with KCl and triple-superphosphate, were similar for all plots.

Two cropping seasons were covered in the study: first from September, 1982 to February, 1983, and second from June to October, 1983, when most production is expected in correspondence with the rainy season. The treatment consisted of 12 combinations of N applied at two levels, 30 and 60 Kg/ha, from two sources (NH_4NO_3 with either *Gmelina* or *Erythrina* mulch) in an incomplete factorial, with *Erythrina* and NH_4NO_3 applied separately as well. Measurements were taken of the soil temperature and moisture; quantity of weeds pre-control and at the end of the experiment; maize total biomass and N content at physiological maturity; ear yield in terms of quality, quantity, weight and total grain weight at harvest.

Results of the first trial demonstrated some trends in treatment differences in soil temperature (mineral + *Erythrina* having highest temperatures, mineral + *Gmelina* having lowest temperatures); whereas no significant difference was found among soil moisture content values. No significant differences resulted in final weed biomass and N content values. Although maize biomass and N content were similar, differences were noted in the quality of ears produced. The presence of and addition of higher levels of mulch, particularly *Gmelina* was associated with a greater number and/or weight of non-commercial quality ears. Most ear damage was due to mold.

Keywords: mulch, nitrogen-fixing trees, green manure, N mineralization, maize

In the second trial only Erythrina and mineral N were used as N sources. Both sources were applied alone at two levels and in combinations at 60, 100, 160 kg N/ha along with a control without N. Periodic measurements were made of the soil temperature and N-NH_4 and N-NO_2+NO_3 in the soil solution. From biweekly samples, maize biomass and N contents were estimated.

Yield differences appeared dependent primarily on the quality of ears produced. In this trial, however, highest production and lowest number of non-commercial ears occurred with the high level of Erythrina mulch while the lowest production and highest number of non-commercial ears occurred with the lower level of Erythrina mulch. Bird damage was considerable.

A concurrent decomposition study using nylon net bags indicated that almost half of the applied N remained in the Erythrina mulch 75 days after application, when the maize was harvested. Even with this limited input, plants contained adequate percentage of N and yields ranged from 2.7 to 4.1 Mg/ha. Maize periodic samples related most closely to the final yield results. Grain moisture content increased with the increase of mulch. Further investigation is needed to evaluate the mulches in nitrogen deficient soils and other climatic conditions.

LAS COBERTURAS DE DOS ESPECIES ARBOREAS TROPICALES DE *ERYTHRINA POEPPIGIANA* (WALPERS) O.F. COOK Y *GMELINA ARBOREA* ROX. COMO FUENTES DE NITROGENO EN LA PRODUCCION DE MAIZ (*ZEA MAYS* L.)

RESUMEN

Se evaluó el material podado del Poró (*Erythrina poeppigiana*) árbol fijador de nitrógeno y Gmelina (*Gmelina arborea*), especie de rápido crecimiento como cobertura. El experimento se localizó en Turrialba, Costa Rica, dentro de una área de clima tropical húmedo. Se utilizó maíz (Tuxpeño C-7) como planta indicadora a razón de 55,500 plantas/ha. El diseño empleado fue de bloques al azar con cuatro repeticiones. Los tratamientos consistieron en diferentes niveles de N proveniente de la cobertura de ambas especies y una fuente mineral. Las parcelas se cultivaron en igual forma, incluyendo una fertilización con KCl y superfosfato triple.

El experimento se realizó en dos épocas, de setiembre (1982) a febrero (1983) y de junio a octubre (1983). En el primer experimento se aplicaron dos niveles de N (30 y 60 kg/ha) como NH_4NO_3 y coberturas. Los tratamientos incluyeron 12 combinaciones de N aplicado a dos niveles, proveniente de dos orígenes (mineral y cobertura) y dos niveles de cada cobertura en un arreglo factorial incompleto, incluyendo el Poró y NH_4NO_3 separadamente. Se midió la temperatura y humedad del suelo; cantidad de malezas pre-tratamiento y al final del experimento; biomasa total del maíz y el contenido de N hacia la madurez; rendimiento de las mazorcas en calidad, cantidad, peso y peso total del grano a la cosecha.

En el primer ensayo se encontraron algunas tendencias debidas al tratamiento en la temperatura del suelo (mineral + Poró con temperaturas mayores, mineral + Gmelina con temperaturas menores). No se encontró efecto sobre el contenido de humedad en el suelo. No se encontró diferencias para la cantidad de malezas a la cosecha. No hubo diferencias para la cantidad de biomasa y contenido de N en el maíz debido a los tratamientos. La calidad de las mazorcas fue diferente significativamente. Las mazorcas de menor calidad se asociaron con los niveles más altos de cobertura especialmente de Gmelina. La menor calidad de las mazorcas estuvo asociada, principalmente a daños causados por hongos.

En el segundo ensayo únicamente se emplearon el Poró y N mineral como fuentes de N. Ambas fuentes se aplicaron, separadamente, a dos niveles y combinados en los niveles 60, 100, y 160 kg N/ha y un control sin N. Se registró periódicamente la temperatura y la concentración de $N\text{-}NH_4$ y $N\text{-}No_2\text{+}NO_3$ en el suelo. Se estimó la cantidad de biomasa y contenido de N en el maíz, tomando muestras cada dos semanas.

Palabras claves: coberturas, árboles fijadores de N, abono verde, mineralización de N, maíz.

Un ensayo simultáneo de descomposición, empleando bolsas de malla de nylon, mostró que aproximadamente 50% del N permanecía aún en la cobertura, al momento de la cosecha, 75 días después de haber sido aplicado. El rendimiento del maíz varió de 2.7 - 5.1 Mg/ha. La concentración del nitrógeno en las planas se consideró adecuada. El contenido de humedad en el grano se incrementó con la aplicación de la cobertura. Se plantea la necesidad de investigar este tipo de cobertura especialmente en suelos deficientes en nitrógeno y otras condiciones climáticas.

LIST OF TABLES

APPENDIX TABLES

LIST OF FIGURES

INTRODUCTION

Increases in maize production in the tropics have generally resulted from the addition of land area to cultivation[20]. Under present social and political conditions in Central America, however, the large portion of arable land left unutilized is not available to the low-capital farmer who is historically the provider for domestic consumption[83]. . Production gains, therefore, must be sought through strategies which aim to obtain higher yields from land already in cultivation.[93].

With high population growth on a land base artificially limited by the presence of large estates producing export crops, long-term fallowing for a natural recovery of fertility levels is no longer practical[66]. Accordingly, mineral fertilizer use in Central America has increased sharply as illustrated by Costa Rica with a rise in nitrogen consumption from 28,488 to 45,200 Mg in only five years (1976-77 average to 1981-82 average[34]). Most of this fertilizer, however, has been applied to export crops which provide a high return for the investment in importing all mineral fertilizers. In contrast, traditional crops have received a mere 20 percent of the region's fertilizer input[88].

Instead of seeking production gains for food crops through an increase in the application of mineral fertilizers, and therefore in costs, farmers in Costa Rica's Acosta and Puriscal provinces have already opted to change their land use decisions[9]. Smaller farms are now planted in high value crops and tobacco while larger farms are dedicated increasingly to cattle production[6]. This trend away from traditional crops can be seen on the national level in terms of a reduction of hectares planted in maize from 58,000 (1948-52 average) to 50,000 (1969-71 average) and to 45,000 (1980-82 average).[31,32,33] The result is that Costa Rica now has the highest maize importation costs for the region even though the crop plays a relatively minor role in that country's diet[34]. In other Central American countries, where maize supplies over a forth of all calories consumed, farmers have been more hesitant to abandon their traditional land use even though maize production is similarly unprofitable[20,56]. Increasing economic pressures could change this. With limits in the available maize and 10 to 20 percent already being channeled to the more affluent in the form of meat and dairy products, the nutritional status of the lower income families will be severely affected[20]. On the national level, growing dependence on external sources of grain is potentially detrimental to security as well as to the economy[93].

To encourage domestic production of traditional food crops in Central America, mulches from easily managed perennial woody species are being investigated as alternatives to costly fertilizers. In the present study prunings from the leguminous tree *Erythrina poeppigiana* and non-leguminous tree *Gmelina arborea* are evaluated as nitrogen sources for the production of maize. The objectives of the study are:

1. To quantify the mulches' contributions to the available nitrogen supply throughout maize growth, based on nitrogen contents in the soil solution and maize plants, and to relate these values to final grain yields;

2. to further account for the results and describe the influences of the mulches by measuring other soil factors, including temperature and moisture; and

3. to estimate the pattern and amount of nitrogen input, based on a decomposition study, of the leguminous mulch *Erythrina poeppigiana*.

LITERATURE REVIEW

Historical importance of mulching

Mulching, covering the soil surface with a natural or artificial material[24], has been historically important in many parts of the world. Perhaps the earliest reports of using plant residues as a nutrient supply for another crop come from Chinese texts dating back to the Chou dynasty (1134-247 B.C.). Writings from Greece and Rome dated around 280 B.C. and later describe the use of leguminous cover crops plowed into the soil. In the Middle Ages, similarly, the few references to the concept that have been discovered refer to Southern France and Italy[76].

In the Western Hemisphere, mulching appears to have been practiced quite early. Though documentation is scarce, the remains of extensive drainage systems in Mexico and Guatemala suggest that the Mayan society had developed an intensive agricultural production which probably utilized mulches to maintain soil fertility[96]. A century later the first North American colonists brought some knowledge of green manuring with them from Europe, with references to rotating with clover being written as early as 1794. A review of mulching research carried out by North American experimental stations discusses several studies from throughout the 19th century, citing maize as the preferred indicator crop[75].

With industralization the traditional practice of adding organic matter to the fields was generally replaced by a reliance on mechanized farming and mineral fertilizers. Popular campaigns for minimum tillage and natural fertilizers coincided with World War energy shortages[58]. One representative book published in 1943, "Plowman's Folly"[28], was more anecdotal than scientific yet was promoted as a guide by agriculturalists from as far away as Colombia[74]. Another literary soil scientist of the period concluded that "leaving crop litter...at the ground surface in farming operations is one of the most significant contributions to American agriculture"[62]. Such enthusiasm did not last, but mulching soils in dry and windy parts of the U.S. continued to be common[48]. Presently, although less than one per cent of the U.S. farmers use strictly organic methods, many more leave crop residues or grow cover crops as soil management, and minimum tillage is once more gaining popularity[97].

Effects of mulching

While the extensive literature from temperate climates demonstrates that mulching can be detrimental by maintaining low soil temperatures during early crop growth[18;98] most tropical research states that mulching and the resulting lower temperatures are often beneficial in these hotter climates[49,59,100]. Improved growth and yields of mulched maize, for example, were attributed to lower soil temperatures when the crop residue was applied at planting. Eight weeks after planting application of mulch had little effect on the maize[2].

Similarly, moisture stress can be greater in a tropical climate since maize transpiration often exceeds the open-pan evaporation rate[12]. Mulching resulted in 38% higher maize yields in Nigeria by simply reducing moisture stress due to 7 to 15 day dry periods which are particularly harmful during the pre-flowering stage of development[44,60].

Weeds, which compete strongly with crops for light and nutrients, are controlled with "living mulches" in tropical plantation systems[4,78]. With annual crops, materials such as rice hulls have proved effective in weed control in Asia as well as Central America[7,77]. Plastics and artificial materials used as mulches control weeds not only by shading but also by heating the soil to extremes at which weed seeds become inviable[49]. Plant residues can perform the same purpose if resupplied frequently and in quantity.

Soil erosion control is accomplished with mulches by lessening the impact of the rain as well as by encouraging the growth of a more superficial root system capable of physically holding the soil in place. This factor is noteworthy in Central America because crops are planted after the rainy season begins so that the initial heavy rains fall on freshly cultivated, bare soils presenting a serious erosion threat until the crop canopy can form in a few weeks[86].

Mulches have been used to improve soil fertility, as well, particularly, mulches from leguminous plants with high nitrogen contents[53]. For this purpose, cover crops are grown on the site or residues are incorporated into the soil as green manure. Surface mulching, though often more practical, has varying effects on soil fertility and must be considered in context of the natural nitrogen fluctuations which occur in high rainfall areas[64].

Soil nitrogen in the humid tropics

In the humid tropics, natural seasonal increases in soil nitrogen are related to reduction or abscence of leaching during the drier season and, in severe cases of soil drying, to the upward movement of nitrogen through the soil profile[40]. The accumulated nitrogen is lost over the rainy season through leaching, denitrification, and ammonia volatilization[72]. Crop assimilation and cultivation methods have empirically little effect on soil NO_2-N and NH_4-N concentrations [90]. Fluctuations are usually seen in NO_3-N levels which, over the course of the rainy season, dropped from 60 ppm to less than 5 ppm in cropped soils in Trinidad[42]. In addition to this seasonal trend, immediate NO_3-N fluctuations can occur on a smaller scale in accordance with the rainfall of the previous fortnight[51].

When early rains are light, nitrate accumulated over the dry season can still be assimilated by crops[43]. Heavy rainfall alone, however, can lead to the loss of 50% or more of the mineral nitrogen from the onset of rains until crop establishment. Leaching losses are greatest under maize in its first weeks of growth. Not until the sixth week are the roots sufficiently developed to reduce leaching losses[72].

When excess water is present, mulching can augment nitrogen losses due to leaching by reducing the surface evaporation rate and maintaining a higher soil moisture content[64]. When water is scarce, this same mechanism directly increases nitrogen uptake by plants through diffusion[68]. A balance between the input of nutrients from the mulch and the potentially increased losses due to greater leaching under mulch must be sought. Small differences could shift the balance, as seen in fully-mulched maize in Nigeria which showed nitrogen deficiency only in lower, wetter areas of the experimental plots[60]. The use of mulches is not expected to become counter-productive, however, when species with high nitrogen contents and rapid decomposition rates are employed.

In Sri Lankan tea plantations, Erythrina lithosperma trees were traditionally pruned two to six times per year to provide a NO_3-N source throughout the growing season[51]. The greater amount and more equal distribution of N inputs which a perrenial N source provides may result in N inputs offsetting leaching losses. Trees as mulch sources are now receiving more attention throughout the humid tropics.

Tree prunings for mulch

Alley cropping, the planting of annual or semi-perennial food crops between rows of established trees, has been emphasized in research at IITA in Nigeria. Trees chosen for alley cropping are generally shrubby, easily established, fast growing and responsive to cutting or burning[36]. Although leguminous mulch sources, including Gliricidia sepium and Leucaena leucocephala, have been employed in past trials, recently the focus of the research has shifted to evaluating non-leguminous trees whose slower decomposing residues should more effectively control weed growth[47]. This change in attitude in Africa and the scarcity of related data from Central America motivated the inclusion of both leguminous and non-leguminous trees in this evaluation.

Although the trees and crop under study are spatially separated, they are considered an agroforestry system[23]. Both tree species in evaluation have been incorporated into agroforestry systems previously. Gmelina arborea Roxb. (Verbenaceae), commonly called Gmelina or Yemane, is a fast growing timber tree native to Asian rain forests. Naturally a transitory species, Gmelina does not establish well in acidic soils nor unfavorable climates[61]. In Nigeria, Gmelina has been succesfully introduced and is used during its first two years of growth in a taungya system including root crops, grains, and vegetables[67]. Similar experiments have shown that after 18 months of growth the tree's low, dense canopy provides effective weed control[36].

In CATIE, yields of up to 3.9 t/ha of maize grain and 1.98 t/ha of beans were obtained in an intercropping experiment without influencing regular Gmelina growth[29]. Such studies emphasize the tree rather than the annual crop component since Gmelina is generally planted for timber and is being encouraged for such use in Costa Rica.

The Erythrina genus has been included in agroforestry systems throughout the world. Erythrina poeppigiana (Walpers) O.F. Cook (subfamily Papilionaceae), used in this study, is commonly called Mountain Immortelle, Coral tree (for its orange flowers) or, in Costa Rica, poró gigante. The natural range of this species is from Panama to Bolivia and Peru, but the nitrogen-fixing tree was introduced into Central America in the early 20th Century[13].

In Central and South America, Erythrina is commonly intercropped as a shade tree in coffee and cocoa plantations[13]. Research on these systems often emphasize production of the tree[5,81], though positive effects on the cocoa tress have also been measured[19,85]. Some studies on coffee also demonstrate the crop's improved production in relation to coffee with Cordia alliodora trees, but control plots of coffee alone were not included[26,37,38]. More recently, Erythrina's influence on pasture growth has been measured and the tree's foliage has been characterized nutritionally for use as a forage for ruminants[16,27].

Although little has been published regarding the tree's effect on annual crops, results from intercropping Erythrina with coffee and a rotation of rice, maize and peanuts in Northern Thailand were encouraging. Maize yields, for example, reached 3.1 T/ha on 54% graded slopes where annual rainfall is 1700 mm[65]. Field trials in CATIE alley cropping Erythrina with a rotation of maize, beans and cassava have also shown positive results, particularly in bean yield which was 1.31 T/ha as compared to 0.66 T/ha in control plots[57].

Evaluation of mulches

The present research was designed to measure the influence of Gmelina and Erythrina tree prunings on a growing annual crop and its final yields with emphasis on the nitrogen status. Similar studies have been carried out to evaluate tree mulches' effects on annual crops. For example, Leucaena leucocephala has proven valuable as a source of nutrients for production of rice in Nigeria[79], Napier grass for forrage[91] and sorghum in Guatemala[92]. Maize, however, is quite commonly planted in mulching trials due to its popularity, wide growing range, and response to soil nutrient levels[8].

Nitrogen supply affects maize grain yield by influencing leaf area produced early in the growth season, therefore periodic biomass masurements relate to the potential yeild, although other factors help determine the actual values[42]. The effect of environmental stresses during formation of the embryonic grains, for example, cannot be reversed. In contrast, stress during the grain filling can be overcome by assimilate translocation[44].

In maize, a third of the N uptake occurs during the 6th to 8th week of growth[42]. Excess N can be taken up and stored but normally the average N concentration from germination to knee-height of growth is 2% or more in leaves and 1% or less in stems. After tasseling both parts average 1.2 to 1.3% N [54]. If lower concentrations are encountered, nitrogen might be limiting growth. Maize preferentially takes up NO_3-N, the form of nitrogen expected to result from decomposing tree prunings if not under flooded conditions[51,94]. Extensive past research using maize as a biological indicator allows for better interpretation of results.

Although in Turrialba temperature and rainfall averages are above optimal for maize production, the climate would permit two successful crops annually in 80% of the years. In practice, however, the majority of grain production is from the rainy season crop, planted between March and June. The first week in June is recommended as the planting date for Turrialba's climate[22].

MATERIALS AND METHODS

Experimental Site

The study was carried out at the Crop Production Department's Experimental Station "La Montaña", CATIE, Turrialba, Costa Rica, Central America. The research center is located at 9°50' latitude north and 83°30' longitude west at 602 meters above sea level. This locality, classified as the humid subtropical forest,[46] experiences an average annual rainfall of 2,636.7mm (42 yrs. data) and an average mean temperature of 21.7°C (25 yrs. data). Although in Turrialba the drier months of January through April are considered "summer", a severe dry season does not occur. Meteorological data taken at CATIE substantiates this observation (Table A1).

The soil in "La Montaña" is of alluvial origen with a loamy texture in the upper 15 cm. Classified as an Inceptisol (sub-order Tropepts, great group Dystropepts, sub-group Typic Dystropepts and family fine, mixed isothermic), the soil is placed in the Instituto series.[1] The specific site used, a half-hectare section in lot 11, is almost completely surrounded by one-to-two meter deep ditches which cause uneven drainage despite the relatively even grade. Soil fertility data (Table 1) is based on an August 1982 sampling with three subsamples mixed together for each of the four blocks. Methods used for soil analysis are presented in Table A2.

TABLE 1. Initial soil fertility of experimental site

Rep.	Dpth.	pH	Organic matter (mg/g)	Extractable acidity (meq/100 ml)	N (mg/g)	P $\frac{\mu g}{100\ ml}$	K $\frac{me}{100\ ml}$
I	0-15	4.5	54.9	0.9	2.8	10.5	0.32
II	0-15	4.4	50.3	1.0	2.2	8.5	0.30
III	0-15	4.4	49.6	0.7	2.3	10.0	0.39
IV	0-15	4.3	44.9	0.7	2.4	8.5	0.37

Experimental Work

The study covered both the dry and wet seasons with the first experiment running from September, 1982 to February, 1983 and the second from June to October, 1983. In both experiments the basic objective remained the evaluation of mulch for the production of maize. In the first experiment, however, two types of mulch were evaluated whereas in the second only one mulch is tested.

EXPERIMENT I

A randomized block design with four replicates of twelve treatments was used. Each plot consisted of 7.2 x 4.2 m of maize variety Tuxpeño-Cycle 7, a white dent grain adapted to tropical lowlands.

Treatments were designed according to the total amount of N theoretically contained in the source applied. For the mulches this was the average N content for three samples of prunings. The mulch applied in the field was calculated as:

$$\frac{\text{dry weight}}{\text{N \%}} \times \frac{\text{fresh wt.}}{\text{dry wt.}} \times \text{(Chosen level of N kg/ha)},$$

with 30 and 60 kg/ha being the chosen levels for Experiment I. Sample calculations for Gmelina and Erythrina mulches at 30 kg N/ha are:

$$\frac{\text{1 kg dry wt.}}{\text{0.01703 kg N}} \times \frac{\text{500 g fresh wt.}}{\text{157.87 g dry wt.}} \times \text{30 kg N/ha} = \text{0.5579 kg fresh wt. Gmelina/m}^2$$

$$\frac{\text{1 kg dry weight}}{\text{0.02879 kg N}} \times \frac{\text{500 g fresh wt.}}{\text{104.21 g dry wt.}} \times \text{30kg N/ha} = \text{0.5000kg fresh wt. Erythrina/m}^2$$

Mulches were cut from neighboring trees with similar ages in both cases. Leaves and small branches (< 4 cm diameter) were cut from 5-month-old Gmelina arborea trees from the Finca Buenavista of Celulosa, a Division of Scott Paper Company, located in the Pavones district, Canton Turrialba, about 19.5 km from Turrialba on the highway to Siquirres. The Erythrina poeppigiana mulch came from a living fence in CATIE's Animal Production Department's Experimental Farm. These branches had grown for six months, since the previous pruning.

The mulches were applied 25-27 days after planting and the ammonium nitrate 43 days after planting (Table 2). Mulches were applied earlier based on the observation that after two weeks in the field they had visibly

TABLE 2. Description of treatments in the first experiment

Treatment	Gmelina Kg fresh/m^2	= kg N/ha	Erythrina Kg fresh/m^2	= kg N/ha	NH_4NO_3 g/hill	= kg N/ha (% N = 33.5)	Total N applied kg/ha
1	0	0	0	0	3.1	30	30
2	0	0	0	0	6.2	60	60
3	0.56	30	0	0	3.1	30	60
4	0.56	30	0	0	6.2	60	90
5	1.12	60	0	0	3.1	30	90
6	1.12	60	0	0	6.2	60	120
7	0	0	0.50	30	3.1	30	60
8	0	0	0.50	30	6.2	60	90
9	0	0	1.00	60	3.1	30	90
10	0	0	1.00	60	6.2	60	120
11	0	0	0.50	30	0	0	30
12	0	0	1.00	60	0	0	60

begun to decompose and, presumably, release N. For the treatments with mulches, similar proportions of leaves, petioles and branches were weighed and distributed over the corresponding plot. In treatments with fertilizer N, the ammonium nitrate was measured volumetrically and applied on a per hill basis. Treatments were positioned in a randomized arrangement (Figure 1).

Further management of the site was uniform throughout both experiments. Initially a one-meter-square frame was used to visually estimate weed cover per plot before the herbicide glyphosate was sprayed at 0.48 kg/ha. On September 21, 1982 a dibble-stick was used on the unplowed site to plant three seeds per hill at 0.6 m, or a density of 83,333 plants if germination had been perfect. Along with the seeds, 0.5 g/hill of carbofuran or 13.9 kg/ha, was added to combat soil pests. After 15 days, 110 kg K_2O/ha and 140 kg P_2O_5/ha were applied in the form of KCl and triple-superphosphate. At 40 days of maize growth the insecticide phoxim was applied, at approximately 1.0 kg/ha, on the upper whorl of each plant in granular form. Evidence of flea beetles (Coleoptera: Chrysomelidae) and fall army worms (Spodoptera frugiperda) was observed earlier on some plants. Ten days later the fungicide metiram was sprayed at 0.60 kg/ha to combat an infestation of Southern Corn Leaf Blight (Helminthosporium maydis) found throughout the site.

When the maize had past physiological maturity, the stalks were doubled over to prevent rain from accumulating in the husks and encouraging ear rot. Ears were harvested the 16th to 18th of February, 1983 after 20 days of drying in the field.

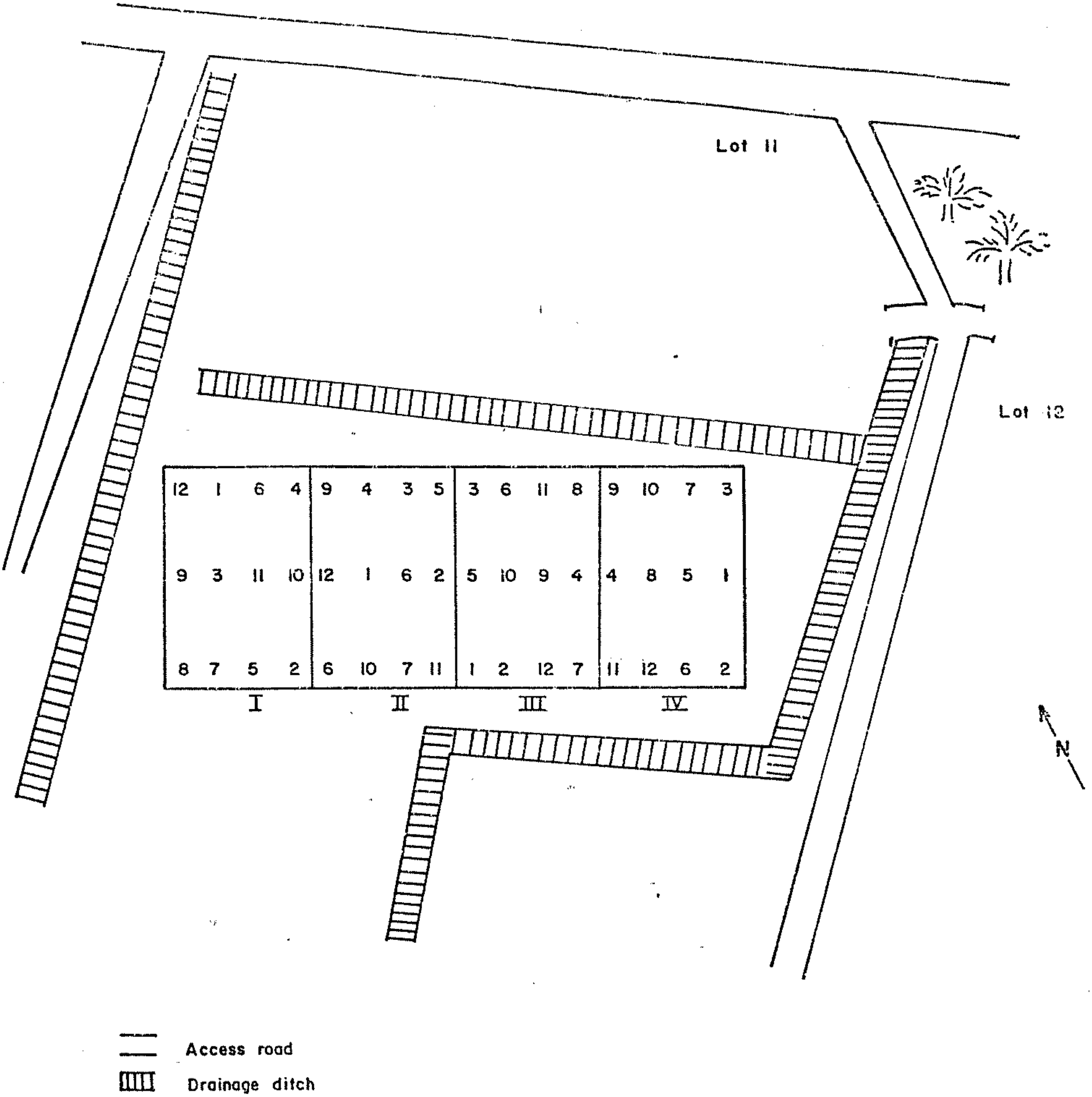

Figure 1. Field map of experiment 1.

The factors measured represented the soil conditions and the crop and weed response. Soil temperature and moisture levels were recorded weekly at 13:00 using Soiltest, Inc. MC310A nylon soil cells and an M-300B soil moisture-temperature meter, measuring in Ohm and operating on batteries (2205 Lee St., Evanston, Illinois, 60202). The resistance of each cell was calibrated with soil moisture tension in a Soilmoisture, Corp. pressure plate apparatus (P.O. Box 30025, Santa Barbara, California, 93105, U.S.A.) at 0, 0.33, 1.0, 2.0, 5.0 and 15.0 bars. The soil cells contain thermistors which report soil temperature in °F directly on the meter without need for conversion factors. To further verify the soil moisture readings, tensiometers were also used in some plots.

At the physiological maturity of the maize the biomass and N content of the stems, leaves, flowers and ears were measured in a sample of four plants per plot using a modification (Table A2) of the semimicro-kjeldahl method described by Bremmer[15]. After another 20 days of drying in the field, the ears from 32 hills were harvested and separated into commercially viable ears and damaged or poorly filled ears. Ears were classified as commercial if more than half the grains were still intact, full and disease-free at the harvest time. The number of ears and their total weight for both groups were taken, as was the weight of the shelled grain, from a sample of eight commercial ears whose weight equaled to $\frac{\text{total weight of commercial ears}}{\text{total number of commercial ears}}$ x 8(ie. 8 ears selected as representative). This latter value, the grain weight, as a percentage of the total weight of the eight representative ears, is referred to as the shelling percentage. Moisture content of a sample of grain was measured with a Dole Model 400 moisture tester (Eaton Corporation, Controls Division, 191 East North Ave., Carol Stream, Illinois, U.S.A. 60187). Yield was then calculated with the equation:

$$\text{field weight of commercial ears (kg/area harvested in m}^2\text{)} \times \frac{100 - \%\ \text{grain moisture}}{85} \times \text{shelling}\ \% \times \frac{10{,}000\ \text{m}^2/\text{ha}}{\text{area harvested in m}^2}$$

which standardizes the grain moisture at 15% and converts the data to a commercial ear grain/ha basis. Although the healthy part left on the damaged ears would not be discarded, it is generally not taken into account in yield calculations and might be considered as compensation for the damaged sections of the commercial ears which were counted as complete [21].

At the time of the maize harvest, weeds were also harvested from a two-meter-square area in the center of each plot. Aerial biomass was recorded. The N content of subsamples was measured in the same manner as for the maize.

EXPERIMENT II

Eight treatments (Table 3) in plots of 9 x 6m with four replicates were placed in a randomized block design (Figure 2). Treatments were calculated by the same system as in Experiment I but only Erythrina poeppigiana mulch was included. The mulch was cut from 30-year-old trees intercropped with coffee plants located on the road between CATIE's residential section 109 and the main entrance to "La Montaña". Almost a year had passed since the previous pollarding. The method of application of the mulch and ammonium

TABLE 3. Description of treatments in the second experiment

Treatment	*Erythrina* kg fresh/m^2	= kg N/ha	NH_4NO_3 g/hill	= kg N/ha (% N = 33.5)	Total N applied kg/ha
1	0	0	2.16	21.0	21
2	0	0	4.32	42.0	42
3	1.00	60	0	0	60
4	2.00	120	0	0	120
5	0.50	30	1.08	10.5	40.5
6	1.00	60	2.16	21.0	81.0
7	2.00	120	2.16	21.0	141.0
8	0	0	0	0	0

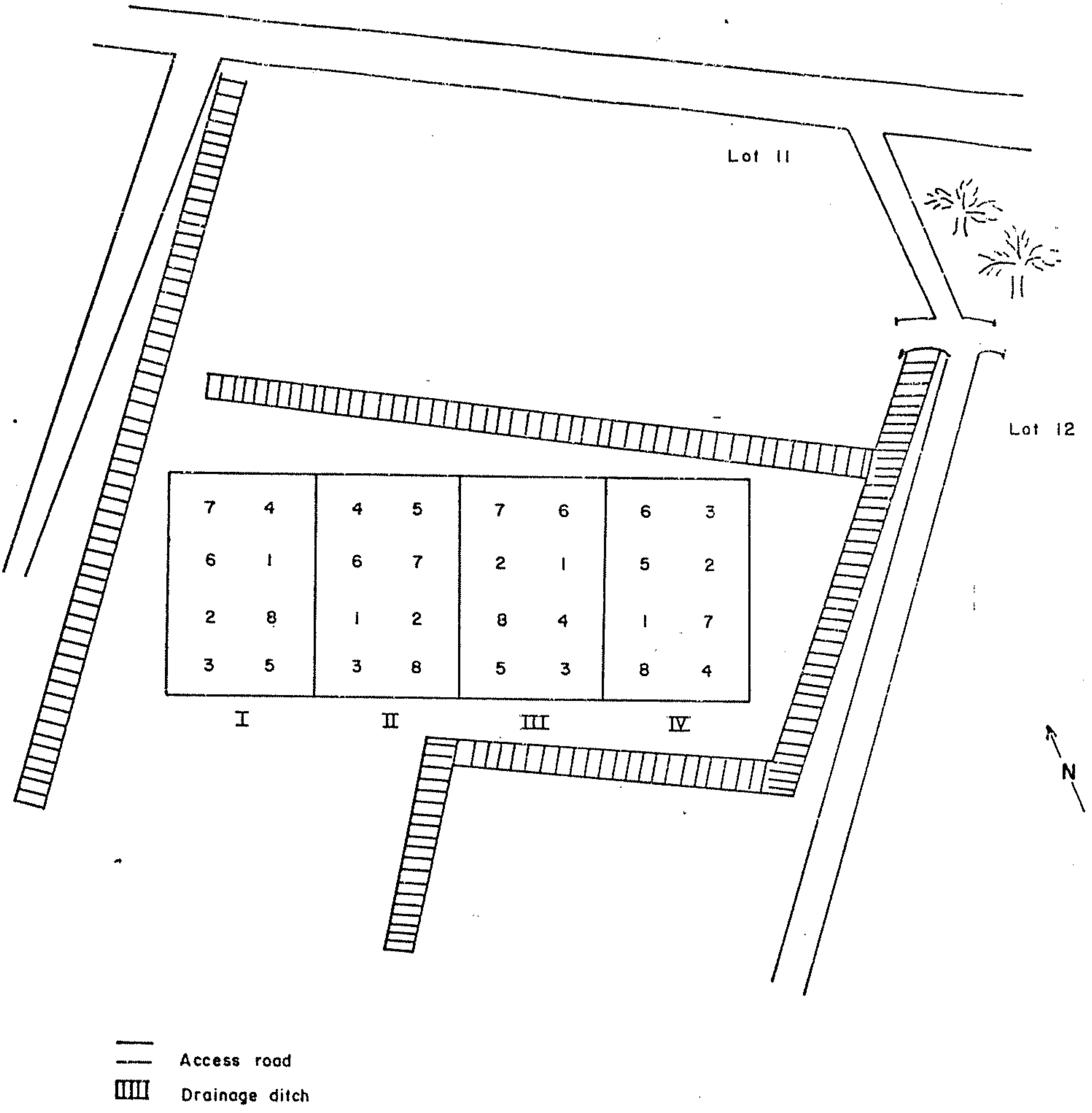

Figure 2. Field map of experiment II.

nitrate was as before; both were applied at 40 days after maize germination.

Site preparation consisted of raking aside and burning maize residues from the previous trial. On June 7, 1983, after the delay of a temporary drought, five seeds of Tuxpeño-cycle 7 maize were buried with the mentioned amount of carbofuran (5G) at a 0.6 x 0.6 m spacing. Soon after germinating, the maize was thinned to two plants per hill or 55,555 plants/ha. A month later the herbicide paraquat was applied at 0.56 kg/ha and K_2O and P_2O_5 were applied as before. Harvest took place the 17th to 20th of October, 1983.

To more thoroughly document the environment of the crop, several factors were measured on a periodic basis from the time that mulch was applied through the physiological maturity of the maize. For example, available N was determined from 2N KCl extracted soil solutions which had been taken as three subsamples per plot as 0-10 cm depth every two weeks. Analysis using a steam distillation procedure measured NH_4-N with MgO and then NO_2-N and NO_3-N with Devarda alloy [14]. Also biweekly, four maize plants (two hills) were cut at ground level, from the third row up to the fifth, for biomass and N content determination. Nitrogen analysis was carried out as above (Table A2). For both factors a total of five sampling dates were reached before physiological maturity and the doubling of the maize. Yields from the harvest were calculated, as in Experiment I, using plants from 24 hills (48 plants).

Throughout this same time soil temperatures were recorded hourly using thermistors at 5 cm depth connected by cables to a Delta T chart-drive system recorder galvanometer (Grant Minature Temperature Recorders model M-261, Grant Instruments, Ltd., Bulbeck Mill, Barrington, Cambridge CB2 5QZ, United Kingdom). A recharged battery replaced the one in the field once-a-week. After the experiment was completed, complete soil fertility analyses were repeated on a mixture of three subsamples for each block.

Concurrent with Experiment II, the decomposition rate of Erythrina mulch was studied using the nylon mesh bag technique[95]. Three-mm^2 mesh was partially sewn into $0.25m^2$ square bags which were closed completely using fine wire after inserting 375 g of fresh mulch material. The filled bags, placed between maize plots in a completely randomized design, were removed four at a time on ten collection dates. First directly from the cutting (day 0), then at 4, 9, 13, 17, 21, 28, 38, 46, 62, and 78 days after mulch application and the placement of the bags. The interval between collection dates increased from 4 up to 16 days as the decomposition rate was observed to have decreased and little change was noted in weight and N content of already collected samples.

Analysis

All of the data taken in both experiments was recorded in the following files: Harvest information, Experiment I. and II.; Physiological maturity maize sample, exp. I.; Weed presence, exp. I.; Soil temperature and moisture exp. I.; Soil moisture (one-week trial), exp. II.; Periodic maize samples, exp. II.; Periodic soil N samples, exp. II.; Decomposition of mulch, exp. II. The data from the second experiment on soil temperature at hourly intervals was not recorded on the diskette for computer analysis but rather analyzed by calculator at the time of tabulating because of the large quantity of numbers.

Each set of data was subjected to a standard analysis of variance (model-treatments, repetitions) and Duncan's Multiple Range Test. For the files of harvest information, periodic maize and periodic N samples, one degree of freedom tests were made using the orthogonal contrasts presented in Table A3.

RESULTS

Complete soil analysis data from samples taken before experiment I (8/82) and after the completion of experiment II (10/83) is presented in Table 4. Although not directly comparable because of sampling variation, apparently organic matter, N, P, K, Ca, Mg, Cu and Fe values declined over the two growing seasons whereas pH, extractable acidity, Zn and Mn increased.

EXPERIMENT I

Soil temperature

Averages from weekly soil temperature measurements in treatments 2 (M60), 4 (M60G30), 6 (M60G60), 8 (M60E30), 10 (M60E60) and 12 (E60) are recorded in Table A3. Readings from representative treatments 2, 6, 10 and 12 are presented graphically in Figure 3. The highest individual reading (at 13:00) from the mulch application til crop harvest was 27.78°C which occurred in treatment 10 (M60E60) 11 weeks after mulch application. The lowest temperature (at 13:00), 22.22°C, was registered from several treatments on various dates. On the whole, lower temperatures were encountered in treatment 6 (M60G60) until the last weeks of the study when treatment 12 (E60) temperatures dropped. Highest temperatures tended to result in treatment 10 (M60E60). After the maize was doubled for drying (January 28), soil temperature-treatment relationships diminished or altered. Previous patterns were never definite, however, neither in relationship to mulch cover nor to final maize yield, which might have reflected the plant growth and therefore shading of the soil.

Often the same soil temperature was registered in several plots. Significant differences did occur on three dates according to Duncan's Multiple

TABLE 4. Soil fertility of experimental site at the initiation and close of the study.

Date	Rep	Dpth (cm)	pH	O.M. (mg/g)	N (mg/g)	P (μg/100ml)	K (me /100 ml)	Ca	Mg	Extr.	Cu	Zn	Mn	Fe
9/82	I	0-15	4.5	54.9	2.8	10.5	0.32	3.3	1.42	0.9	27.1	3.7	17.8	402
	II	0-15	4.4	50.3	2.2	8.5	0.30	3.2	1.36	1.0	28.7	3.0	18.6	536
	III	0-15	4.4	49.6	2.3	10.0	0.39	3.9	1.54	0.7	27.9	3.6	20.0	444
	IV	0-15	4.3	44.9	2.4	8.5	0.37	3.6	1.38	0.7	25.4	3.1	14.8	348
		$\bar{x}$ =	4.4	50.0	2.4	9.4	0.35	3.5	1.43	0.8	27.3	3.4	17.8	433
10/83	I	0-20	5.6	42.2	2.1	10.0	0.15	1.6	0.77	1.6	21.3	6.0	27.5	175
	II	0-20	5.7	36.9	1.8	7.5	0.16	1.7	0.91	1.3	21.9	4.9	27.5	168
	III	0-20	5.7	46.9	2.5	11.5	0.60	2.5	1.33	0.6	24.4	14.8	18.5	342
	IV	0-20	5.7	44.2	2.1	7.5	0.36	2.0	1.04	0.6	19.8	3.8	17.4	226
		$\bar{x}$ =	5.7	42.6	2.1	9.1	0.32	2.0	1.01	1.0	21.9	7.4	22.9	228

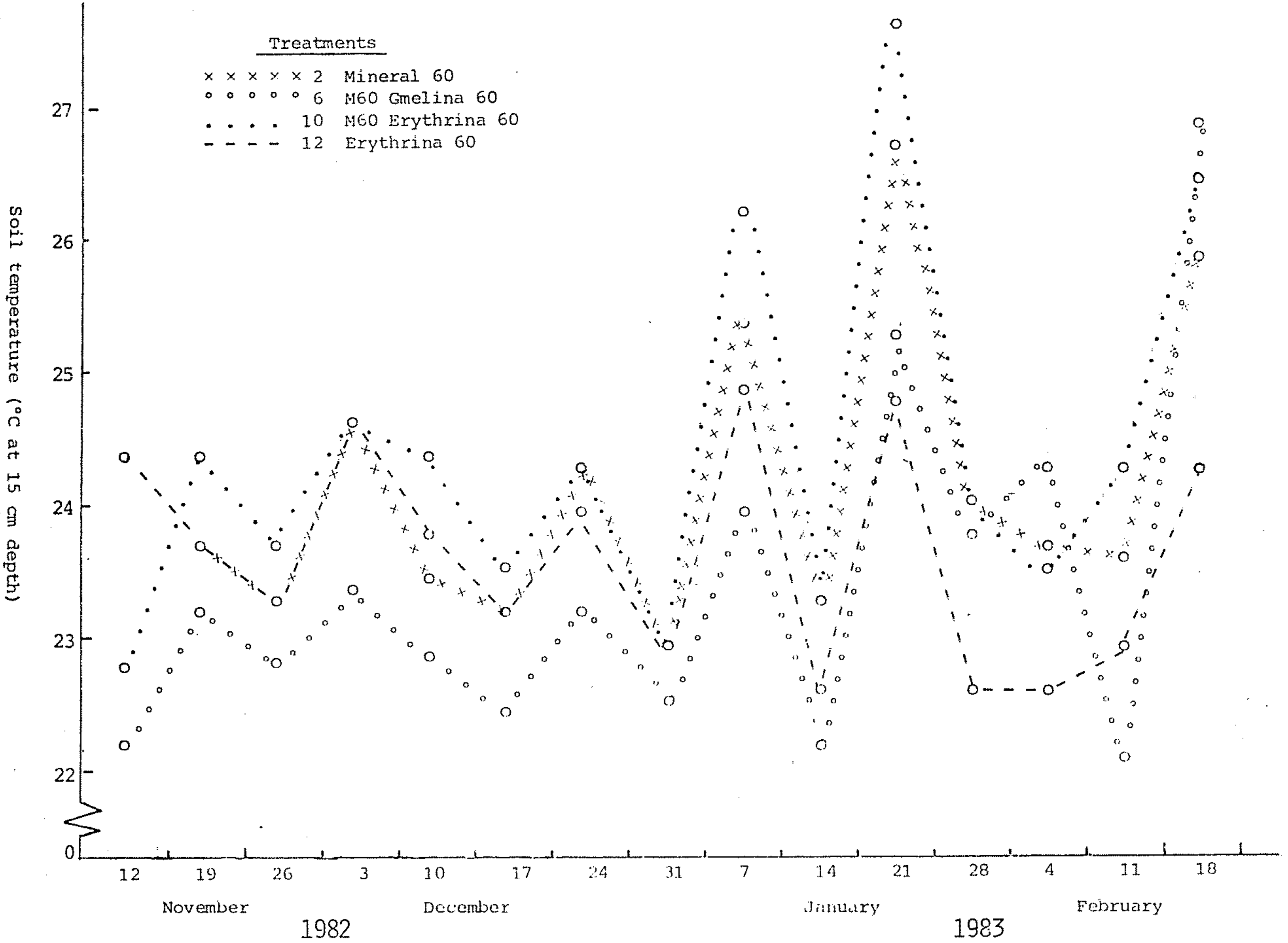

FIGURE 3. Average weekly soil temperature readings from representative treatments (2 reps, exp I.).

Range Test (DMRT) at $\alpha=0.05$: the 1st and 2nd weeks after mulching treatments with Gmelina experienced lower average soil temperatures (at 13:00) than those with Erythrina mulch; and on the 13th reading date treatment 6 (M60G60) had a higher soil temperature than both 4 (M60G30) and 12 (E60).

Soil moisture

Soil moisture values, although showing wide variation, were significantly higher (DMRT $\alpha=0.05$) for treatment 2 (M60) during the 11th and 12th weeks of recording with 34.00% and 32.00% in comparison with treatment 8 (M60E30) which had 31.05% and 20.00% soil moisture content for the respective dates. Once more, in the 13th week after mulching, treatment 2 soils had significantly higher moisture than in treatments 8 and 4 (M60G30) which had 26.00% and 27.00% in comparison with 31.50% soil moisture content.

In the first weeks after mulching, treatment 10 (M60E60) tended to have the highest moisture contents, being replaced in later weeks by treatment 2 (M60). Treatments 4 (M60G30) and 8 (M60E30) were generally lowest in soil moisture content. From individual readings the values were highest for treatment 12 (E60) in the 8th week (49.75%) and lowest for treatment 8 (M60E30) in the 15th, or last week of recording (16.00%).

Higher soil moisture percentages did not consistently occur with low soil temperatures nor with treatments including mulch. The varying relationships among treatments 2 (M60), 6 (M60G60), 10 (M60E60) and 12 (E60) are presented graphically in Figure 4.

Weed indices

There was no significant relationship between the pre-herbicide weed

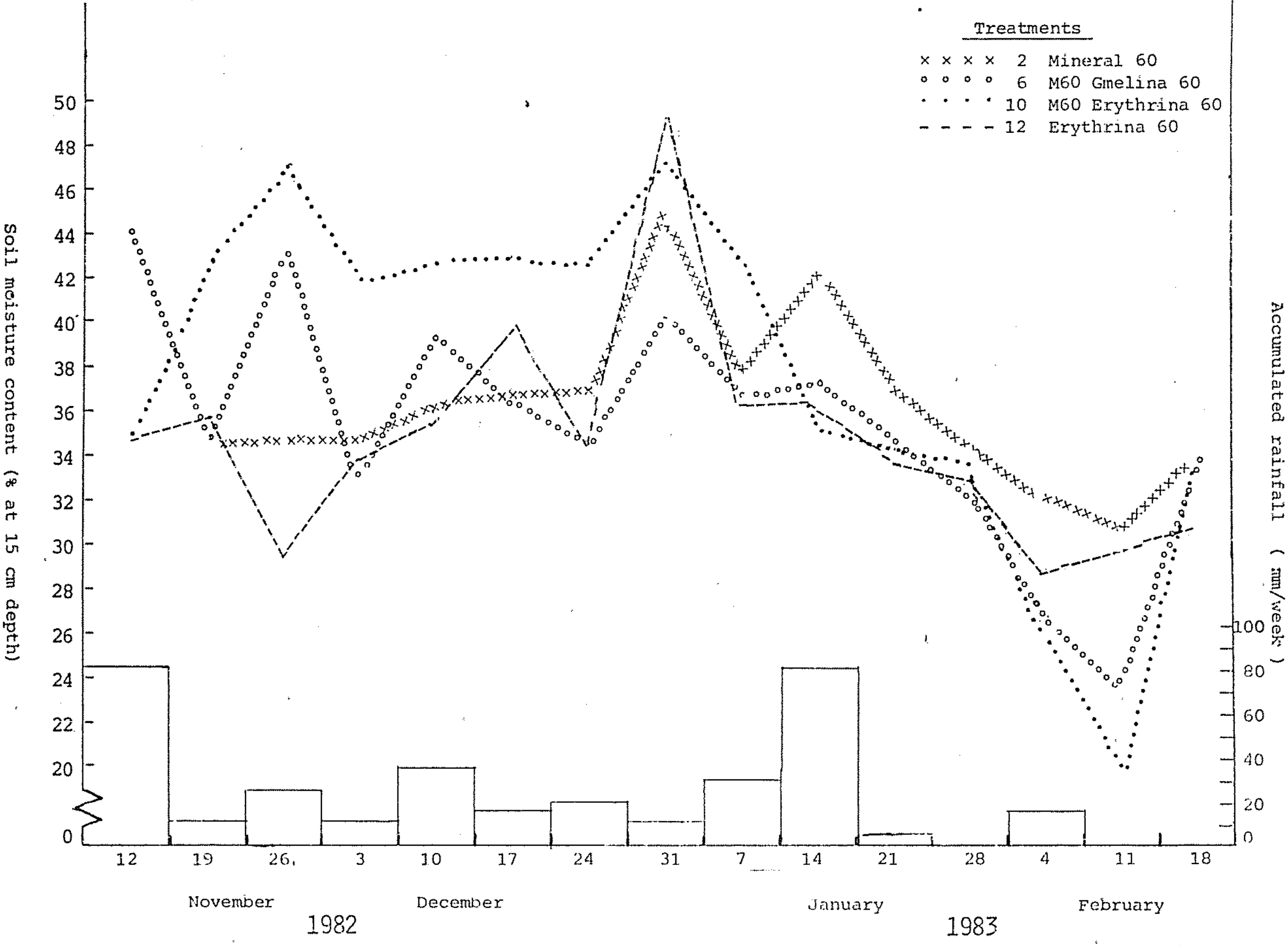

FIGURE 4. Average weekly soil moisture content readings from representative treatments (2 reps, exp I.) and weekly rainfall accumulation at CATIE's meteorological station.

cover in each plot by area and the final biomass of the weeds at the time of maize harvest (PR > T 1.0001, r = 0.3427). Regrowth was similar throughout the site and, according to analysis of variance (ANOVA) and DMRT, was not significantly affected by treatment differences neither in terms of weed biomass nor weed N content at the sampling time.

In summary the treatment differences did not strongly influence the soil factors of temperature and moisture content, nor the weed regrowth after the initial chemical control, nor the weed uptake of N which represents the crop-weed competition to some extent. For the first experiment, therefore, effects of the mulches were not seen in the plant's growth environment but rather in the maize crop itself.

Maize growth and production

At the time of the crop's physiological maturity, some significant differences were noted among the treatments' leaf, stem, flower and ear samples in weights or N concentrations. Notably, treatment 4 (M60G30) --which later had the highest grain yields-- produced significantly greater ear weight and N content than did treatment 1 (M30), the lowest producer, according to a DMRT at $\alpha = 0.05$. Total plant dry weights and N contents were lower in treatments with a mineral source of N at 30 kg/ha versus at 60 kg/ha (contrasts, 10%). The average N and dry weights for maize plants are listed in Table 5. The N concentrations are listed in Table 6.

Harvest values --plants harvested, number and weight of ears, grain

TABLE 5. Dry weight and N for maize at physiological maturity (4 plants/plot, 4 reps, experiment I)*

Treatments (kg N/ha)	Dry weight (kg/ha)	N (kg/ha)
1. Mineral 30	501.42[b]	63.90[a]
2. Mineral 60	777.00[a]	93.40[a]
3. Mineral 30 Gmelina 30	670.02[ab]	78.93[a]
4. Mineral 60 Gmelina 30	766.35[a]	93.98[a]
5. Mineral 30 Gmelina 60	589.02[ab]	71.30[a]
6. Mineral 60 Gmelina 60	646.97[ab]	77.40[a]
7. Mineral 30 Erythrina 30	627.45[ab]	78.25[a]
8. Mineral 60 Erythrina 30	688.42[ab]	82.48[a]
9. Mineral 30 Erythrina 60	605.40[ab]	72.45[a]
10. Mineral 60 Erythrina 60	773.57[a]	96.23[a]
11. Erythrina 30	584.02[ab]	76.25[a]
12. Erythrina 60	586.25[ab]	69.45[a]
C.V. =	22.262	24.086

*N calculated as % N x dry wt. Values, in each column, followed by the same letter do not differ significantly at $\alpha = 0.05$ based on Duncan's Multiple Range Test.

TABLE 6. Weighted average of N concentrations in maize at physiological maturity calculated from the N contents of stems, leaves, flowers and ears (4 reps, experiment I).

Treatment (kg N/ha)	g N* / 100 g dry wt.**
1. Mineral 30	1.27
2. Mineral 60	1.20
3. Mineral 30 Gmelina 30	1.18
4. Mineral 60 Gmelina 30	1.23
5. Mineral 30 Gmelina 60	1.22
6. Mineral 60 Gmelina 60	1.20
7. Mineral 30 Erythrina 30	1.26
8. Mineral 60 Erythrina 30	1.21
9. Mineral 30 Erythrina 60	1.22
10. Mineral 60 Erythrina 60	1.22
11. Erythrina 30	1.38
12. Erythrina 60	1.18

*Sum of N contents of stems, leaves, flowers and ears.

**Sum of dry weights of stems, leaves, flowers and ears.

yields -- can be found in Table 7. No differences were determined among treatments using an ANOVA. With DMRT and contrasts (at 10%), treatment 6 (M60G60) was shown to have produced more non-commercial ears than treatments 2 (M60), 4(M60 G30) and 11 (E30), and a greater non-commercial ear weight than treatments 3 (M30 G30) and 11. In broader terms, treatments with some mineral N had fewer non-commercial ears than those with no mineral N added. Furthermore, with a higher level of mineral N the addition of either mulch was related to a greater number of non-commercial ears. The weight of these ears was higher in treatments with a lower level of mineral N when Gmelina was applied at its higher level than when added in the lesser amount.

In view of these relationships between mulching and low quality ear production, it is noteworthy that the main cause of damage in the first field trial was Diplodia ear rot, probably in association with Giberella spp.

EXPERIMENT II

Soil temperature

Although some of the soil temperature data was lost during the study due to a wild dog attack on the cables connecting the thermistors to the recording unit, enough values were collected for valid statistical analysis. No significant differences occurred among the representative treatments 1 (M21), 6(M21E60) and 7(M21E120), but tendencies were noted. The mean temperature for each hour, calculated from a sample of 30 days, was an average of 0.11°C higher for treatment 7 (M21E120) than for 1 (M21) in the first repetition (σ_{n-1}=0.12) Daily mean soil temperatures were also higher

TABLE 7. Harvest data (4 reps., experiment I)

TREATMENT (kg N/ha)	Number of plants (per sample)	Number of ears* Commercial (per sample)	Number of ears* Non (per sample)	Field weight* Commercial (kg/ha)	Field weight* Non (kg/ha)	Commercial grain yield* (15% moisture) (kg/ha)
1. Mineral 30	74.25	42.00[a]	26.50[ab]	3.64[a]	0.98[ab]	2,260.6[a]
2. Mineral 60	75.25	45.00[a]	24.25[b]	3.79[a]	1.05[ab]	3,273.9[a]
3. Mineral 30 Gmelina 30	76.00	44.00[a]	24.50[b]	3.89[a]	0.83[b]	3,173.5[a]
4. Mineral 60 Gmelina 30	83.75	48.25[a]	29.75[ab]	4.41[a]	1.26[ab]	3,709.6[a]
5. Mineral 30 Gmelina 60	81.75	46.00[a]	29.50[ab]	3.86[a]	1.27[ab]	3,094.6[a]
6. Mineral 60 Gmelina 60	84.75	48.00[a]	36.25[a]	3.98[a]	1.49[a]	3,213.4[a]
7. Mineral 30 Erythrina 30	81.75	41.50[a]	32.50[ab]	3.36[a]	1.10[ab]	2,772.5[a]
8. Mineral 60 Erythrina 30	80.75	47.25[a]	28.00[ab]	4.12[a]	1.22[ab]	3,366.9[a]
9. Mineral 30 Erythrina 60	75.75	46.25[a]	27.00[ab]	4.05[a]	1.16[ab]	3,387.3[a]
10. Mineral 60 Erythrina 60	80.25	47.75[a]	28.75[ab]	4.15[a]	1.19[ab]	3,395.2[a]
11. Erythrina 30	79.50	46.50[a]	22.75[b]	3.91[a]	0.92[b]	3,242.5[a]
12. Erythrina 60	81.50	47.25[a]	26.50[ab]	4.08[a]	1.04[ab]	3,474.3[a]
C.V. =	-	15.38	22.08	19.23	29.74	19.51

*Values in each column followed by the same letter do not differ significantly at $\alpha = 0.05$ based on Duncan's Multiple Range Test.

in treatment 7 than in 1 in the first repetition by an average of 1.29 °C (σ_{n-1}=4.22 n=22 days of 24 hours each). Averaging the data from both repetitions lowers this difference to only 0.0616°C (σ_{n-1}=0.37 n=22 days).

The highest individual reading, 45.5°C, which occurred in all treatments, might have been related to disruption of the equipment; but even the second highest value, from treatment 7 (M21E120) repetition 2, reached 41.0°C. The lowest temperature registered was 20.4°C which also occurred at the same time and date in all treatments. Most values were between 20° and 30°C.

Soil moisture

Readings taken thrice daily for one week were not significantly different for the representative treatments 1 (M21), 6(M21E60) and 7 (M21E120). Values were consistently higher, however, in treatment 7($\bar{x}$=36.35%) than in 6 ($\bar{x}$=33.93%) and 1 ($\bar{x}$=33.51%). This corresponds with lower biomass production in 7 and, presumably, less water assimilation by the crop. There was very little difference among soil moisture contents measured at different times of day.

Soil nitrogen

Soil nitrogen data appears in Table 8. Clear patterns did not result in relation to treatments' effect on $N\text{-}NH_4$ or $N\text{-}NO_2+NO_3$. Statistically significant differences determined using orthogonal contrasts are presented in Table 9.

TABLE 8. N-NH_4 and N-NO_2+ NO_3 in extracted soil solutions over the maize growing period. (4 reps., experiment II)*

TREATMENT (kg N/ha)	Sample: Days after mulching:	1 0	2 14	3 32	4 43	5 57
1. Mineral 21	N-NH_4	30.1[a]	33.4[a]	27.6[ab]	26.9[b]	36.6[ab]
	N-NO_2+NO_3	23.5	22.1	20.8	23.5	21.8
2. Mineral 42	N-NH_4	34.7[a]	33.9[a]	37.0[a]	42.2[a]	27.0[b]
	N-NO_2+NO_3	25.9	22.9	18.0	28.5	19.3
3. Erythrina 60	N-NH_4	31.1[a]	33.2[a]	32.4[ab]	29.7[b]	45.9[a]
	N-NO_2+NO_3	24.8	22.5	21.0	21.2	20.4
4. Erythrina 120	N-NH_4	35.4[a]	30.1[a]	36.2[a]	28.7[b]	26.6[b]
	N-NO_2+NO_3	23.9	20.9	20.5	28.7	19.3
5. Mineral 10.5	N-NH_4	36.6[a]	23.8[a]	25.9[b]	32.1[ab]	28.9[b]
Erythrina 120	N-NO_2+NO_3	35.8	24.6	19.7	21.3	20.5
6. Mineral 21	N-NH_4	30.2[a]	28.0[a]	27.0[ab]	28.7[b]	31.3[ab]
Erythrina 60	N-NO_2+NO_3	27.1	28.0	20.2	20.8	20.2
7. Mineral 21	N-NH_4	30.9[a]	28.4[a]	27.7[ab]	27.2[b]	25.1[b]
Erythrina 120	N-NO_2+NO_3	24.2	18.8	20.6	20.8	21.8
8. Control 0	N-NH_4	36.1[a]	35.2[a]	33.3[ab]	30.2[b]	27.6[b]
	N-NO_2+NO_3	40.3	22.5	28.9	22.4	1.83
C.V. =	N-NH_4	18.04	29.11	19.88	25.18	33.21
	N-NO_2+NO_3	45.76	21.75	32.21	22.14	15.45

*Micrograms/gram of soil at field capacity.

**N-NH_4 values in each column followed by the same letter do not differ significantly at α = 0.05 based on Duncan's Multiple Range Test. N-NO_2+NO_3 values showed no significant differences. Mulch was applied on the 40th day of maize growth.

TABLE 9. Significant differences in soil nitrogen values based on orthogonal contrasts (experiment II)*

Soil Sample**	Significant contrast	Significance level
$N-NH_4$		
1	None	-
2	B.2 Low total: one source > mix	10%
3	A.3 Mulch, high N: with < without mineral	10%
	A.5 No mulch: high > low N	5%
	B.3 High total N: one source > mix	10%
	C.1 Mineral < none	5%
	C.3 (M42) > (M21E120)	5%
4	A.5 No mulch: high > low N	1%
	B.5 High total N: mineral > mulch	5%
	C.2 Mineral: (M21) < (M42)	10%
	C.3 (M42) > (M21E120)	1%
5	A.2 Mulch: high < low N	5%
	A.4 Mulch low N: with < without mineral	10%
	B.1 Total N: high < low	5%
	B.2 Low total N: one source > mix	10%
	C.6 Erythrina: (E60) > (E120)	5%
$N-NO_2 + NO_3$		
1	A.7 No mulch: mineral > without	5%
	B.6 Total N: 141 < 0	5%
	C.5 Erythrina alone < control	5%
2	None	-
3	A.7 No mulch: mineral < without	5%
	B.6 Total N: 141 < 0	10%
	B.7 Total N: medium < extremes	10%
	C.5 Erythrina alone < control	10%
4	A.3 Mulch, high N: with < without mineral	5%
	B.1 Total N: high > low	10%
	B.3 High total N: one source > mix	5%
	C.3 (M42) > (M21E120)	5%
	C.6 Erythrina 60 > 120	5%
5	None	-

*Contrast matrices appear in Table A5.

**Sample times listed in Table 8.

Maize growth and nitrogen

Significant differences in periodic maize biomass and N content data are noted in Table 10. Contrasts (Table 11) confirmed that, throughout the season, the maize in treatment 6 (M21E60) generally had greater biomass and N content values while treatment 7 (M21E120) presented relatively poor growth indicators. Greater dry weights usually correspond to higher N levels, although N concentrations did vary, as shown in Table 12.

Maize production

Harvest parameters for the second trial appear in Table 13. The only significant difference was between the high weight of non-commercial ears from treatment 6 (M21E60) and the low weight from treatment 4 (E120) (DMRT, $\alpha = 0.05$). Although experiment I had more ears, the mean weights of both categories of ears were greater in experiment II and the resulting grain yields were higher. Moisture content in the grain ranged from 10.5 to 14.3% in the first trial whereas in the second the values were between 18.2 and 23.0%.

Mulch decomposition

Results from the decomposition study are shown in Figure 5. The date of recollection of the sample bags was highly significant (ANOVA, 5%) for fresh and dry weights as well as N contents. Replications were also significant for dry weight and N content. The variation becomes more apparent by applying Duncan's Multiple Range Test to the values recorded. Decomposition parameters do not always proceed in chronological order. Fresh weights were particularly erratic because of the fluctuating moisture contents in the mulch. The overall trend, however, is a decrease in dry weight and N

TABLE 10. Dry weight and N for maize over the growing period (4 plants/plot, 4 reps., experiment II)*.

TREATMENT (kg N/Ha)	Sample: Maize age (days):	1 41	2 52	3 64	4 79	5 93
1. Mineral 21	Dry wt.	1,387.3[a]	3,028.5[a]	6,273.8[a]	9,474.0[a]	12,445.0[b]
	N	30.60[f]	65.39[f]	94.49[f]	111.44[fg]	147.32[f]
2. Mineral 42	Dry wt.	1,567.8[a]	3,423.9[a]	5,886.0[a]	9,867.0[a]	13,997.0[ab]
	N	33.80[f]	71.22[f]	99.06[f]	108.79[fg]	174.31[f]
3. Erythrina 60	Dry wt.	1,573.0[a]	3,189.7[a]	5,976.3[a]	10,915.0[a]	11,599.0[a]
	N	31.57[f]	61.70[f]	91.28[f]	126.69[fg]	134.07[f]
4. Erythrina 120	Dry wt.	1,382.0[a]	3,408.2[a]	6,677.6[a]	9,528.0[a]	12,490.0[b]
	N	31.83[f]	70.20[f]	93.74[f]	102.81[g]	154.90[f]
5. Mineral 10.5 Erythrina 30	Dry wt.	1,264.0[a]	2,707.9[a]	6,223.1[a]	9,814.0[a]	13,916.0[ab]
	N	29.28[f]	53.99[f]	88.58[f]	100.63[g]	174.26[f]
6. Mineral 21 Erythrina 60	Dry wt.	1,637.3[a]	2,975.6[a]	5,267.0[a]	11,763.0[a]	18,019.0[a]
	N	37.69[f]	61.22[f]	90.01[f]	148.20[f]	213.61[f]
7. Mineral 21 Erythrina 120	Dry wt.	908.0[a]	2,252.8[a]	4,839.7[a]	9,119.0[a]	12,620.0[b]
	N	22.33[f]	53.74[f]	82.43[f]	115.79[fg]	152.81[f]
8. Control	Dry wt.	1,387.3[a]	2,644.8[a]	5,849.8[a]	8,976.0[a]	13,737.0[ab]
	N	28.62[f]	50.57[f]	82.35[f]	98.37[g]	133.73[f]
C.V. =	Dry wt.	44.67	34.65	22.58	19.21	24.13
	N	44.68	30.75	28.51	21.32	39.49

*All values in kg/ha. N calculated as % N x dry wt.

**Values in each column followed by the same letter do not differ significantly at $\alpha = 0.05$ based on Duncan's Multiple Range Test. Mulch was applied on the 40th day of maize growth.

TABLE 11. Significant differences in maize production values based on orthogonal contrasts (experiment II)*

Soil Sample**	Significant Contrast	Significant level
Dry weight		
1	None	–
2	None	–
3	A.3 Mulch: high N with > without mineral	10%
4	A.2 Mulch: high < low N B.3 High total N: one source < mix	5% 10%
5.	A.4 Mulch: low N with > without mineral B.3 High total N: one source < mix C.4 M21 < M21E60	1% 5% 5%
N content		
1	None	–
2	None	–
3	None	–
4	A.2 Mulch: high < low N B.3 High total N one source < mix C.4 M21 < M21E60	5% 1% 5%
5.	A.4 Mulch: low N with > without mineral	10%

*Contrast matrices appear in Table A5.

**Sample times listed in Table 10.

TABLE 12. Weighted average of N concentrations in maize at different sampling dates calculated from the N contents of the stems, leaves, flowers and ears (4 reps, experiment II).

TREATMENT (kg N/ha)	SAMPLE: Maize age (days):	gN* / 100 g dry wt.** 1 / 41	2 / 52	3 / 64	4 / 79	8 / 93
1.	Mineral 21	2.21	1.99	1.51	1.12	1.18
2.	Mineral 42	2.15	2.08	1.68	1.10	1.24
3.	Erythrina 60	2.00	1.93	1.53	1.16	1.15
4.	Erythrina 120	2.30	2.06	1.40	1.08	1.24
5.	Mineral 10.5 Erythrina 30	2.32	1.99	1.42	1.03	1.25
6.	Mineral 21 Erythrina 60	2.30	2.06	1.71	1.26	1.19
7.	Mineral 21 Erythrina 120	2.46	2.28	1.70	1.27	1.21
8.	Control 0	2.06	1.91	1.41	0.99	0.97

*Sum of N contents of stems, leaves, flowers and ears.

**Sum of dry weights of stems, leaves, flowers and ears.

TABLE 13. Harvest data (4 reps, experiment II)

TREATMENT (kg N/ha)	Number of plants (per sample)	Number of ears* Commercial (per sample)	Number of ears* Non (per sample)	Field weight* Commercial (kg/sample)	Field weight* Non (kg/sample)	Commercial grain yield* (15% moisture) (kg/ha)
1. Mineral 21	47.25	31.75[ab]	14.25[a]	5.80[a]	1.19[ab]	4,716.9[a]
2. Mineral 42	46.75	32.75[ab]	13.00[a]	6.05[a]	1.07[ab]	4,917.8[a]
3. Erythrina 60	47.75	25.75[b]	16.50[a]	4.51[a]	1.13[ab]	3,626.3[a]
4. Erythrina 120	47.50	35.25[a]	11.50[a]	6.22[a]	0.83[b]	5,118.3[a]
5. Mineral 10.5 Erythrina 30	46.75	31.00[ab]	12.50[a]	5.54[a]	1.03[ab]	4,531.6[a]
6. Mineral 21 Erythrina 60	46.25	29.75[ab]	15.00[a]	5.88[a]	1.38[a]	4,750.5[a]
7. Mineral 21 Erythrina 120	46.25	30.00[ab]	14.00[a]	5.18[a]	1.11[a]	4,275.1[a]
8. Control 0	47.00	29.00[ab]	14.25[a]	4.98[a]	1.00[a]	4,056.9[a]
	C.V. =	15.31	28.20	22.11	25.67	21.75

*Values in each column followed by the same letter do not differ significantly at $\alpha = 0.05$ based on Duncan's Multiple Range Test.

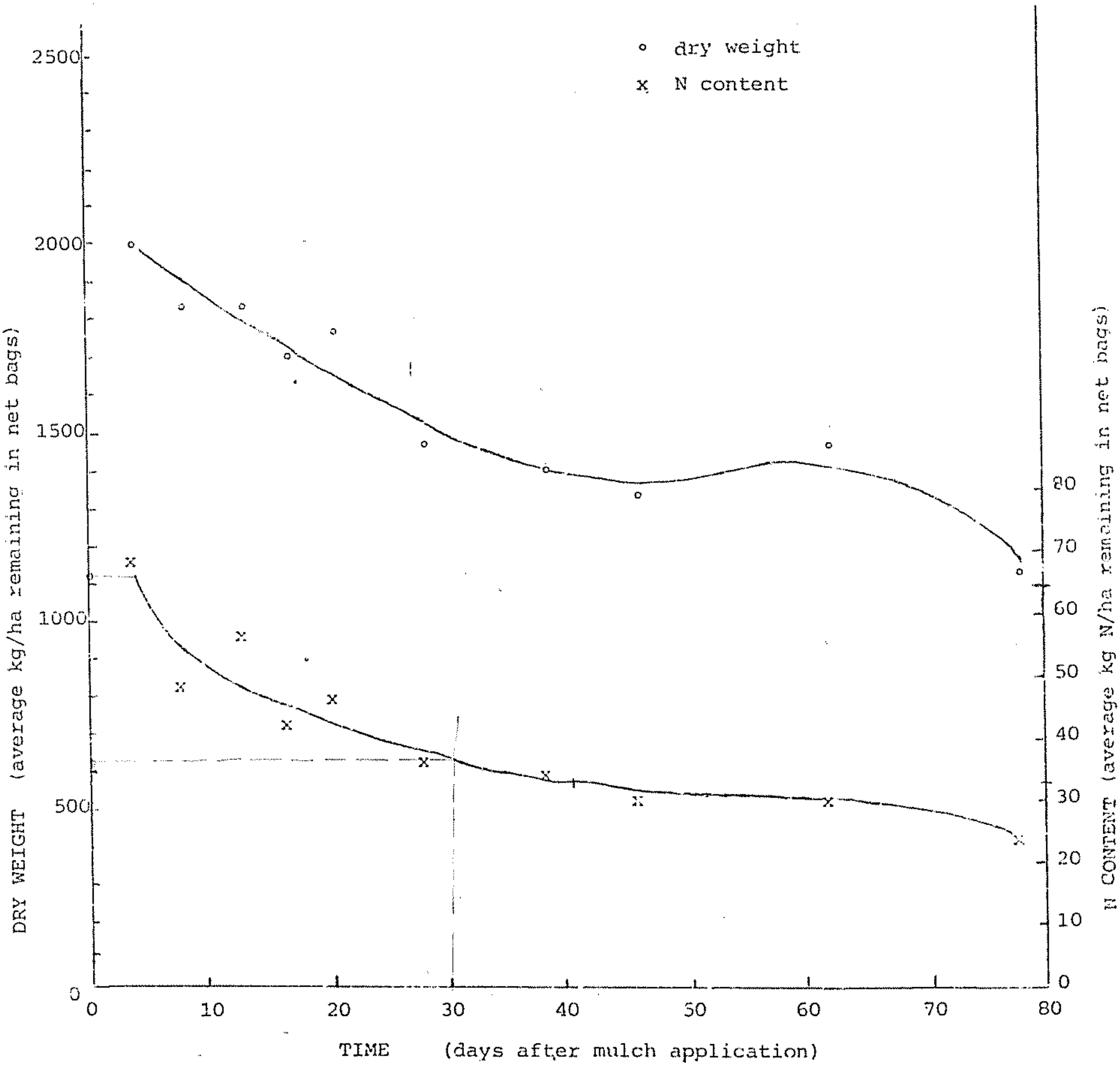

FIGURE 5. Decay curve from *Erythrina* decomposition study using the net bag technique.

over time. Mulch dry weight and N content varied from the calculated values which were based on earlier samples, as seen in sample 0 and 1. In later samples, it is impossible to separate the effect of this variation from the decomposition itself.

DISCUSSION

Soil properties

Mulching is often practiced to improve soil physical properties and increase the organic matter content. In this experiment, however, two seasons of applying mulch did not result in an increase but rather a decrease in soil organic matter. This loss is considered to be a temporary response to the increased microbiological activity. With further additions of organic mulch materials a long term increase in the soil's content would probably occur[3]. Predictions can not be made, however, from the results of only one year of mulching.

The significant rise in the pH of the experimental site's soil agrees with results from mulching experiments in Tanzanian and Kenyan coffee soils where banana leaf and Napier grass were applied and from Nigerian coffee soils mulched with leguminous cover crops.[17,70,80] Burning caused a similar effect on Peruvian soils which experienced a change in pH of 4 to 4.5.[84]

In the same study exchangeable Al dropped immediately after the burn but had risen to previous levels in ten months because of the release from Al-organic complexes which began to decompose rapidly.[84] The same mechanism could explain the rise in extractable acidity (approximately 75% Al^{+++}) in the present study. This would also be consistent with the rise which occurred in Mn. Although other mulching studies show a drop in Mn in tropical climates, it was associated with increased soil moisture caused by mulching with crop residues, paper and other materials which differ from the relatively fast decomposing tree leaves.[69,73,87]

Most elements in the soil decreased over the research period. This could be attributed to plant uptake, losses from leaching, and a response to the pH change although the rise in pH appears inconsistent with the conditions. Soil microorganisms are also reported to contain a large portion of the soil nutrients, particularly N and P. For instance as much P was found in the soil microflora as in the standing vegetation per hectare in one study.[45] With the decomposition process, levels of K, Mg and Ca tend to drop, as occurred in this study, until the inputs from decomposing matter balance with the losses.[95] Once more, the long term effect could not be determined using only one year's data.

The rise in Zn values was almost surely due to the application of a Zn-based fungicide during the first experiment. Decreases in P and K despite the fertilizations indicate that the mulches can not supply sufficient quantities of those elements. This deficiency in P had been noted previously in Erythrina species and has caused accumulated deficiencies in agro-forestry systems studied over several years.[5]

Clear effects of mulch applications can be seen in some other variables which would be expected to respond more rapidly to mulch correlation than soil natural levels. In the first trial, soil temperatures appear to have been influenced by the type of mulch material during the first weeks after application. Treatments with Gmelina had lower temperatures at that time. By the end of the experiment, however, no relationship was observed between the treatments and soil temperatures. Earlier conclusions that applying higher levels of mulch on the soil surface results in lower maximum temperatures were not confirmed. Perhaps higher levels would be necessary before this effect could be noted.

Plant growth rather than mulch cover may have been the primary influence under these circumstances. In the 13th week when treatment 4(M60G30) had the lowest average soil temperature at the reading time (13:00), it also had low soil moisture content. The interpretation that plant growth and therefore shading with greater water uptake, affected the soil environment more is also supported by the high number of ears and their N content in treatment 4. It appears that treatment 4 had produced more growth by physiological maturity and perhaps lower soilwater content while also shading the plots to lower the temperatures. Not all differences in the experiment confirm that interpretation, however.

The maximum temperature reached in experiment I was 27.78°C in treatment 8 (M60G60), even though over time that treatment tended to have lower soil temperatures. The minimum of 22.22°C occurred in several plots, supporting the observation that differences in crop management resulted in variation among the maximum soil temperatures rather than the minimum temperatures.[86] Tilling the site would have probably resulted in more significant differences among the treatments.[100]

In experiment II soil temperatures fluctuated more widely, in correspondence to the air temperatures. The highest temperatures reached, although not common and occurring for less than an hour apparently, were above the level optimal for maize growth. Soil temperatures above 35°C can damage the crop if occurring over much time or in early development.[59] The trend among those treatments studied was for treatment 7 (M21E120) to have higher temperatures than treatment 1 (M21). In Table 9 the difference in these treatments' maize growth is presented, with treatment 7 having lower biomass production up til the last sampling date at 93 days of maize growth. Although not significantly different, this trend supports the theory from the first experiment that the higher temperatures are more closely related to low crop production than to the amount of mulch cover. This is further supported by the trend for treatment 7 to have slightly higher moisture content in the soil in comparison to treatments 6 and 1. With lower production being the significant influence, less water would be taken up by the crop leaving higher moisture contents in the soil.

In the first experiment the soil moisture readings showed wider variation at any one date than did the temperatures (see Figure 4). Soil moisture averages are generally not as significant in humid areas but distribution problems can cause short term plant stress which would only be noted in more frequent readings. Weekly readings were not conclusive in terms of seasonal differences either. Those readings taken in experiment II were even more limited in representation of the actual dynamics of the soil moisture over time according to soil management.

Weed growth

Results in the earlier trial that no significant differences existed among the plots in terms of weed presence at the time of harvest do not indicate that mulches had no effect on the weed population. An earlier weed sampling at the critical growth period of the maize is needed to draw conclusions on the crop-weed competition. Presumably, however, the differences at the beginning of the experiment did not contribute significantly to variations in the maize yield.

Maize nutrition

The maize plants in the first trial had sufficient N (expressed as concentration) at physiological maturity, or between 1.2 and 1.3% N in the dry material.[54] Exceptions were treatment 3 (M30G30) and 12 (E60) which had plants with an average of 1.18% N concentration. Treatment 11 (E30) plants reached 1.38% N, surpassing the necessary concentration, but did not produce higher grain yields. The dry weight and N conent in the ears at physiological maturity seemed to relate more closely to the final outcome.

Because N nutrition is especially important for leaf area production at an early stage of maize development, periodic samples, as were taken in the second trial, would be more useful for identifying influences on the crop yield.[42] Indeed, the values from maize samples in experiment II do relate more closely to the yields that followed. The dry weight variations show little relationship but the N content and to a lesser extent the weighted average of N concentrations are reflected in the harvest. Yet this is true only for the first samples, particularly the sample taken at 52 days after the maize was planted which corresponds to the earliest flowering.

Other research has established that from 38 to 52 days after emergence the maize takes up around 30% of the season's total N assimilation. Excess N taken up at that time can be stored for later translocation but deficiencies can not always be compensated.[43,44] To the extent that distinct anatomical parts of the plant vary in their optimum N concentrations, the weighted average of N concentrations does not represent clearly the state of N nutrition after the earliest stage of development. The first sample, for example, was primarily leaves which should contain approximately 2% N in the dry weight at that time.

In fact, all samples did contain 2.00 % N or above. By the second sample, however, the stems which should contain only 1% N would have influenced the whole plant's average.[54] Averages did drop (see Table 12) with the N concentrations of stem samples ranging from 0.98 to 1.75% and of leaf samples from 2.20 to 3.04%. Care must be taken to obtain a representative sample since plant to plant variations related to slight differences in the growth environment can obscure or minimize nutritional differences.[12] These factors limit the applicability of such measurements to predict final yields.

Another manner of viewing the treatment variation is as percent efficiency in N recovery by the crop. In the first experiment this comparison is not possible without the presence of a control treatment with no application of N. It is noteworthy, however, that the amount of N in the maize in kg/ha varies between treatments which theoretically provided the same amount of N.

For instance, an increase in mineral N applied was closely reflected in the N recovered in the maize (M30 with 63.90 kg/ha versus M60 with 93.40). Increasing the mineral N by 30 or 60 kg N/ha of Gmelina, however, did not affect the N recovery as dramatically. At the highest levels (M60 G60) the combination actually caused a decrease in N recovery as compared to mineral N alone (M60).

The same depressing affect occurred with Erythrina (M60E30 compared to M60) although at the highest level (M60E60) the N recovery was unaffected by the mulch. For both types of mulch the best efficiency in N uptake by the crop occurred at the lowest levels (M30G30 and M30E30). This was the case for Erythrina alone as well. In fact, treatment II (E30) resulted in higher N uptake by the maize than did treatment I (M30). Since the highest values for maize N content are all similar, the maize may have been limiting the expression of further variation.[101]

The percent efficiency of N recovery is presented for experiment II in Table 14. In this case it becomes obvious that treatment 3 (E60), which resulted with only 0.006 kg N in the maize per kg N applied, has suffered some serious loss of nitrogen in the last stages of development which is also related to the low grain yields. Up to the last sample the average N recovery remained high with a recovery of 0.622 kg N/kg N applied, only two weeks earlier than that sample shown in the table. This sudden drop is concurrent with a high grain loss due to bird damage. One might speculate that the earlier, higher N content ears in plots with the E60 treatment were selected by the birds while other plots' ears were damaged less. No observation was made as to other factors such as the condition of the husks in relationship to Erythrina mulch, therefore this observation is not conclusive.

Values for the other treatment with mulch alone (E120) were also low, although this reflected a trend from earlier samples as well and was associated with the highest yield in that trial. Adding some mineral N (M21E120) did not significantly affect the efficiency in recovery of N but did produce a negative difference of almost 1 Mg/ha in grain yield. Highest N recovery resulted from combinations of mineral N with Erythrina (M10.5E30 and M21E60) which seems to confirm other researchers' conclusion when using Leucaena with maize[55], that mulch needed some mineral N input in order to substain high yields. The proportions are definitely important, however, because N from

TABLE 14. Efficiency of nitrogen recovery by maize at physiological maturity under various N fertilization managements. (4 reps, experiment II)*

TREATMENT (kg N/ha)	Kg N recovered/Kg N applied
1. Mineral 21	0.647
2. Mineral 42	0.966
3. Erythrina 60	0.006
4. Erythrina 120	0.176
5. Mineral 10.5 Erythrina 30	1.001
6. Mineral 21 Erythrina 60	0.986
7. Mineral 21 Erythrina 120	0.135

*N recovered is calculated by subtracting the N content in treatment 8 (control) maize from the N content of the other treatments (values in Table 10). This amount is then divided by the level of applied N to show the efficiency of recovery.

the mulch for example (M21E120) was not as readily available. Despite a relatively low efficiency of nitrogen recovery. Also mineral N appears to be more efficient in production of grain yields as seen in the case of treatment 1 (M21). These comparisons are based on the amounts of N applied in the different forms. Economic comparisons would reveal the mulch as the more efficient N source.

Although statistically significant differences did not result, final grain yields in experiment I were higher for plots with Erythrina alone than with ammonium nitrate alone (treatments 11 and 12 vs. 1 and 2). For combined sources of N, Gmelina mulch with mineral N related to higher production than did Erythrina with mineral N (comparing treatments 3-6 with 7-10) even though at the higher level of application Gmelina lost its advantage. All treatments resulted in relatively high yields compared to regional averages.

Differences were significant in the number and weight for the ears and their classification as commercial or non-commercial quality. In Nigeria the type of mulch applied affected the number of ears and the shelling per cent (grain weight per whole ear weight).[69] This effect occurred in the plots with Gmelina mulch which had lower grain yields than might be expected from the ear production because of higher moisture content in the grain and a lower shelling per centage. The advantages of a slower decomposing mulch could be diminished in a humid environment such as found in Turrialba.

Soil nitrogen

In experiment II the soil $N\text{-}NH_4$ and $N\text{-}NO_2$, $N\text{-}NO_3$ levels fluctuations, showed no clear pattern. Other investigators have encountered that changes in the $N-NH_4$ and $N-NO_2$ in the soil were minor. Fertilization affected the NO_3 values more, causing them to rise on a whole.[90] For maize the form of N is significant since with age and increased concentration of NO_3 in the soil, more NO_3 is absorbed relative to other forms.[94] Not all loss of NO_3 is due to plant absorption, however, and many of the other causes of loss would be the same for all forms of N (eg. leaching from heavy rainfall). Studies with Gliricidia sepium, another high N containing mulch source (3.3% N dry weight in leaves), showed an increase in all forms of N over a period of seven weeks in incubation. Field trials were not carried out, however.[99]

Mulch decomposition

The decomposition of the Erythrina was studied using the litter bag method which is the most accepted method even though it subestimates natural decomposition.[89] The method, therefore, could have contributed to the variation in the results. Further studies on this source of mulch are recommended because they would be applicable to many areas since the decomposition rate and pattern is less affected by soil types [39] and microclimate,[50] than by soil temperature regimes on a regional scale. Table 15 presents an extrapolation of the field data which suggests that only half of the N contained in the mulch was released by the time the maize ceased to accumulate N from the soil. This would explain the low recovery of N from mulch. The litter bag method tends to underestimate decomposition rates, however, so more studies are needed before forming a recommendation regarding the best date for mulch application.

Several factors are presented in Figure 6: N in the crop, N released from the mulch, N levels in the soils and rainfall. The N released from the Erythrina

TABLE 15. Erythrina decomposition values extrapolated

Sample	Days after application	N content remaining* (as % of calculated initial content)	N released** at 60 kg N/ha (kg/ha)	Rate of N release at 60 kg N/ha (kg/ha/day)
at application	0	(93.3)	(9.61)	--
1	4	117.4	-10.44	-2.61
2	9	91.3	5.22	3.13
3	13	99.6	0.24	-1.25
4	17	73.4	15.96	3.93
5	21	80.5	11.70	-1.06
6	28	61.7	22.98	1.61
7	38	59.6	24.24	0.13
8	46	54.9	27.06	0.35
9	62	54.6	27.24	0.01
10	78	40.9	35.46	0.51

*N content is calculated as % N x dry weight of material remaining in the bags at the corresponding collection date, divided by the N content, as above, but at the time of application according to earlier analysis of foliage samples.

**N released is (100-% of initial)[previous column] multipled by 60 for a hypothetical equivalence. Dividing these values by days between sampling gives the rate of N release.

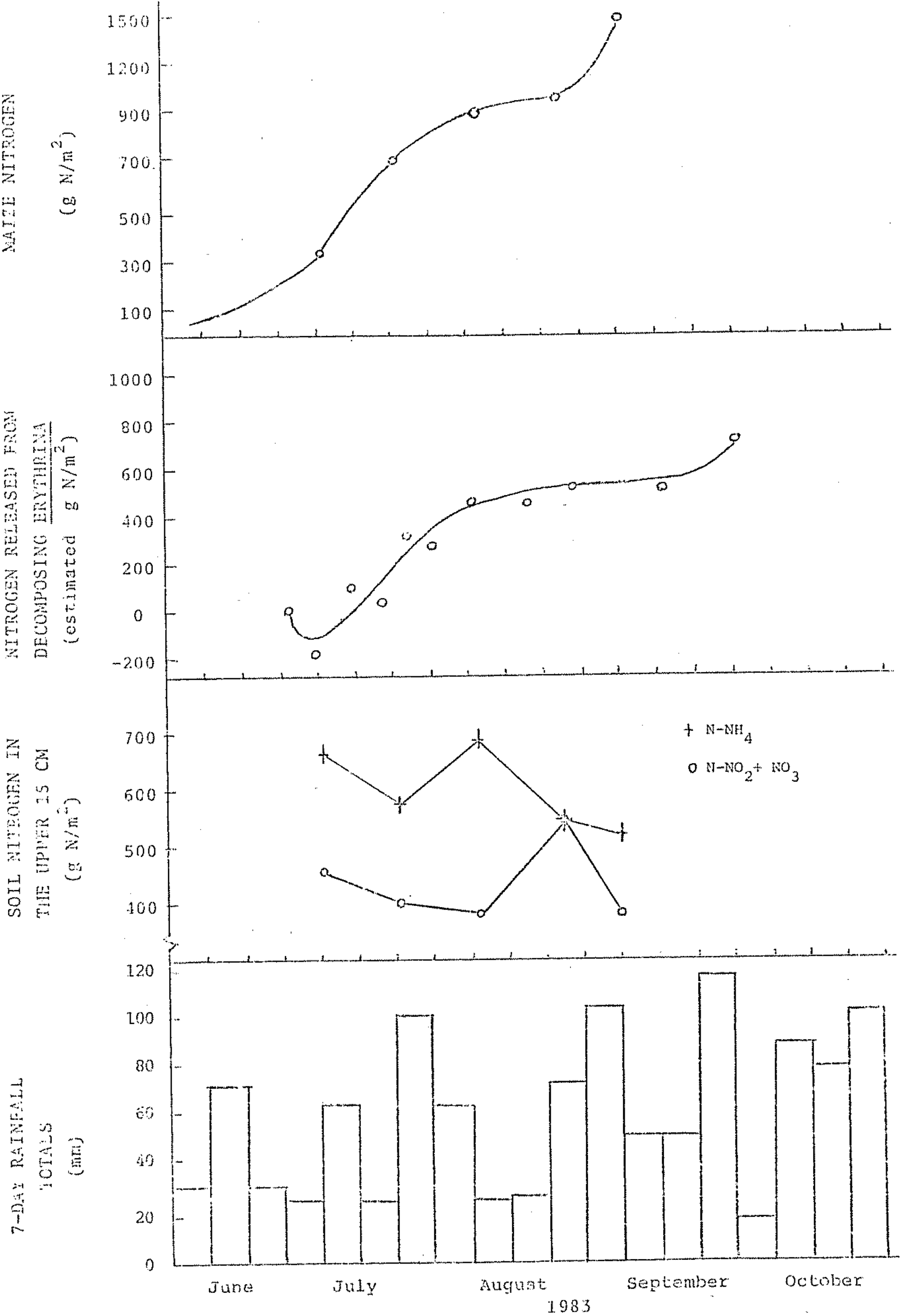

FIGURE 6. NITROGEN FLUCUTATIONS FOR A MAIZE CROP MULCHED WITH <u>ERYTHRINA</u> IN TURRIALBA, COSTA RICA. (APPLIED AT 120 KG N/HA)

mulch does not relate directly to the sequential N-NH_4 and N-NO_2+ NO_3 levels encountered in the extracted soil solution. Neither do the soil nitrogen values clearly indicate what content of N would be expected to result in the maize tissue samples. Whether these relationships are obscured by the passage of time between measurements or by other factors influencing the N balance, such as the rain fall intensity or leaching, which were not measured, cannot be determined without further studies. Presumably part of the N released by the mulch is absorbed by microorganisms which would initially lower the soil N levels before contributing to the available N through decomposition of the mulch as well as already present organic material. Since N levels were sufficiently high in the control plot's soil to allow for high maize yields, it is difficult to conclude what additional N was actually being supplied and from what source. Data from this study only begins to reveal the complexity of the maize-mulch system and its nitrogen balance.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

1. High maize yields, statistically similar to those resulting with the application of mineral nitrogen, occurred when Gmelina arborea or Erythrina poeppigiana mulch was also applied.

2. Other soil factors, principally temperatures and moisture contents, were associated with the plant growth rather than directly with the amount of mulch applied.

3. Erythrina mulch, applied after a month of maize growth, experienced rapid decomposition and N loss yet retained as much as half of the original amount of N when the maize had already passed maturity and presumably was no longer assimilating N.

4. High initial levels of N and organic matter in the Experimental Station's soil probably obscured any potentially significant differences in relation to the various N levels and sources.

5. Periodic maize N contents were most representative of the final grain yields, especially values taken early in the crop's development.

6. Grain yield differences were due primarily to the number and weight of ears considered non-commercial rather than to any wide difference among total production values.

Recommendations

1. Carry out similar studies in nutrient poor soils and under varying climatic conditions, on farms if possible.

2. Test higher levels of mulches, continuing to consider several possible limiting factors to the crop yields (e.g. N supply, moisture stress, weed competition).

3. Include simple decompostion studies in mulching trials and quantify the influence of changing the mulch application date in relation to the crop's planting date and the season.

4. Limit measurements to those of the biological indicator or increase the dependent variables to be measured to provide a more complete representation of the N cycle, including leaching, soil mineralization potential, microbiological activity and N volatization measurements.

5. Observe causes of ear quality loss and quantify any relationship to N levels or sources.

6. Include economic equivalents of labor involved in mulching to compare with fertilizer costs and differences in market value of final yields.

7. Encourage small-scale producers of traditional annual crops to adopt mulching as a management practice while improving domestic marketing and price scales.

LITERATURE CITED

1. AGUIRRE, V. Estudio de los suelos del área del Centro Tropical de Enseñanza e Investigación. IICA-Turrialba, Costa Rica. Mag. Sc. thesis, Turrialba, Costa Rica, IICA-CTEI, 1971. 139 p.

2. AINA, P. O. Effects of time and duration of mulching on maize (Zea mays L.) in Western Nigeria. Field Crops Research 4:25-32. 1981.

3. ALEXANDER, M. A. Introduction to soil microbiology. 2nd ed. N. Y., Wiley, 1977. 467 p.

4. ALKÄMPER, J. The influence of weeds on the yield of tropical crops. Plant Research and Development 9:127-137. 1979.

5. ALPIZAR, L., ENRIQUEZ, G. FASSBENDER, H. W. and HEUVELDOP, J. Estudio de sistemas agroforestales en el Experimento Central de CATIE, Turrialba. II. Producción agrícola y maderable. Turrialba, Costa Rica, CATIE-INFORAT, 1983. 26 p.

6. ANGERN, M. Survey and measurements; consumption of firewood on samll farms. Turrialba, Costa Rica, CATIE-GTZ. 1984. 7 p.

7. ARAYA V., R. Control químico y físico de malas hierbas en tomate (Lycopersicon esculentum M.). Ing. Agr. thesis, San José, Costa Rica, UCR. 1976. 60 p.

8. ARNON, I. Mineral nutrition of maize. Bern-Worblaufen, Switzerland, Intl. Potash Institute, 1975. 452 p.

9. BARLETT, P. F. Agricultural choice and change: decision making in a Costa Rican community. New Brunswick, N. J., Rutgers Press, 1982. 189 p.

10. BEER, J. Erythrina poeppigiana con pasto. Turrialba, Costa Rica, CATIE-INFORAT, 1980. 4 p.

11. BENAVIDES, J. E. Investigación en árboles forajeros. In Curso Corto Intensivo Técnicas Agroforestales. Turrialba, Costa Rica, CATIE, Natural Renewable Resources Department, 1983. irreg. p.

12. BENOIT, G. R., HATFIELD, A. L. and RAGLAND, J. L. The growth and yield of corn. III. Soil moisture and temperature effects. Agron. J. 57:223-226. 1965.

13. BORCHERT, R. Phenology and ecophysiology of tropical trees; Erythrina poeppigiana O. F. Cook. Ecology 61(5):1065-1074. 1980.

14. BREMNER, J. M. Exchangeable ammonium, nitrate, and nitrite by steam distillation methods. In Black, C. A., ed. Methods of soil analysis. Madison, WI., Am. Soc. Agron., 1965. pp. 1191-1206.

15. ________. Total nitrogen. In Black, C. A., ed. Methods of soil analysis. Madison, WI., Am. Soc. Agron., 1965. pp. 1149-1178.

16. BRONSTEIN, G. E. Producción comparada de una pastura de Cynodon plectostachyus asociado con árboles de Cordia alliodora, con árboles de Erythrina poeppigiana y sin árboles. Mag. Sc. thesis, Turrialba, Costa Rica, UCR-CATIE, 1984. 109 p.

17. BULL, R. A. Effects of mulching on some East African coffee soils. Turrialba 13:22-27. 1963.

18. BURROWS, W. C. and LARSON, W. E. The effect of the amount of mulch on soil temperature and early growth of corn. Agron. J. 54:19-23. 1962.

19. CADIMA R., A. and ALVIM, P. de T. Infuencia del árbol de sombra Erythrina glauca sobre algunos factores edafológicos relacionados con la producción del cacaotero. Turrialba 17(3):330-336. 1967.

20. CENTRO INTERNACIONAL DE MEJORAMIENTO DE MAIZ Y TRIGO. World maize facts and trends; report one: an analysis of changes in production, consumption, trade, and prices over the last two decades. Mexico, D. F., CIMMYT, 1981. 31 p.

21. ________. Adiestramiento en maíz experimentos fuera de la estación; 1982 B. Mexico, D. F., CIMMYT, 1982. 36 p. + appendices.

22. COEN, E. Zonas potenciales del cultivo del maíz y épocas de siembra en Costa Rica, UCR, 1968. 26 p. Serie agronomía N° 9.

23. COMBE, J. Agroforestry techniques in tropical countries; potential and limitations. Agroforestry Systems (Netherlands) 1:13-27. 1882.

24. DAVIES, J.W. Mulching effects on plant climate and yield. Geneva, Switzerland, World Meteorological Organization, 1975. 92 p.

25. DIAZ ROMEU, R. and HUNTER, A. Metodología de análisis de suelos y tejido vegetal e investigaciones de invernadero. Turrialba, Costa Rica, CATIE-Proyecto Centroamericano de Fertilidad de Suelos, 1978. 62 p.

26. ENRIQUEZ, G.A. Breve resumen del Experimento Central de plantas perennes de La Montaña, CATIE, Turrialba, Costa Rica. Turrialba, Costa Rica, CATIE, 1983. 13 p.

27. ESPINOZA B., J.E. Caracterización nutritiva de la fracción nitrogenada de Madèro Negro Gliricidia sepium y Poró Erythrina poeppigiana. Mag. Sc. thesis, Turrialba, Costa Rica, UCR-CATIE, 1984. 90 p.

28. FAULKNER, E.H. Plowman's folly. Norman, Oklahoma, U. of Oklahoma Press, 1943. 161 p.

29. FERNANDEZ V., S. Comportamiento inicial de Gmelina arborea Roxb. asociado con maíz (Zea mays L.) y frijol (Phaseolus vulgaris L.) en dos espaciamentos en Turrialba, Costa Rica. Mag. Sc. thesis, Turrialba, Costa Rica, UCR-CATIE, 1978. 125 p.

30. FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS. Trade yearbook 1966. v.20. Rome, FAO, 1967. 461 p.

31. ________. Production yearbook 1970. v.24. Rome, FAO, 1971. 822 p.

32. ________. Production yearbook 1980. v.34. Rome, FAO, 1981. 264 p.

33. ________. Production yearbook 1982. v.36. Rome, FAO, 1983. 320 p.

34. ________. Trade yearbook 1982. v.36. Rome, FAO, 1983. 366 p.

35. GAMBOA, J., PAEZ, G. and BLASCO, M. Un modelo para describir los procesos de retención y lixiviación en los suelos. Turrialba 21(3):312-316. 1971.

36. GETAHUN, A. Increasing food production in the agro-forestry systems of the humid tropical lowlands. IITA Research Briefs (Ibadan) 2(3):2-7. 1981.

37. GLOVER, N. Coffee yields in a plantation of Coffea arabica var. caturra shaded by Erythrina poeppigiana with and without Cordia alliodora. Turrialba, Costa Rica, CAITE, Serie técnica, Inf. técnico N° 17, 1981. 26 p.

38. GONZALEZ, L. E. Efecto de la asociación de Laurel (Cordia alliodora (Ruiz y Pav.) Oken) sobre producción de café (Coffea arabica L.) con y sin la sombra de Poró (Erythrina poeppigiana (Walpers) O. F. Cook). Mag. Sc. thesis, Turrialba, Costa Rica, UCR-CATIE, 1981. 110 p.

39. GONZALEZ, M. A. and SAUERBECK, D. R. Decomposition of ^{14}C-labeled plant residues in different soils and climates of Costa Rica. In Colóquio Regional sobre Matéria Orgânica do Solo, Piracicaba, Brazil, 1982. Proceedings. Piracicaba, Brazil, CENA, 1982. pp. 141-146.

40. GREENLAND, D. J. Nitrate fluctuations in tropical soils. J. Agric. Sci. 50:82-92. 1958.

41. GURNAH, A. M. and MUTEA, J. Effect of mulches on soil temperature under arabica coffee at Kabete, Kenya. Agric. Meteorology 25(4):237-244. 1982.

42. HANWAY, J. J. Corn growth and composition in relation to soil fertility. II. Uptake of N, P and K and their distribution in different plant parts during the growing season. Agron. J. 54:217-222. 1962.

43. HARDY, F. Seasonal fluctuations of soil moisture and nitrate in a humid tropical climate (Trinida, BWI). Trop. Agric. (Trinidad) 23(3):40-49. 1946.

44. HAWKINS, R. C. and COOPER, P. J. M. Growth, development and grain yield of maize. Expl. Agric. 17:203-207. 1981.

45. HAYMAN, D. S. Phosphorus cycling by soil micro-organisms and plant roots. In Walker, N. Soil microbiology; a critical review. N. Y., Wiley 1975. 262 p.

46. HOLDRIGE, L. R. Ecología basada en zonas de vida. Trad. H. Jiménez-Saa. San José, Costa Rica, IICA, 1978. 216 p.

47. IBADAN, NIGERIA. INTERNATIONAL INSTITUTE OF TROPICAL AGRICULTURE. Annual report 1980. Ibadan, 1980. pp. 36-43.

48. JACKS, G. V., BRIND, W. D. and SMITH, R. Mulching. Farnham Royal, England, Commonwealth Agricultural Bureaux, Tech. Comm. 49, 1955. pp. 7-87.

49. JACOBSONH, R., GREENBERGER, A., KATAN, J., LEVI, M. and ALON, H. Control of Egyptian Broomrape (Orobanche aegyptiaca) and other weeds by means of solar heating of the soil by polyethylene mulching. Weed Sci. 28(3):312-316. 1980.

50. JENNY, H., GESSEL, S. P. and BINGHAM, F. T. Comparative study of decomposition rates of organic matter in temperature and tropical regions. Soil Sci. 68:419-432. 1949.

51. JOACHIM, A. W. R. The principles of green manuring and their application in Ceylon. Trop. Agriculturalist (Sri Lanka) 76:4-32. 1931.

52. JOHNSON, C. M. and ULRICH, A. Analytical methods for use in plant analysis. California Exp. Station. Bull. N° 766. 1959. pp. 28-45.

53. JONES, G. H. G. The effect of leguminous cover crops in building up soil fertility. E. Africa J. 8:48-52. 1942.

54. JORDAN, H. V., LAIRD, K. D. and FERGUSON, D. D. Growth yields and nutrient uptake by corn in a fertilizer-spacing experiment. Agron. J. 42(6):261-268. 1950.

55. KANG, B. T., GRIME, H. and LAWSON, T. L. Alley cropping sequentially cropped maize and cowpea with Leucaena on a sandy soil in Southern Nigeria. Plant & Soil (in press). 1985.

56. KASS, D. L. Vegetables suitable for association with subsistence maize and beans in the highlands of Guatemala. Turrialba, Costa Rica, CATIE, 1981. 26 p. Presented in: Cong. Anual de Soc. Am. de Ciencias Hort., 29th, Campinas, Brazil, 1981.

57. ________, RUSSO, R. and QUINLAN, M. Leguminous trees as nitrogen sources for annual crops. Agron. Abstracts 1983:45.

58. KUIPERS, H. Introduction; historical notes on the zero tillage concept. Netherlands J. Agric. Sci. 18:219-224. 1970.

59. LAL, R. Soil temperature, moisture and maize yield from mulched and unmulched tropical soils. Plant and Soil 40:129-143. 1974.

60. ________. Influence of within-and between-row mulching and soil temperature, soil moisture, root development and yield of maize (Zea mays L.) in a tropical soil. Field Crop Research 1:127-139. 1978.

61. LAMB, A. F. A., comp. Fast growing timber trees of the lowland tropics; 1. Gmelina arborea. Oxford, Commonwealth Forestry Institute, 1968. 31 p.

62. LOWDERMILK, W. C. Conquest of the land through seven thousand years. U.S. Department of Agriculture. Agric. Info. Bull. N° 99. 1953. 30 p.

63. MULLER, L. Un aparato micro-Kjeldahl simple para análisis rutinarios rápidos de materiales vegetales. Turrialba 11(1):17-25. 1961.

64. NICHOLAIDES III, J. J., COUTS, W. and WADE, M. K., eds. Agronomic-economic research on soils of the tropics; 1980-81 technical report. Raleigh, N. C., N. C. State U., 1983. 139 p.

65. NUNTAPONG, S. Analysis of testplot experiments at Huai Thung Choa, Northern Thailand, for the year 1981. Chiengmai U., 1982. 27 p.

66. NYE, P. H. and GREENLAND, D. J. The soil under shifting cultivation. Farnham Royal, England, Commonwealth Agric. Bureaux, 1960. 156 p.

67. OJENIYI, S. O., AGBEDE, O. O. and FAGBENRO, J. A. Increasing food production in Nigeria. 1. Effect of agrisilviculture on soil chemical properties. Soil Sci. 130(2):76-82. 1980.

68. OKAJIMA, H. and TANIYAMA, J. Significance of mass flow in nitrate-nitrogen supply to plant roots. Soil Sci. and Plant Nutri. 26(3): 363-374. 1980.

69. OKIGBO, B. N. Essaís sur le maïs dans la plaine de Nsukka (Nigeria). III. Les effets de differentes sortes de mulch sur le rendement du maïs en climat tropical humide. L'Agronomie Tropicale 27(10):1036-1047. 1972.

70. OLADOKUN, M. A. O. Legume cover crops, organic mulch and associated soil conditions, and plant nutrient content for establishing Quillou coffee. Hortscience 15(3):305-306. 1980.

71. OLSON, T. C. and HORTON, M. L. Influence of early, delayed and no mulch residue management on corn production. Soil Sci. Soc. Am. Proc. 39: 353-356. 1975.

72. OSINAME, O., VAN GIJN, H. and VLEK, P. L. G. Effect of nitrification inhibitors on the fate and efficiency of nitrogenous fertilizers under simulated humid tropical conditions. Trop. Agric. (Trinidad) 60(3): 211-216. 1983.

73. PARKER, D. T. Influence of mulching on the Manganese content of corn plant tissue. Agron. J. 54:303-305. 1962.

74. PEDRAZA, R. La fertilidad del suelo agrícola, su defensa, restauración y conservación. Agric. Trop. (Colombia) 4(7):49-52. 1948.

75. PIETERS, A. J. Green manuring; a review of the American experiment station literature. J. Am. Soc. Agron. 9:62-82, 109-126, 162-190. 1917.

76. ________. Green manuring; principles and practices. N. Y., Wiley 1927. 356 p.

77. PLUCKNETT, D. L., RICE, E. J., BURRILL, L. C. and FISHER, H. H. Approaches to weed control in cropping systems. In Symposium on cropping systems research and development for the Asian rice farmer, Los Baños, Philippines, IRRI, 1976. Proceedings. Los Baños, Philippines, IRRI, 1977.

78. POPENOE, H. Symposium; legumes in tropical agriculture. Soil and Crop Sci. Soc. Florida Proc. 27:322-366. 1967.

79. RAINTREE, J. B. and TURAY, F. Linear programming model of an experimental Leucaena-rice alley cropping system. IITA Research Briefs (Ibadan) 1(4):5-7. 1980.

80. ROBINSON, J. B. D. and HOSEGOOD, P. H. Effects of organic mulch and fertility of a latosolic coffee soil in Kenya. Expl. Agric. 1:67-80. 1965.

81. RUSSO, R. O. Efecto de la poda de Erythrina poeppigiana (poró) sobre la nodulación en el suelo en un sistema agroforestal "café-poró". Mag. Sc. thesis, Turrialba, Costa Rica, UCR-CATIE, 1983. 106 p.

82. SAIZ DEL RIO, J. F. and BORNEMISZA, E. Análisis químico de suelos, métodos de laboratorio para diagnóstico de fertilidad. Turrialba, Costa Rica, IICA, 1971. 107 p.

83. SANCHEZ, P. A. Suelos del trópico; características y manejo. Trad. E. Camacho. San José, Costa Rica, IICA, 1981. 634 p.

84. ________, VILLACHICHA, J. H. and BANDY, D. E. Soil fertility dynamics after clearing a tropical rainforest in Peru. Soil Sci. Soc. Am. J. 47(6):1171-1178. 1983.

85. SANTANA, M. B. M. and CABALA R., P. Dynamics of nitrogen in a shaded cacao plantation. Plant and Soil 67:271-281. 1981.

86. SHENG, T. C. Erosion problems associated with cultivation in humid tropical hilly regions. In American Society of Agronomy and Soil Science Society of America. Soil erosion and conservation in the tropics. Madison, WI, Am. Soc. Agron. 1982. pp. 27-39.

87. SHERMAN, G. D. and FUJIMOTO, C. K. The effect of the use of lime, soil fumigants, and mulch on the solubility of Manganese in Hawaiian soils. Soil Sci. Soc. Am. Proc. 11:206-215. 1946.

88. SHIELDS, J. T., AHRENS, C. L. and TATUM, H. B. Appraisal of fertilizer markets and distribution system in Central America; with emphasis on small farmers. Muscle Shoals, Alabama, Natl. Fert. Dev. Center, 1974. 114 p.

89. SIGHN, J. S. and GUPTA, S. R. Plant decompositon and soil respiration in terrestrial ecosystems. The Botanical Review 43(4):449-528. 1977.

90. SMITH, S. J. and YOUNG, L. B. Distribution of nitrogen forms in virgin and cultivated soils. Soil Sci. 120:354-360. 1975.

91. SOLANO, R. A. Aporte de nitrógeno por Leucaena al Napier en cultivo asociado. In ROCAP-ICTA-CATIE. Proyecto Sistemas de Prod. para Pequeñas Fincas, Annual report 1983. Guatemala, 1984. 47 p.

92. ________. El sistema de cultivo sorgo-Leucaena en asociación para la producción de grano y forraje. In ROCAP-ICTA-CATIE. Proyecto Sistemas de Prod. para Pequeñas Fincas, Annual report 1983. Guatemala, 1984. 47 p.

93. SPAGUE, E. W. Improving maize production in Latin America. Mexico, D.F., CIMMYT, 1981. 10 p. Presented in: Latin Am. Food Prod. Conf., 17th, 1981, Santiago, Chile.

94. STEWARD, F. C. and DURZAN, D. J. Metabolism of nitrogenous compounds. In Steward, F. C., ed. Plant physiology; IV. A. Metabolism organic nutrition and nitrogen nutrition. N. Y., Academic Press, 1976. 717 p.

95. SWIFT, M. J., HEAL, O. W. and ANDERSON, J. M. Decomposition in terrestrial ecosystems. Berkley, U. of Calif. Press, 1979. 372 p.

96. TURNER II, B. L. Prehistoric intensive agriculture in the Mayan lowland. Science 185:118-185. 1974.

97. DEPARTMENT OF AGRICULTURE. Report and recommendations on organic farming. Washington, D. C., U.S.D.A., 1980. 94 p.

98. VAN WIJK, W. R., LARSON, W. E. and BURROWS, W. C. Soil temperature and early corn growth of corn from mulched and unmulched corn. Soil Sci. Soc. Am. Proc. 23:428-434. 1959.

99. WEERARATNA, C. S. Pattern of nitrogen release during decomposition of some green manures in a tropical alluvial soil. Plant and Soil 53: 287-294. 1979.

100. WIERENGA, P. J., NIELSEN, D. R., HORTON, R. and KIES, B. Tillage effects on soil temperature and thermal conductivity. In American Society of Agronomy and Soil Science Society of America. Predicting tillage effects on soil physical properties and processes. Madison, WI, 1982. pp. 69-90.

101. YAMAGUCHI, J. Varietal traits limiting the grain yield of tropical maize. IV. Plant traits and productivity of tropical varieties. Soil Sci. and Plant Nutri. 20(3):287-304. 1974.

APPENDIX

TABLE A1. Meteorological Data for the Experimental Area.

MONTH	Temperature (°C) mean max.	mean min.	absolute avg.	absolute max.	absolute min.	Precipitation (mm) monthly	avg. # days 0.1mm or more
January	25.7	16.4	20.5	31.0	10.0	169.8	18.4
February	26.0	16.4	20.6	30.5	10.4	133.4	15.1
March	26.9	17.0	21.4	31.5	10.5	78.2	13.6
April	27.2	17.7	21.9	31.7	11.8	122.4	15.1
May	27.9	18.6	22.5	32.0	13.5	227.2	23.0
June	27.7	18.8	22.4	31.5	15.2	282.4	22.1
July	27.1	18.6	22.0	31.5	14.1	279.7	25.4
August	27.4	18.4	22.1	30.2	14.9	242.4	24.5
Septemper	27.7	18.3	22.2	30.8	14.8	246.6	22.8
October	27.4	18.3	22.1	31.0	14.5	254.1	22.2
November	26.4	18.1	21.5	32.0	13.7	278.1	22.1
December	25.7	17.1	20.7	29.9	10.6	322.4	21.5
TOTAL	—	—	—	—	—	2636.7	245.8
MEAN	26.9	17.8	21.7	—	—	219.7	20.5
YEARS	1959-1983 (25)					1944-1984 (42)	

	Sunlight (hrs.)	Monthly radiation (cal/cm)	Relative humidity (%)	Monthly evapotranspiration (mm)
TOTAL:	—	153,255	—	1,193.7
MEAN	4.6	12,771	87.5	99.5
YEARS:	1959-1983 (27)	1965-1983 (19)	1957-1983 (25)	1968-1983 (16)

*Prepared by F. Jiménez O., and R. Salas D., Meteorological Station, Crop Production Department, CATIE.

TABLE A2. Methods used in analysis of soils and plant tissue for both experiments.

SOIL	
Total N	Bremmer, 1965 a, personnal communication, Díaz-Romeu, CATIE*
Organic Matter	Saiz del Rio and Bornemisza, 1971
P, K, Ca, Mg, Microelements, pH Extractable acidity	Díaz-Romeu and Hunter, 1978
PLANT TISSUES	
Nitrogen	Müller, 1961
Microelements	Díaz-Romeu and Hunter, 1978
P, K, Ca, Mg	Johnson and Ulrich, 1959

*Method described by Bremmer, 1965a, modified as explained:

Recommended 2ml. of H_2O was not added; input of acid was raised from 3 ml to 5 ml; digestion was carried out for 2 hours rather than the recommended 5. These modifications are based on a series of tests to assure that they do not influence results.

TABLE A3. Average weekly soil temperature readings in °C using nylon resistance cells at 15 cm depth (2 reps, exp I.)*.

Date	Treatment:	2 M60	4 M60G30	6 M60G60	8 M60E30	10 M60E60	12 E60
12/11/82		-	22.22^{c}	22.22^{c}	-	22.78^{b}	24.44^{a}
18/11/82		23.89^{ab}	24.17^{ab}	23.33^{b}	24.17^{ab}	24.44^{a}	23.89^{ab}
26/11/82		23.33^{a}	23.33^{a}	22.96^{a}	23.33^{a}	23.89^{a}	23.33^{a}
3/12/82		24.72^{a}	24.72^{a}	23.52^{a}	24.72^{a}	24.72^{a}	24.72^{a}
10/12/82		23.61^{a}	24.17^{a}	22.96^{a}	23.61^{a}	24.44^{a}	23.89^{a}
17/12/82		23.33^{a}	23.33^{a}	22.59^{a}	23.06^{a}	23.61^{a}	23.33^{a}
24/12/82		24.44^{a}	23.89^{a}	23.33^{a}	23.89^{a}	24.44^{a}	24.17^{a}
31/12/82		23.06^{a}	22.78^{a}	22.59^{a}	23.06^{a}	23.06^{a}	23.06^{a}
7/1/83		25.28^{a}	25.56^{a}	24.07^{a}	24.72^{a}	26.39^{a}	25.00^{a}
14/1/83		23.33^{a}	22.78^{a}	22.22^{a}	22.78^{a}	23.33^{a}	22.78^{a}
21/1/83		26.94^{a}	26.11^{a}	25.56^{a}	25.83^{a}	27.78^{a}	25.00^{a}
28/1/83		24.17^{a}	23.33^{a}	23.89^{a}	23.61^{a}	24.17^{a}	22.78^{a}
4/2/83		23.89^{ab}	23.06^{b}	24.44^{a}	23.61^{ab}	23.61^{ab}	22.78^{b}
11/2/83		23.89^{a}	23.33^{a}	22.22^{a}	23.61^{a}	24.44^{a}	23.06^{a}
18/2/83		26.11^{a}	26.67^{a}	27.04^{a}	25.83^{a}	26.67^{a}	24.44^{a}

*Values reading across, followed by the same letter do not differ significantly at $\alpha = 0.05$ using Duncan's Multiple Range Test. Data converted from °F to °C.

TABLE A4. Average weekly soil moisture content readings in per cent using nylon resistance cells at 15 cm depth (2 reps., exp. I)*

Date	Treatments:	2 M60	4 M60G30	6 M60G60	8 M60E30	10 M60E60	12 E60
12/11/82		-	35.50	44.25	-	35.00	35.00
18/11/82		34.75[a]	33.90[a]	35.83[a]	33.45[a]	43.00[a]	36.00[a]
26/11/84		34.50[a]	41.00[a]	44.00[a]	32.50[a]	46.90[a]	29.75[a]
3/12/82		34.60[a]	33.00[a]	33.67[a]	32.50[a]	41.75[a]	34.00[a]
10/12/82		36.75[a]	34.50[a]	39.50[a]	41.25[a]	43.00[a]	36.50[a]
17/12/82		37.10[a]	34.50[a]	36.50[a]	34.15[a]	43.00[a]	39.50[a]
24/12/82		36.90[a]	34.50[a]	34.77[a]	33.85[a]	43.00[a]	34.75[a]
31/12/82		45.00[a]	35.00[a]	40.67[a]	38.90[a]	47.50[a]	49.75[a]
7/1/83		38.00[a]	35.00[a]	37.00[a]	34.75[a]	43.00[a]	36.50[a]
14/1/83		41.90[a]	34.50[a]	37.67[a]	34.55[a]	35.00[a]	36.10[a]
21/1/83		37.75[a]	34.00[ab]	34.67[ab]	33.50[b]	34.50[ab]	34.25[ab]
28/1/83		34.00[a]	32.00[ab]	32.67[ab]	31.05[b]	33.75[ab]	33.00[ab]
4/2/83		32.00[a]	20.00[b]	26.83[ab]	20.00[b]	26.00[ab]	28.50[ab]
11/2/83		31.50[a]	27.00[a]	23.67[a]	26.00[a]	20.00[a]	30.25[a]
18/2/83		33.60[a]	34.00[a]	32.67[a]	16.00[a]	33.50[a]	31.50[a]

*Values, reading across, followed by the same letter do not differ significantly at $\alpha = 0.05$ using Duncan's Multiple Range Test.

TABLE A5. Matrices for Orthogonal Contrast Analysis

Experiment I

CONTRAST	TREATMENT											
	1	2	3	4	5	6	7	8	9	10	11	12
1. Mineral *vs.* none	+1	+1	+1	+1	+1	+1	+1	+1	+1	+1	−5	−5
2. None: high *vs.* low N	0	0	0	0	0	0	0	0	0	0	+1	−1
3. Mineral: highs *vs.* low N	−1	+1	−1	+1	−1	+1	−1	+1	−1	+1	0	0
4. Low mineral: mulch *vs.* without	−4	0	+1	0	+1	0	+1	0	+1	0	0	0
5. Low mineral: Gmelina *vs.* Erythrina mulch	0	0	−1	0	−1	0	+1	0	+1	0	0	0
6. Low mineral: Erythrina high *vs.* low N	0	0	0	0	0	0	−1	0	+1	0	0	0
7. Low mineral: Gmelina high *vs.* low N	0	0	−1	0	+1	0	0	0	0	0	0	0
8. High mineral: mulch *vs.* without	0	−4	0	+1	0	+1	0	+1	0	+1	0	0
9. High mineral: Gmelina *vs.* Erythrina mulch	0	0	0	−1	0	−1	0	+1	0	+1	0	0
10. High mineral: Erythrina *vs.* low N	0	0	0	0	0	0	0	−1	0	+1	0	0
11. High mineral: Gmelina high *vs.* low N	0	0	0	−1	0	+1	0	0	0	0	0	0

TABLE A5. (continued)

EXPERIMENT II.

CONTRAST	TREATMENT							
	1	2	3	4	5	6	7	8
A) 1. Mulch *vs.* no mulch	−5	−5	+3	+3	+3	+3	+3	−5
2. Mulch: high *vs.* low N	0	0	−1	+1	0	−1	+1	0
3. Mulch: high N with *vs.* without mineral	0	0	0	−1	0	0	+1	0
4. Mulch: low N with *vs.* without mineral	0	0	−1	0	0	+1	0	0
5. No mulch: high *vs.* low N	+1	−1	0	0	0	0	0	0
6. Mulch *vs.* M10.5E30	0	0	+1	+1	−4	+1	+1	0
7. No mulch: mineral *vs.* without	+1	+1	0	0	0	0	0	−2
B) 1. Total N: high *vs.* low	−1	+1	−1	+1	−1	+1	0	0
2. Low total N: one source *vs.* mix	−1	0	−1	0	+2	0	0	0
3. High total N: one source *vs.* mix	0	−1	0	−1	0	+2	0	0
4. Low total N: mineral *vs.* mulch	+1	0	−1	0	0	0	0	0
5. High total N: mineral *vs.* mulch	0	+1	0	−1	0	0	0	0
6. Total N: 141 *vs.* 0	0	0	0	0	0	0	+1	−1
7. Total N: medium *vs.* extremes	+1	+1	+1	+1	+1	+1	−3	−3
C) 1. Mineral *vs.* none	−3	−3	+5	+5	−3	−3	−3	+5
2. Mineral: 21 *vs.* 42	−1	+1	0	0	0	−1	+1	0
3. M42 *vs.* M21E120	0	−1	0	0	0	0	+1	0
4. M21 *vs.* M21E60	−1	0	0	0	0	+1	0	0
5. Erythrina alone *vs.* control	0	0	−1	−1	0	0	0	+2
6. Erythrina 60 *vs.* 120	0	0	−1	+1	0	0	0	0
7. Mixed sources: higher *vs.* lowest N	−1	−1	0	0	+4	−1	−1	0