THE EFFECT OF MANAGEMENT OF *CROTALARIA JUNCEA* GREEN MANURE ON THE YIELD AND NITROGEN UPTAKE OF MAIZE

A THESIS SUBMITTED TO THE GRADUATE DIVISION OF THE
UNIVERSITY OF HAWAII IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF SCIENCE

IN AGRONOMY AND SOIL SCIENCE

DECEMBER 1981

by

Dale Ordway Evans

Thesis Committee:

Peter P. Rotar, Chairman
James L. Brewbaker
Yoshinori Kanehiro
Russell S. Yost

We certify that we have read this thesis and that in our opinion it is satisfactory in scope and quality as a thesis for the degree of Master of Science in Agronomy.

THESIS COMMITTEE

Peter P. Rotar
Chairman

James L. Brewbaker

Yoshinori Kanehiro

Russell Yost

ACKNOWLEDGMENTS

I would like to express my gratitude to those members of the Department of Agronomy and Soil Science whose concern and support enabled me to bring my degree program to a completion. Dr Peter Rotar persevered with me as I found my way, helped when support was needed, encouraged and admonished me along. Dr Russell Yost was very helpful with details and problems of the conduct and interpretation of the experiment. The considerable effort that they both applied to reviewing and criticizing the manuscript drafts is very much appreciated. Dr Kanehiro allowed me the use of his laboratory and showed his concern for me as the Graduate Program Chairman. Dr Brewbaker's succinct advice was often useful. Dr Samir El-Swaify was GPC at the time I applied to the Department, and acted as my interim advisor. Dr Rolly Jones has been supportive in a number of ways in matters ranging from the mundane to patient explanations of the arcane. Dr James Walker was a special source of inspiration and encouragement. I am grateful to these men not only for their support in their professional capacities but for their personal kindnesses and friendships.

Others who provided valuable assistance to me on various aspects of this thesis project were Mr Oshiro, Mr Nakatani, Ernest Okazaki, and Dawn Oshima of the Department; Mr Waki, Herbert Omizo, their staff, and Rye Huang at the Waimanalo Experiment Station; and Bob Joy of USDA PMC.

My wife Kathy has my most and special appreciation, for enduring the ups and downs of a student's life with me.

ABSTRACT

In Hawaii, Crotalaria juncea green manure (GM) grown 2 months on an N-deficient soil and incorporated 1 month before sowing hybrid maize yielded 121 kg/ha N in 5.8 t above-ground dry matter (tops) and resulted in maize yields equivalent to those obtained with 150 kg/ha urea N (N_{150}). Tops alone (G) at rates of up to 180 kg/ha N were not as effective as GM but were equivalent to N_{100}; low rates of tops (under 100 kg/ha N) were equivalent to similar urea rates. The below-ground GM component (green manure residue, GMR) provided rapidly available N and produced maize yields similar to N_{100}, G_{120} and G_{180}. Application of tops as mulch was inferior to burial in soil. Response to urea was linear and significant between all rates. Combined GMR and G_{120} maize yields were greater than responses to GM. Results of intercropping maize with C. juncea and Sesbania cannabina were also reported. A second crop comparing residual effects with urea reapplications found significant maize yield responses to applied N but did not show strong differences in residual value among previously applied urea and legume N treatments.

Additional keywords: green leaf manure; Sesbania spp.; green manure residual effect.

TABLE OF CONTENTS

Page

ACKNOWLEDGMENTS iii

ABSTRACT iv

LIST OF TABLES vii

LIST OF ILLUSTRATIONS viii

INTRODUCTION . . . .

1.1 Green manuring and agricultural production 1
1.2 Definitions and use alternatives of green manuring . . 3
1.3 Inorganic nitrogen fertilizers 5
  1.3.1 Historical development 5
  1.3.2 Effect on production and use in the tropics . 6
  1.3.3 Relation to non-renewable energy resources . . 8
1.4 Relative efficiency of green manure N and inorganic N . 9
1.5 Nitrogen requirement of maize 10
1.6 Green manuring of maize 11
1.7 Intercropping green manures and maize 13
1.8 The components of green manure effects 14
  1.8.1 Green manure below-ground residue 14
  1.8.2 Green leaf manure 17
1.9 *Crotalaria juncea* 18
  1.9.1 Species characteristics 18
  1.9.2 Yields 19

MATERIALS AND METHODS

2.1 Experimental site and design 22
2.2 Plantings and field operations 23
  2.2.1 Maize crops 23
  2.2.2 Fertilization, irrigation and weed control . . 25
  2.2.3 Legume crops 25
  2.2.4 Application of treatments 26
    2.2.4.2 Major treatments 26
    2.2.4.2 Secondary treatments 28
2.3 Sampling, data collection and analysis 29

RESULTS AND DISCUSSION

3.1 Yield of N-depletion crops 31
3.2 Yield of *C. juncea* 31
3.3 Maize yield response to legume and inorganic nitrogen . 34
  3.3.1 Dry matter yield 34
  3.3.2 Maize nutrient uptake 41
    3.3.2.1 Nitrogen uptake 41
    3.3.2.2 Phosphorus and potassium uptake . . 44
  3.3.3 Yield of maize seedlings 44
  3.3.4 Maize plant height 46

Page

3.4 Comparison of legume and inorganic nitrogen sources . . 50
  3.4.1 Efficiencies of applied nitrogen 50
  3.4.2 Inorganic N-equivalents and equivalent efficiencies 52
  3.4.3 Effect of green leaf manure 54
  3.4.4 Effect of mulched v.s. incorporated green leaf manure 58
  3.4.5 Effect of legume below-ground residue 62
  3.4.6 Effect of in situ green manure 63
3.5 Intercropping treatments 66
  3.5.1 Legume-sweet maize intercrops 66
  3.5.2 *C. juncea* green manure intercrop 68
  3.5.3 Other intercropping treatments 69
3.6 Soil extractable nitrogen 70

SUMMARY 78

APPENDICES

I. Analyses of variance for maize test crop yield parameters 80
II. Residual effects of treatments 81

LITERATURE CITED 86

LIST OF TABLES

Table		Page
1	Nitrogen uptake of third N-depletion crop (sweet maize grown 11 weeks) and analyses of variance	32
2	*Crotalaria juncea* fresh, dry matter and nitrogen yields and population densities	33
3	Maize dry matter and nitrogen yield responses to inorganic fertilizer and *Crotalaria juncea* nitrogen sources and rates, ranked and separated by BLSD	36
4	Maize nitrogen content as affected by inorganic fertilizer and *Crotalaria juncea* nitrogen sources and rates .	42
5	Phosphorus and potassium uptake of maize grain and stover in response to inorganic fertilizer and *Crotalaria juncea* nitrogen sources and rates, ranked and separated by BLSD.	45
6	Five-week-old maize plant yield, nitrogen content and nitrogen uptake in response to inorganic fertilizer and *Crotalaria juncea* nitrogen sources and rates, ranked and separated by BLSD.	47
7	Inorganic nitrogen equivalents of legume treatments and their efficiencies in relation to applied nitrogen . . .	53
8	BLSD values applied to regressions of maize yield responses on urea and *C. juncea* green leaf manure levels.	59
9	Sweet maize yield and N uptake when intercropped with green manure legumes during third N-depletion cropping period	67
10	Budget of extractable soil ammonium plus nitrate nitrogen levels at three sampling times, with nitrogen additions as *C. juncea* tops or inorganic fertilizer and nitrogen removals by maize crops	71
11	Extractable soil ammonium plus nitrate nitrogen (5/81 sampling) in two sampling zones	73
12	Maize grain and stover response to residual effects of previous inorganic and legume N treatments and to inorganic N reapplication, ranked and separated by BLSD, with analyses of variance	85

LIST OF ILLUSTRATIONS

Figure		Page
1	Experimental plot and block plans	24
2	Increase in height of *Crotalaria juncea* over time	35
3	Total dry matter yield of maize (grain plus stover) in relation to levels of N applied as inorganic fertilizer or as *Crotalaria juncea*	38
4	Grain yield of maize in relation to levels of N applied as inorganic fertilizer or as *Crotalaria juncea*	39
5	Stover yield of maize in relation to levels of N applied as inorganic fertilizer or as *Crotalaria juncea*	40
6	N uptake of grain and total N uptake of maize (grain plus stover) in relation to levels of N applied as inorganic fertilizer or as *Crotalaria juncea*	43
7	N uptake of five-week-old maize plants in relation to levels of N applied as inorganic fertilizer or as *Crotalaria juncea*	48
8	Increase in height of maize, given different rates and sources of nitrogen, over time	49
9	Efficiency of applied N from inorganic fertilizer and *Crotalaria juncea* sources at different levels of application	51
10	Efficiency of N applied as *Crotalaria juncea* green leaf manure in terms of the urea N-equivalents of application levels as determined on the bases of four maize yield parameters	56
11	Soil temperature of maize plots at 15 cm depth under mulch and bare soil	61
12	Extractable soil ammonium plus nitrate nitrogen after test crop in relation to N applied before test crop . . .	74
13	Relationship between nitrogen not accounted for in the nitrogen budget (Table 10) and rates of nitrogen applied.	76
14	Maize grain yield response to residual effects of previous inorganic and legume N treatments and to inorganic N reapplication	83

Figure Page

15 Maize stover yield response to residual effects of previous inorganic and legume N treatments and to inorganic N reapplication 84

INTRODUCTION

1.1 Green manuring and agricultural production.

The demand for increased food production has created constraints on space, time and labor in most agricultural areas. Adaptation to these conditions has been facilitated by the use of industrially fixed inorganic nitrogen fertilizers. In many tropical countries it is only recently that industrial fertilizers have become available to contribute to bridging the gap between production and rising demand. If rising fertilizer manufacturing or transportation costs prohibit the maintenance of N fertilizer supplies or subsidies, farmers will face the same demands without the strong basis for maintaining productivity that these materials now provide. If inputs of inorganic nitrogen to agriculture cannot be sustained, biological nitrogen will have to become a major element of crop management again.

Legumes have been an important source of nitrogen for agriculture, and have been managed by farmers to a greater extent than any other biological N source excepting animal manures. Allowing volunteer legume stands during fallows has been known to be beneficial since the time of the Roman Empire at least, and the encouragement of these stands through seed management and selective weeding is probably as old. Rotations with pulses and leguminous forages, and sowing legume catch crops, are other techniques that have long been recognized to be "restorative" to the soil, and to promote luxuriant growth in following non-legume crops. Burning of fallow vegetation is probably the earliest related management practice. The application of rogued weeds or cut plants to the soil surface as mulch may also be quite ancient. It is probable that the practice which we know as green manuring, the incorporation of natural or planted fallow crops into the soil, did not become common until the plow became available as a tool for this purpose.

Since Boussingault first demonstrated legume nitrogen accumulation in sand culture one hundred-fifty years ago, the phenomena has been elucidated in great detail, and the present state of sophisticated biochemical and microbiological knowledge rests on a foundation of early investigations motivated by and centered on practical agricultural applications (Burris, 1974). Since the 1970's there has been an effort to turn the attention of scientists to the exigency of reapplying research on biological nitrogen fixation to those early agricultural motivations (Wittwer, 1976). Agricultural scientists have been largely distracted from problems of biological N management by increased availability of inorganic fertilizers, concern for fertility problems related to other plant nutrients, such as phosphorus, and perhaps an illogical aversion to "organic" agricultural methods.

Green manuring is a technique for managing legume nitrogen which had barely become a subject of scientific inquiry before it became an anachronism. P. de Sornay's early work, Green manures and manuring in the tropics (1916), was not so much an agricultural text as an economic botany of the Leguminoseae. Pieters' Green manuring, principals and practices (1927) remains to this day as the classic monograph on the subject and is the most thorough, if dated, text available. The International Institute of Agriculture's publication on legumes and their uses in tropical agriculture (Bally and Legros, 1936) stood as the major non-temperate survey of green manuring until updated by FAO

(Whyte, et al.) in 1953. Local reviews of experimental work are few and far between. Pieters' (1917) review of the U.S. experiment station literature and Panse et al.'s (1965) review of experimental results in India are the major efforts of their kind. Other notable but less extensive reviews from India are those of Dobbs (1915) and Allan (1915), Joachim (1925), and Singh (1962); van der Giessen (1942) reviewed some of the research done in Indonesia.

Experimental research on green manuring in the tropics has mainly been done in Asia, particularly India. As demands for production rose in the post-WWII period, research on green manuring increased in India, perhaps culminating in the all-India research scheme which Panse et al. (1965) surveyed. As inorganic nitrogen became more available, interest in green manuring waned even in India. Respondents to a questionnaire in 1980 (Evans and Yost, unpublished) cited the constraints on time, space and labor already mentioned, as the reasons for the decline. Should N fertilizer supplies become restricted by economic conditions, these constraints will tighten, since nitrogen is the nutrient most commonly limiting crop yields. It is further recognized that continued cropping practices that disregard soil organic matter without consideration to its replenishment cannot be tolerated in the future, especially in tropical soil situations, to avoid further jeopardizing potential soil productivity (Fox and Yost, 1980).

1.2 Definitions and use alternatives of green manuring.

Green manuring is the use of fresh plant materials to modify soil conditions with the objective of improving the soil as a medium for plant growth. In its classic sense, green manuring is the growing of a crop for in situ incorporation, into the same field, to benefit a subsequent crop, ordinarily a food crop. This sense is distinct from green leaf manuring, where the green manure is not grown in situ but is harvested from field borders, waysides, forests or other fields, constituting a transfer of fertility from one area to another.

One advantage of the in situ green manuring practice is associated with the effect of the plants having grown in the field, specifically, with the actions and the presence of their roots. Although leaving behind the roots of plants is not green manuring, when green manure crops are removed for use as green leaf manure, the below-ground portions are termed green manure residues in this investigation. This residue component of the green manure effect includes roots, root nodules, stubble, surface litter, and rhizosphere exudates. The term "residual effect," when applied to green manuring or green leaf manuring, is usually restricted to the effects on crops subesequent to the one immediately following application.

Crops grown as green manures are usually annual legumes, and most often are selected for rapid early growth and abundant production of succulent vegetative material. Many different kinds of plants are utilized as green leaf manures; legumes are usually preferred, and often include perennial, arboreal types. Plants for green leaf manure may be deliberately sown in field borders and unused areas, and field-planted green manure crops may be harvested or partially harvested for green leaf manure on nearby fields. Green plant material may be laid on the soil surface but usually it is incorporated into the soil, and plants may be considered green manures when they are grown or harvested for these kinds of use.

An additional use alternative is to intercrop green manure legumes with non-legumes. This practice is most common with row crops such as maize and sugarcane, commonly sowing the legume during the early growth stage of the companion crop. With shorter-duration companion crops, the legumes are usually incorporated after harvest to benefit the following crop. Intercropping has also been done with rice to some extent, usually sown simultaneously and incorporated during thinning and weeding operations.

1.3 Inorganic nitrogen fertilizers.

> The increase in the use of fertilizer nitrogen has been particularly impressive and....is due in no small part to the efficiency of the nitrogen producers and the low cost with which these materials have been offered to growers.
>
> (Tisdale and Nelson, 1975)

1.3.1 Historical development.

Pre-industrial agriculturists relied on organic nitrogen sources, mainly animal manures. More concentrated natural sources became available in the 19th century with the mining of Chilean sodium nitrate and the recovery of ammonium sulfate from coking; these and the synthetic fertilizers available through the arc process of direct oxidation or the cyanamide process were limited and localized in their impact (Tisdale and Nelson, 1975). The two latter synthetic processes require especially high energy inputs, and it was not until the development of the Claude-Haber process in 1910 that the potential for large-scale commercial fixation of nitrogen existed. Actual production on such a scale did not begin until after World War II. Between 1942 and 1967 chemical fertilizer use increased tenfold in the United States while the cost of nitrogen decreased to 50-25% of its price at the end of the war (Lappe et al., 1978, Aldrich, 1980). Toward the end of this period, although in adequate supply at moderate prices, nitrogen generally accounted for over half of farmers' expenditures on fertilizers (Allison, 1966).

Synthetic ammonia production by the Claude-Haber process and its modifications requires energy for heat and pressure, and a hydrogen source, most commonly methane or petroleum hydrocarbon byproducts. Increasing demand for energy worldwide and manipulation of prices of a major energy source, petroleum, have resulted in great increases in the value and costs of energy from all sources.

1.3.2 Effect on production and use in the tropics.

The use of synthetic fertilizers including nitrogen has without doubt contributed to increased yields. Between 1950 and 1972 in the United States, average yields increased 157% for maize, 128% for wheat and 84% for cotton (Tisdale and Nelson, 1975). Factors other than fertilizers contributing to these increases are also linked to petrochemical resources, such as agricultural mechanization and pest control methods. The implication of fertilizer nitrogen as an important factor in yield increases is made clear when increases in yields of legumes for the same period are examined: 29% for soybeans and 28% for alfalfa.

Improved crop varieties have made a large impact on grain production. Maize, rice, and wheat varieties producing high yields in response to high inputs have particularly affected production in the tropics. Between 1966 and 1972 in India and Pakistan, total rice production increased 26% and 85%, and wheat production 124% and 77% respectively, while nitrogen fertilizer consumption increased 145%

and 206% (Manshard, 1979). In a context of rapid population growth, increases in yields and total production are widely welcomed, but the enormous demand for chemical fertilizers created by proliferation of high-response varieties has been criticized on the basis of political-economic considerations and their impacts on agrarian social structures (Lappe et al., 1978; Jacoby, 1974) and ecological hazards to the biosphere (Manshard, 1979).

The need for chemical fertilizers to maintain high levels of production carries with it a dependency on inorganic nitrogen. In free market situations adequate supplies of nitrogen fertilizers are available to meet demands, but in areas where capital-intensive agriculture has been imposed on labor-intensive production systems and limited economic democracy restricts access to capital, non-availability of fertilizers can play a role in limiting production. Thus, governments of many countries in the tropics subsidize fertilizers. Of replies received in response to a questionnaire on green manuring in the tropics (Evans and Yost, unpublished), one-half of the respondents indicated that fertilizers were made available to farmers through government agencies. In becoming increasingly dependent on industrialized nations for technologies, less developed nations commit large sectors of productivity toward maintaining foreign exchange, making their overall economies particularly sensitive to market fluctuations of many types. Increased costs of imported nitrogen fertilizers or of the construction and operation of domestic manufacturing facilities can have greatly amplified effects in these situations.

1.3.3 Relation to non-renewable energy resources.

Eighty-seven percent of the energy used in fertilizer production in the United States is used for nitrogen fertilizers (Aldrich, 1980). Achorn has recently (1981) summarized some of the relationships between energy and fertilizer that exist in the U.S., where one unit of N requires around 25 times the amount of energy needed for production of a unit of P_2O_5 or K_2O. Natural gas is used as a hydrogen source for most of the ammonia produced, and its cost has increased 539% to TVA in the past ten years. Cost of electrical power used in manufacture of fertilizers in the TVA power area increased 432% between 1972 and 1979. Other energy inputs based on crude oil, for which costs increased 300% in the last seven years, also influenced the cost of producing, transporting and applying fertilizers. The importance of natural gas as a hydrogen source was emphasized by showing that as its price increased tenfold, the percentage of the total ammonia manufacturing cost attributable to it rose from 27.5% to 79%. General fuel cost increases of 60% in 1980 were projected to continue at about the same rate.

Stangel (1979) has assessed global needs for and capacities to produce inorganic nitrogen, and concluded that natural gas reserves are adequate to meet regional needs in Asia, Latin America and Africa for the rest of this century. Increases in production capacity will be constrained by high capital costs of production complexes, and locations of low-cost natural gas which are not often fortuitously situated. Pricing policies and political-economic motivations of major N exporters, which include the USSR and several of its satelites, will also effect the costs of inorganic N to developing country farmers.

In tropical countries lacking either resources or adequate production capacities, it may be assumed that increases in energy costs are felt even more acutely than in the United States. In these countries, where large numbers of malnourished people totter on the brink of starvation, easily upset by natural disasters, crop failures or military conflicts internal or external, increases in costs of nitrogen fertilizers can only exacerbate the critical balance between crop yields and nutritional requirements. While some concerned observers (Lappe et al. (1978), for example) argue that food distribution rather than production is the main problem, there is little doubt that the link between energy costs and nitrogen fertilizer production has an increasing effect on their agricultures and their nutritional well-being.

1.4 Relative efficiency of green manure N and inorganic N.

Much of the experimental work on green manures has been done with rice. In a pot study, Mahalingam et al. (1975) found the yield response to green leaf manure N equivalent to calcium ammonium nitrate and greater than ammonium sulfate when N was applied equally for the sources at 67 kg/ha. Nitrogen requirements for traditional varieties of rice are not as high as for other crops such as maize, and experiments are often performed on fertile soils of research stations. For example, on a soil where rice responded to 22 but not 44 kg/ha N, green manuring with *Sesbania bispinosa* was as effective as applying inorganic N (Relwani and Ganguly, 1959). In a later experiment (Ali and Morachan, 1974) on a fertile soil, high-response IRRI rice varieties produced 5.3 and 5.9 t/ha grain respectively for *Crotalaria juncea* green leaf manure (25 t/ha) and an equal amount of N (187.5 kg/ha) as ammonium sulfate, compared to 4.2

t/ha grain when the N was supplied as farmyard manure. Staker (1958), in a survey on green manuring in SE Asia, reported that C. juncea green manure was better than ammonium sulfate at 100 kg/ha. Patnaik and Rao (1979), reviewing N sources for rice, concluded that "on an equal-N basis, at moderate levels of 20-40 kg N/ha, green manure is as efficient as chemical N."

Growing maize, Ruiz and Laird (1961) found that C. juncea green manure providing 84 to 97 kg/ha N in the green matter resulted in grain yields greater than the fallowed control by over one ton, and equivalent to inorganic N at 80 kg/ha. Stickler et al. (1959) in Iowa found similar maize response (95% of maximum yield) to 122 kg/ha N in green manured legume tops and roots as to from 56 to 112 kg/ha inorganic N.

1.5 Nitrogen requirement of maize.

Maize has a high requirement for nitrogen. Grove (1979) reported that rates of 80 to 120 kg/ha N resulted in 95% maximum yield on Oxisols and Ultisols, where maximums were from 5 to 6 t/ha grain. Fertilization rates of up to 150 kg/ha N are recommended for top grain yields (Litzenberger, 1974), and even higher rates may be applied under optimal management. At Waimanalo in Hawaii, Fox (1972) found a linear response to urea in yields of fresh husked hybrid sweet maize that did not tend to level off at the highest rate of 225 kg/ha N. In contrast to these yield levels, Mudaliar reported in 1960 that maize grain yields in India were from 1.1 to 1.7 t/ha on "dry lands" and twice these levels on "garden lands." At that time, cattle manure was the principal N input, and improved hybrids were not widely available.

Jong et al. (1981) reported yields of plantings throughout the year at the Waimanalo Research Station that ranged from 3.5 to 11.5 t/ha (mean 7.8 t/ha) grain. One hundred-thirty kg fertilizer N was applied to each successive crop in these trials; the soil undoubtably retained high levels of available N.

Hanway (1971) demonstrated that maize generally takes up 70% of its nitrogen by the tenth week of growth, at which time it has accumulated about 60% of its dry matter. From that point until maturity, grain filling occurs, involving both continued N uptake and translocation of N from other plant parts to the grain, so that grain generally contains over 60% of total plant N. Hanway emphasized that "an adequate supply of nutrients at each [growth] stage is essential for optimum growth at all stages."

1.6 Green manuring of maize.

In other experiments with maize, direct comparison with inorganic N was not particularly an objective. Many of these were conducted before N fertilizers became widely available at relatively low prices.

The time required to grow a green manure crop becomes especially critical in subtropical and temperate zones where loss of an entire growing season may be involved. In the Stickler et al. (1959) experiment, legume-oat mixtures were grown for two years before the maize test crops. Brown (1958), working in Nyasaland, thought that the loss of a growing season was uneconomical, in spite of the fact that Rattray had reported earlier (1950) that over a period of twenty-one years in Rhodesia total maize yield was greater when green manure was grown alternately in eight of those years than when maize was grown annually.

Similar results were reported by McKee (1946) for Mississippi, where continuous maize over eight years yielded less in total than maize grown four years alternating with crotalaria for green manure. In another example of long-term green manure stands for maize, Stokes et al. (1936), comparing incorporation of C. striata or Mucuna grown for ten months with incorporation of a non-legume cover, both supplemented with 27 kg/ha N, found that legumes produced maize yield increases more than 90% greater than non-legumes. In a similar comparison, Fuggles-Couchman (1939) found in Tanzania that C. juncea green manure increased yields whereas buried weeds did not.

Generally in the tropics, shorter-duration green manure crops are common, and green manures and their following crops are grown in the same season. In Indonesia, van der Geissen (1947) obtained significant maize yield responses to C. juncea green manure in six out of nine years. In the Philippines, maize following Vigna unguiculata green manure had a significant yield increase, but use of other pulses did not increase yield (Barros, 1940). In a later trial there, pulses were found to increase maize yields when green manured (Eusebio and Umali, 1952). In tropical America, Ruiz and Laird (1961) and Ramirez (1972) compared C. juncea with several other green manures for maize production.

Residual effects of green manures on maize are generally non-significant, but occasionally responses are reported. In the Eusebio and Umali experiment with pulses, cowpea green manure also increased yields of the second successive maize crop. In Indonesia, van de Goor (1954) reported that C. juncea grown after maize as green manure for rice increased maize yield in the following cycle. Rattray and Ellis (1952) found that second maize crops grown after green manure produced only one-half the yields of the first maize.

1.7 Intercropping green manures and maize.

It is generally reported that intercropping green manures with maize for following crops does not reduce maize yields, and frequently maize yields are favorably affected. Van de Goor (1954) reported favorable effects of intercropping various green manure spp on the associated maize. Panse et al. (1965) cited one example of increased maize yield when intercropped, and another where yields were depressed. Van der Geissen (1947) found that intercropped *C. juncea* increased maize yields 58% over no intercrop, and that maize intersown with *C. anagyroides* seven weeks after sowing every year produced yields 156% of those when undersown in alternate years. *Crotalaria* sp sown in maize produced yields 185% of those where maize grew alone over an eight-year period in Mississippi; intercropped maize during the period produced 135% of total yields when crotalaria was grown in single stand for green manure in alternate years (McKee, 1946).

Crotalaria juncea is an ideal intercrop for maize as its rapid vertical growth allows it to compete for light; in one case in Mexico where it was unable to do so (Guevara-Calderon, 1958), it was seen to recover after the maize stand withered. Crotalaria does not climb on the maize as does mucuna, which when intercropped in Brazil increased following maize yields significantly over no green manure in three of five years, but which interfered with harvest of the first maize crop ears (Vieria, 1961).

C. juncea has also been used extensively as a green manure intercrop with sugarcane; some of this work in India was reviewed by Iyer and Tandon (1960). In one example, Bhadauria and Mathur (1973) obtained a yield increase of 5.4% applying intersown *C. juncea* as mulch, representing a 300% return on investment in the practice.

Other green manure legumes have also been successfully intercropped with maize. *Melilotus alba* seeded in maize at the last weeding as a green manure for the following maize crop produced yields equivalent to the application of 600 kg/ha ammonium sulfate when only half that amount was applied (Peregrina et al., 1955). Vieria (op cit), in addition to *Mucuna*, intercropped *Canavalia* and cowpea with some success. In Africa, *Pueraria* intersown one to five weeks after maize did not reduce maize yields, and intercropped *Leucaena leucocephala* leaf loppings mulched at 10 t/ha was equivalent to 5 t/ha plus 50 kg inorganic N, or to 100 kg inorganic N (IITA, 1980). Leucaena intercrops in Hawaii supplied 60 to 180 kg/ha N to maize, producing yields comparable to maize alone given 75 kg/ha N as urea (Guevarra, 1976).

1.8 The components of green manure effects.

The below-ground parts of legumes form one component of the total effect resulting from the incorporation of whole plants grown in situ; the aerial plant parts form the second component.

1.8.1 Green manure below-ground residue.

When the aerial plant is harvested, the residues remain, including litter, stubble, roots, and root nodules. The physical effects of the action of living roots penetrating the soil, and later decomposing (Allison, 1973) are part of the green manure residue effect. Increases in soil aggregation (Shende and Sen, 1958) and in soil waterstable aggregation and bulk density (Sharma and Singh, 1970) after growing legumes such as *Cyamopsis tetragonoloba* (guar) and *Trifolium alexandrium* (berseem) are probably largely attributable to root action. Joffe (1955) noted that roots increase soil permeability, and Yadav and Agarwal (1961) found that roots of *Sesbania bispinosa* grown in saline-alkali soils enhanced the effect of gypsum, increasing permeability and leaching of salts. Chemical effects of exudations by the roots also play a role, but mechanisms and effects are not well characterized.

Khanna and Mahajan (1968) noted that soil available P increased two months after harvesting 60-day-old sesbania grown in light soils in pots, whether or not P had been applied. The mineralization of nitrogen immobilized by root tissues is thus only one of the ways in which decomposing roots can aid a following crop.

Legume root biomass varies considerably: Allison (1973) reported a range among temperate species from 12% of the plant for soybeans to 33% for alfalfa. Direct estimation of the root mass is difficult and not often undertaken. Fribourg (1954) measured root mass of some temperate species. Inforzato and Mascarenhas (1967) estimated that *Dolichos lablab* roots amounted to 1.5 t/ha dry matter. Rojas and Lotero (1970) in Colombia reported on root mass of *Mucuna*, *Cajanus* and eleven other legumes. A. Singh (1975) found *C. juncea* tops and roots dry matter to be in a ratio of 10.5 to 1; the roots accounted for only about 3.5% of whole-plant N.

The high lignin contents of roots should retard their decomposition. Root nodules, on the other hand, decompose rapidly because of their high N content, and it is common to find nodules in all stages of growth and decomposition during the life of a symbiotic legume as the plant undergoes stresses affecting photosynthesis, or preferentially reroutes photosynthate to roots exploiting nutrient-rich pockets of soil (J. Halliday, personal communication). Joshi (1919) found that *C. juncea* roots decomposed very slowly, with nitrification increasing from an initial low level only after the sixth week of decomposition. He found 9% of the N in six-week-old plants in the roots. R. Singh et al. (1970) found 17% of the N in pot-grown *C. juncea* in the roots and nodules, and estimated that N added by roots, nodules and excretions would amount to 40 kg/ha.

Reports of *C. juncea* residue effects vary. Kute and Mann (1969b) obtained higher yields of wheat from control plots than from residues. Similar results with potatoes were obtained by Swaminathan and Singh (1960) in dry years, but in normal years responses to residues equaled yields following fallow. Joshi (1922, 1928) reported yields of oats with residues to be as little as half of control yields in one year, and equal in only two out of six years. Van der Geissen (1942) stated that the effects of *C. anagyroides* residues on rice were negligible.

Positive responses to residues are about as frequently reported. Singh and Gautam (1973) obtained significant yield increases of barley after harvesting eight-week-old *C. juncea* for fodder. Walunjkar et al. (1968) obtained tobacco yields with residues that were 85% of the yields obtained with whole-plant green manure, which contributed about 70 kg/ha N. Panse et al. (1965) reported responses to residues that were 88% of responses to green manure when wheat followed *C. juncea*, and similar values when sugarcane followed; for wheat grown on guar residues, yields were 79% of those obtained with whole-plant green manuring. Cutting legumes before final harvest may enhance residue effects. Wheat following berseem cut four to five times yielded from 30 to 50% more than wheat after fallow (Acharya, 1952). After the second cutting of a dense C. juncea stand grown for 70 days, wheat yield increase due to residues averaged 57% over control, and amounted to 60% of the increase over control due to whole plant green manure (Jadhav et al., 1979).

1.8.2 Green leaf manure.

Green leaf manures are either the succulent portions of plants lopped periodically, as in the case of shrubs and trees, or herbaceous species cut as though for fodder. In the case of legumes grown for short periods in situ, they may also be the whole aerial plants, and if much older than four weeks the stems will contain lignin which will retard N mineralization. Panse et al. (1965, and Panse and Ayachit, 1954) concluded from surveying numerous trials that there was a plateau in rice yield responses to added legume nitrogen, and determined that around 5 t/ha green matter was optimum. Should such plateaus exist for different crops, options open to use all or part of a green manure crop for other purposes, such as green leaf manure elsewhere, fodder, leaf protein extraction (Jadhav et al., 1979), or fiber as is sometimes the case with C. juncea. However, yield responses to green leaf manure reported in the literature are as variable as those cited above in reference to the residue component.

Shende and Sen (1958) found that the contribution of guar to available soil N decreased in the order: whole plant green manure, green leaf manure, residues. Yield responses of following crops follow the same general pattern. Low responses to both the green leaf and the residue components are sometimes obtained (e.g., Kanwar and Singh, 1959). Sometimes the tops produce significantly greater yields than the residues (Kute and Mann, 1969 a and b), and sometimes responses to the above-ground component are equal to those to whole plants (van der Geissen, 1942).

Burial of tops as green manure in situ or as green leaf manure elsewhere provides two distinct N sources: the leaves, rich in nitrogen and with a large surface to volume ratio, and stems, low in N, high in lignin and cellulose, and not nearly as accessible to microbial attack. These two components have very different decomposition and N mineralization rates and qualities (Singh, B.N. and Singh, 1936; Huang and Wang, 1974) and undoubtably also different effects on soil physical characteristics. Whole plant green manure components are yet more complex in this regard, as roots are included. According to Russell (1973), readily decomposed tissue contributes quickly to soil available N and more resistant material contributes to soil organic matter over a longer term. The existence of such differences between or within these plant parts means that the release of legume nitrogen is a prolonged process compared to the release of N from inorganic fertilizers.

1.9 Crotalaria juncea.

1.9.1 Species characteristics.

Crotalaria juncea is an annual shrub with erect growth habit from 1 to 3 meters high, with oblong, lanceolate leaves 7-13 cm long and 1.5-2.5 cm wide, and yellow flowers borne 8-20 in loose terminal racemes.

Branching begins about 75 cm above the ground when plants are not crowded, but higher and to a lesser extent when grown in the high populations favored for green manure or fiber production. Seed pods are cylindrical and inflated, 3-6 cm long by 1-2 cm wide, with seeds around 6 mm in length and brown to greenish-black in color; there are 30-35,000 seeds per kilogram.

Seed production is a problem in the subtropics where daylengths short enough for flowering occur during cool winter months unfavorable to growth. In the United States, seed is only obtained in commercial quantity in southern Texas (McKee, 1946). Flowering in Hawaii may begin at 6 weeks of age; maturity is reached at 4 months or more. Seed pods do not dehisce readily in the field and may be combine harvested when mature and dry. Hand harvesting and threshing may be done without difficulty. Seed yields of over 2.25 t/ha have been recorded with the accession (HA-6) used in this study (USDA-SCS, 1979). Scarifying seeds before sowing is unnecessary for some varieties.

C. juncea is a warm-season crop, intolerant of frost, growing well year-round in the tropics below 300 m elevation but best planted in summer above 600 m. At intermediate elevations growth may be slower in winter months. _C. juncea_ is known to grow on poor sandy soils; light, loamy soils are preferred for fiber production; poorly drained soils are the major soil limitation, but good growth can be obtained on clay soils in drier periods. Soil alkalinity is tolerated, as is soil acidity, although in the case of acidity yields fall off at pH's below 5 (Yost, et al., 1981).

On any soil type, constant wet weather is unfavorable to growth. C. juncea grows in areas with as little as 500 mm annual rainfall and is tolerant of drought, but for good yields irrigation is desirable during dry periods.

Seed inoculation with a superior cowpea-type Rhizobium strain is recommended. Emergence occurs 3-5 days after sowing; thereafter, rapid growth allows it to compete well with weeds, especially when sown thickly. Stems are succulent during the first 4-6 weeks of growth, later becoming fibrous; high populations favor prolonged stem succulence.

Sowing rates may vary from 25 to 90 kg/ha; within this range broadcast rates are higher than for drilling. When the crop is grown for more than one month, rates of 35-40 kg/ha broadcast and 30-35 kg/ha drilled are adequate. For seed production, lower rates are sown.

C. juncea is perhaps the most widely grown green manure crop in the tropics, used extensively in India both as a fiber crop and a green manure for rice, maize, wheat, barley, tobacco, sugarcane, potatoes and other crops. Other major use locations are Indonesia and Rhodesia. It has generally been rejected when tried as a cover crop because of its determinate growth and erect habit.

Other Crotalaria spp used as green manure in the tropics include C. anagyroides and C. usarmoensis. In subtropical areas C. striata, C. spectabilis and other species have been grown for green manuring or soil improvement. McKee (1946) estimated that several hundred thousand acres were seeded to Crotalaria spp in the southern U.S. in 1945. The limitation of toxicity to livestock restricting wider use of many crotalarias does not apply to C. juncea (USDA-SCS, 1979).

1.9.2 Yields.

Reports of yields of *C. juncea* grown for two to three months generally range from 12 to 22 t/ha fresh material. Paul (1938) found no difference between seed rates of 67 and 90 kg/ha for a two-month crop. Panse et al. (1965) reported varying yields of stands for sowing times (May v.s. June) and soil types (sandy loam v.s. "black cotton"), and striking differences for seasons (16 t/ha fresh weight before main season rice, 5 t/ha before second season rice. Van de Goor (1954) reported a range from 17 to 25 t/ha fresh yield for a number of trials in Indonesia.

Estimates in the literature of nitrogen accumulation by *C. juncea* begin at about 90 kg/ha (Staker, 1958; Joshi, 1928) with a mid-range between 110 and 130 kg/ha (Kurup and Kaliappan, 1969). N yields of up to 170 kg/ha are predicted for accession HA-6 in Hawaii (USDA-SCS, 1979). Rao and Sadasivaiah (1968) found 296 kg/ha N in plants grown in soil in lysimeters with 160 kg/ha P, 213 kg/ha N with 20 kg/ha P, and 132 kg/ha N when no P was applied.

MATERIALS AND METHODS

2.1 Experimental site and design.

The experiment was conducted on a portion of field T2 of the University of Hawaii's Waimanalo Experiment Station. This field is located on a fan of alluvium 1.6 km inland on coastal windward Oahu, elevation 21 m, longitude 157°43' E., latitude 21°20'30" N. The soil is the Waialua clay series described by Foote et al. (1972) as a very fine, kaolinitic, isohyperthermic, Typic Haplustoll (order Mollisol) revised to Vertic Haplustoll as reported by McCall (1975), moderately drained with a pH of 6.0. The site is stony with a slight slope.

The randomized complete block design was used with twelve plots in each of four blocks. Plot dimensions were 4.5 by 7 m allowing for five interior rows within each plot spaced 75 cm apart in maize-only plots, and a border row along the outside length shared by adjoining plots. The sample area for the maize-only plots consisted of the three interior five-meter row sections, an area of 0.001125 ha.

Ten treatments, replicated in each block, constituted the core of the experiment and are included in the analysis of variance. These were: a control receiving no nitrogen (N_0); three levels of fertilizer nitrogen receiving 50, 100 and 150 kg/ha N as urea (N_{50}, N_{100} and N_{150}); three levels of fresh legume tops grown in an adjacent field and buried in the plots as green leaf manure (GLM) to provide 60, 120 and 180 kg/ha N (G_{60}, G_{120} and G_{180}); green manure legumes grown and buried in situ at yield rate for each plot (GM); the below-ground residues of green manure legumes grown on the plots and tops removed (GMR); and legume green leaf manure grown elsewhere and applied as mulch to provide 120 kg/ha N (GLMM).

Figure 1 shows the plot layout of one replication and a plot plan with sample areas indicated. In the analysis of variance, sources of variation and associated degrees of freedom were:

source	df
treatments	9
blocks	3
error	27
total	39.

2.2 Plantings and field operations.

2.2.1 Maize crops.

Three successive maize crops were grown without fertilizer nitrogen for the purpose of depleting soil nitrogen before the application of treatments and subsequent test crop. The first crop, H68 hybrid sweet maize, was sown August 10, 1979, at a population of approximately 90,000 plants/ha and was removed from the field 12 weeks later. The second crop, H634 hybrid maize, was sown at approximately 55,000 plants/ha on December 21, 1979, and harvested 110 days later. For the third N-depletion crop, plots not planted to green manure legumes were again sown to sweet maize, Hawaiian Supersweet No. 9, on August 1, 1980, to provide a population of 66,000 plants/ha, and harvested 76 days later on October 16, 1980.

One month after the application of green manure and urea treatments, maize was again sown. The test crop was H763 hybrid maize, sown in 75 cm rows to provide 66,000 plants/ha on November 28, 1980, and harvested 125 days later on April 2, 1981.

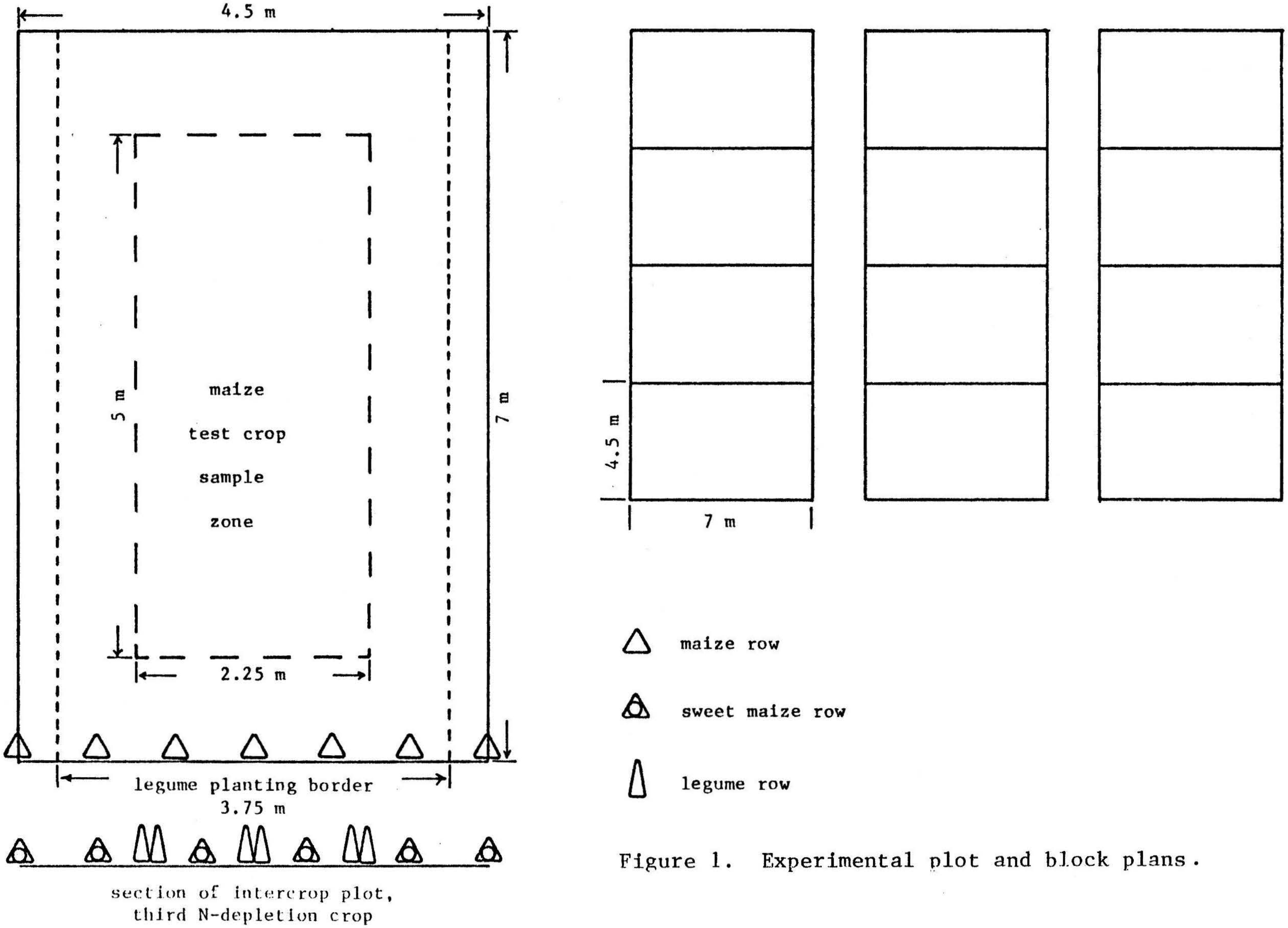


Figure 1. Experimental plot and block plans.

2.2.2 Fertilization, irrigation and weed control.

Fertilizer was applied before the first N-depletion crop as a blanket application of 110 kg/ha P as treble superphosphate and 172 kg/ha K as muriate of potash. Before sowing the third N-depletion crop, a second blanket application of fertilizer was applied at per hectare rates of 38 kg P as treble superphosphate, 134 kg K as muriate of potash, 2.5 kg Zn as zinc sulfate and 0.22 kg Mo as sodium molybdate. At the time of green manure and urea treatment applications before the test crop, potassium sulfate was applied to every plot to provide 112 kg/ha K.

Irrigation for all crops was by overhead sprinkler. Pre-emergence herbicides were not applied to the first two N-depletion crops. For the third N-depletion crop and the test crop, plots planted to maize alone received pre-emergence applications of lasso and atrazine.

2.2.3 Legume crops.

During the period of the third N-depletion maize crop, selected plots for GM and GMR treatments and an area adjacent to the experimental site (for green leaf manure) were planted with *Crotalaria juncea* selection HA-6, seed provided by the USDA-SCS Plant Materials Center, Molokai, Hawaii. Seed was inoculated with a *Rhizobium* inoculum in a peat carrier containing a mixture of three strains: TAL 309 (CB756), TAL 310 (CB1024) and TAL 658 (CIAT 71), provided by the Department of Agronomy and Soil Science's Nitrogen Fixation in Tropical Agricultural Legumes Project. A 40% gum arabic solution was used as a sticker to hold the inoculum to the seed. Sowing was done with a Planet Jr. seeder in rows 15-20 cm apart on August 8, 1980, achieving a population of 270,000 plants/ha. Rows were sown lengthwise on the plots beginning

37 cm from the maize border row, and extending beyond the 7 m plot length into the field alleyways. Harvest area for GM and GMR plots was the whole plot, minus border plants in the alleyways, an area 3.95 by 7 m or 0.00277 ha. The legumes were harvested and applied as green manure or mulch during the period of October 24 to 30, 1980, during their ninth week of growth. Samples from the adjacent GLM planting were taken on October 15 for dry matter and N content determination to provide a basis for GLM application rates which were intended to correspond to rates of N as urea. Subsequent GLM samples taken two weeks later at the time of treatment applications revealed changes in dry matter and N content such that N was applied as GLM at rates 120% higher than the urea-N rates.

2.2.4 Application of treatments.

2.2.4.1 Major treatments.

After harvest of the third N-depletion crop, all plots were tractor-rotovated in preparation for planting the test crop. Urea was tilled into the urea-N plots with a hand-operated rototiller. Crotalaria tops were removed from the GMR plots before tillage. GM plots were also rotovated after cutting and moving the crotalaria tops to the side for subsequent incorporation. GM yields were applied within the full plot dimensions, 4.5 by 7 m or 0.00315 ha. This area was slightly larger than the area on which harvest yield was calculated, accounting for discrepancies between yield and application rates of GM tops. Green manure (GM) and green leaf manure (GLM) application rates were:

treatment	fresh weight t/ha	dry matter t/ha	nutrients kg/ha N	P	K
G_{60}	11.4	3.0	60	7	41
G_{120}	22.8	6.0	120	13	81
G_{180}	34.2	9.0	180	20	122
GM*	16.0	4.5	105	10	62

* GM application rates given are 87% of yield/ha.

Legume tops for the first GM plot to receive incorporation treatment were chopped into 15 cm lengths and an attempt was made to rototill the material into the surface soil. However, the chopped material snarled in the rototiller tines and an alternate method was adopted for the remaining GM and GLM plots. Five furrows were opened lengthwise in those plots with a middle-buster mounted on the tractor tool bar. Whole crotalaria tops were then laid in the furrows and earthed over with the soil displaced from the furrows. Crotalaria from the GM plots was distributed evenly in the furrows in those plots; weighed amounts of tops from the adjacent crotalaria field were carried into the experimental area and applied to the furrows of the GLM plots. Appropriate amounts of tops were laid on the surfaces of the GLMM plots; by the time of sowing the test crop, the mulch had dried sufficiently that the maize seed could be planted through it. The mulch was raked to the side and then replaced after pre-emergence herbicide application. A four-week decomposition period with irrigations elapsed between treatment application and the sowing of the test crop.

2.2.4.2 Secondary treatments.

Other treatments, not included in the analysis of variance, were green manure intercrops (GMI), live mulch manure intercrop (LMMI), and mulched intercrop (MI).

Green manure intercrops were grown with maize during the third N-depletion crop period. Four legumes were used: *Crotalaria juncea*, *Sesbania cannabina*, *S. speciosa* and *S. grandiflora*. Each legume was grown in two plots but through an error in design the two plots were assigned within the same blocks. Maize in the GMI plots was sown in four rows 1 m apart with the inner 5 m of the two central maize rows serving as the sample area (0.001 ha). Legumes were drilled in two rows 20 cm apart in the centers of the three maize interrow spaces on August 11, 1980, 10 days after sowing maize. The legume harvest sample was the inner 5 m of all three interrow plantings, 0.0015 ha. *C. juncea* was inoculated as described above; the *Sesbania* spp were not inoculated because inoculum was not available. *S. speciosa* seed was mechanically scarified with sandpaper before sowing.

Only the *C. juncea* GMI treatment was carried over into the test crop phase. Failure of the rototiller to incorporate chopped plants prompted an attempt to shred the tops of the crotalaria intercrops with a garden-type shredder. The resulting material was very stringy and fibrous and again snarled in the rototiller tines. It was allowed to remain on the surface of the plots for three weeks at which time it was tilled in with less difficulty. The harvested GMI *C. juncea* was incorporated over a larger area than that from which it was sampled, resulting in N application rates lower than N yields.

Because of low green matter yields of the intercropped legumes, the six sesbania intercrop treatments were not carried over into the test crop phase. Instead, live mulch manure intercrop plots were established on four of those intercrop plots after harvest of the third N-depletion crop, two plots in each of two blocks. On November 1, 1980, at the beginning of the decomposition period for the incorporated treatments, inoculated *C. juncea* was drilled into these plots in rows 10 cm apart. After 24 days, strips were cultivated in the legume stand, centered on 75 cm spacings, for subsequent planting of the maize test crop. The legumes in the untilled interrow strips were allowed to grow, were topped to a height of 15 cm two weeks after maize sowing to reduce shading of maize seedlings, and were hoed down five weeks later and left in the interrow as mulch.

Two mulch intercrop plots were established on the remaining two former sesbania GMI plots in the remaining block. Single rows of *C. juncea* were drilled in the 75 cm maize interrow spaces at the time of planting the test crop, with the intention of cutting the legumes and laying them in the interrows as mulch at maize tasseling.

2.3 Sampling, data collection and analysis.

Three sets of soil samples were taken from each plot: at the time of planting and after the harvest of the third N-depletion crop, and after harvest of the test crop. Samples were composites of an average of five locations per plot from the surface 15 cm of the soil. In the third sampling, two sets of samples were taken from each plot in which legumes had been buried in furrows: one set from the bottom of the furrows which included undecomposed crotalaria stem materials, and another set from the surface 15 cm adjacent to the furrows. Soils were passed through a 3 mm screen. Ammonium and nitrate contents were determined by extracting an equivalent of 20 gm oven-dry soil with 1 N KCl and distilling with a Micro-Kjeldahl apparatus.

Data collected on the maize test crop were yields of five-week-old plants to assess N availability during seedling stage, plant height at 47, 57, 67, and 87 days, and whole plant, grain and stover yield at maturity. Crotalaria plant height was recorded over time, and yield and populations of GM, GMR and C. juncea GMI plots measured. Soil temperature was recorded under mulched and non-mulched plots over a 16-day period before canopy closure with Reotemp bimetal dial thermometers inserted to a depth of 15 cm in the maize interrows. Whole plant yields of the third N-depletion maize crop were recorded.

Chemical composition of maize and legume plant tissues was determined by X-ray flourescence spectroscopy with an Applied Research Laboratories spectrophotometer model 72 000. Total N in plant tissues was determined by a modification of the Berthelot method developed by Schuman et al. (1973) described by Suehisa (1980).

RESULTS AND DISCUSSION

3.1 Yield of N-depletion crops.

Three successive crops of maize were planted to deplete the nitrogen in the soil. No data was taken on the first crop during the fall of 1979. The second crop, grown during the cool, cloudy (low-sunlight availability) winter months of 1979-80 produced only 6 t/ha green matter. Heavy rains and severe weed competition helped to reduce the yield of this crop.

The third crop, sweet maize, was grown during a more favorable time of year (August to October). Plants exhibited pronounced nitrogen deficiency symptoms. Average whole-plant fresh weight was 19.7 t/ha, or 5 t/ha dry matter. Nitrogen uptake data presented in Table 1 show that an average of 27.4 kg/ha N was accumulated by the plants during their eleven-week growth period, with no significant differences between blocks. Grouping plot N yields according to their subsequent treatments for analysis of variance showed no significant "treatment" effects. Plot N yields were poorly correlated with extractable soil NH_4 plus NO_3-N during either the seedling stage (r= 0.2709) or after harvest (r= 0.2196).

3.2 Yield of C. juncea.

Data for yields of C. juncea grown either in solid stands for green manure (GM) or green manure below-ground residue (GMR) treatments or intercropped with sweet maize (GMI) are presented in Table 2. An average of 120 kg/ha N was accumulated by the solid stands in 21.6 t/ha fresh material during their eight-week growth period; dry matter production was 5.8 t/ha. Nitrogen yields of C. juncea were more strongly correlated

Table 1. Nitrogen uptake of third N-depletion crop (sweet maize grown eleven weeks) and analyses of variance.

A. Treatment means.

Subsequent treatment	N uptake
	kg/ha
N0	23.7
N50	26.6
N100	30.4
N150	30.8
G60	26.0
G120	27.9
G180	29.0
GLMM	24.7
$\overline{X}$	27.4

B. ANOV.

Source	df	Mean Squares
"Treatments"	7	27.17
Blocks	3	65.49
Error	21	35.45
C.V. = 22 %		
Blocks	3	65.49
Samples	28	33.38

Table 2. *Crotalaria juncea* fresh, dry matter and nitrogen yields and population densities.

		Yield/Plot					Yield/Ha*		
Treatment	Rep.	Fresh	Dry Matter	N Content	N Uptake	No. of Plants	Fresh	Dry Matter	N Uptake
		kg	%	%	gm	m^{-2}	tons	tons	kg
GM	1	68.7	25.1	2.17	374	29	24.9	6.24	135
	2	60.7				22	21.9		
	3	58.2	24.9	1.87	271	24	21.0	5.46	98
	4	53.0	29.5	2.26	353	23	19.2	5.66	128
$\bar{X}_{GM}$		60.1		2.10	333	25	21.8	5.79	120
GMR	1	60.8	26.9	2.06	337	25	30.0	5.91	122
	2	67.9				34	24.6		
	3	56.1	28.8	2.05	331	22	20.3	5.84	120
	4	53.0	29.6	2.13	334	34	21.5	5.67	121
$\bar{X}_{GMR}$		59.4				29	21.5	5.81	121
$\bar{X}_{GM+GMR}$		59.8	27.5	2.09	333	27	21.6	5.80	121
GMI	1(04)	23.3	31.9	2.00	149		15.5	4.95	99
	1(06)	26.3	35.8	1.78	168		17.5	6.28	112
$\bar{X}_{GMI}$		24.8	33.8	1.89	159	29	16.5	5.62	106
GLM	-		25.6	2.06					

* Harvest areas: GM, GMR = 0.00277 ha; GMI = 0.0015 ha.

Key to abbreviations:

GM, GMR = *C. juncea* grown in solid stand.
GMI = *C. juncea* intercropped with sweet maize.
GLM = *C. juncea* grown in solid stand on adjacent field.

with extractable soil N than were N yields of the concurrent maize crop: r= 0.7183 for the pre-planting sampling, and r= 0.5783 for the post-harvest sample. Green matter yield of C. juncea grown adjacent to the experimental site for green leaf manure (GLM or G) is estimated at 27 t/ha and N accumulation in tops at 142 kg/ha. Seed was sown at the same time and spacing as in the experimental area plots. The higher estimated yield might be expected because the GLM field had been fallow during the N-depletion cropping periods.

C. juncea growth rate as represented by increasing plant height is illustrated in Figure 2. When intersown ten days after maize in GMI plots, C. juncea caught up with maize in height about six weeks after sowing the legume.

3.3 Maize yield response to legume and inorganic nitrogen.

3.3.1 Dry matter yield.

Treatment means for grain, stover, grain plus stover, total N uptake and N uptake in grain are presented in ranked order according to their appropriate BLSDs in Table 3; analyses of variance are presented in Appendix 1. For all sets of comparisons, GM (green manure grown in situ) was equivalent to fertilizing with 150 kg/ha N as urea (N_{150}). Green leaf manure (G) at the highest rate was equivalent to N_{150} in grain production but not in stover or total dry matter yield. The control (N_0) was in all cases significantly less than other treatments. Urea levels were significantly different from one another in each case, indicating that the soil was depleted of N to such an extent that a clear response to added N was obtained.

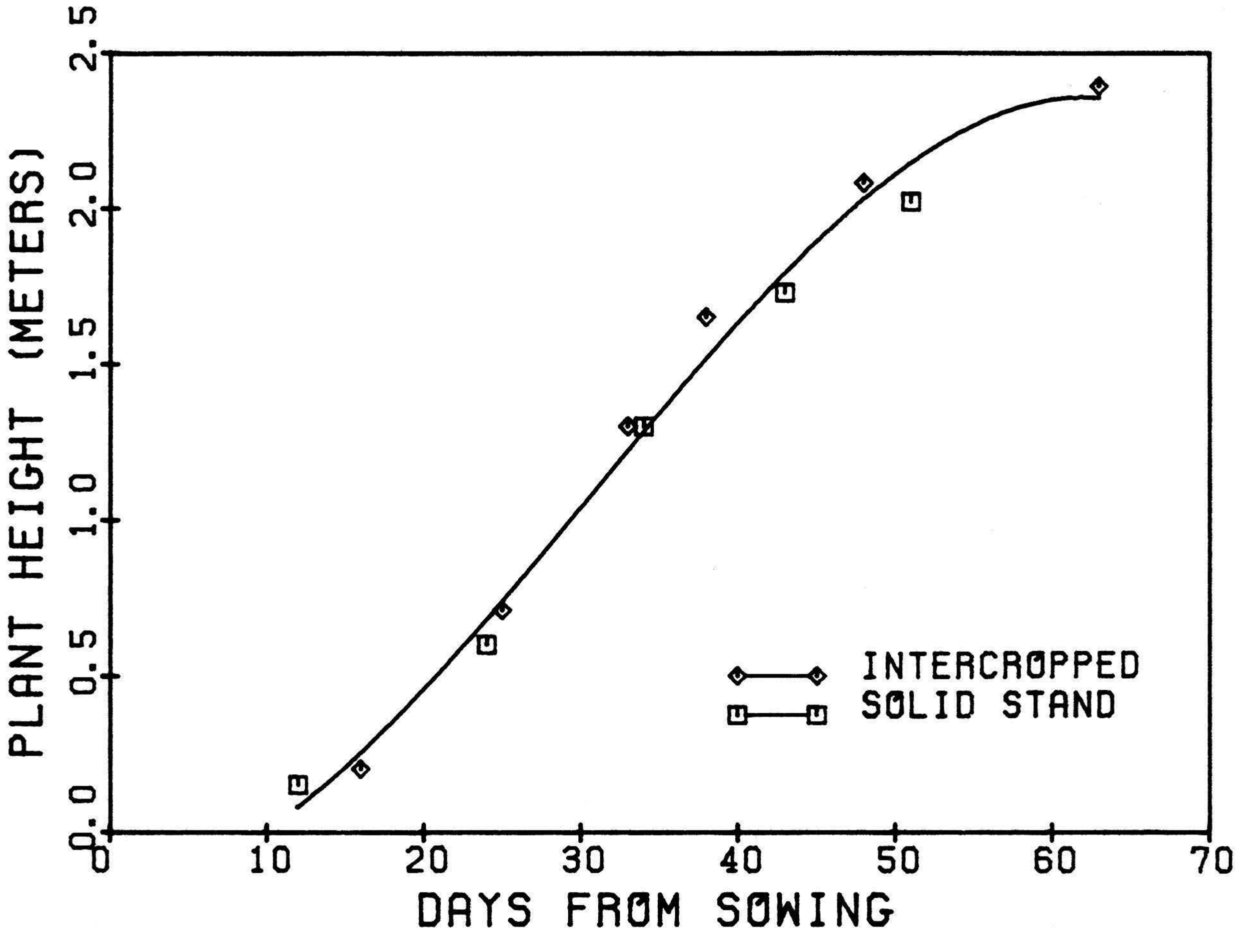


FIGURE 2.
INCREASE IN HEIGHT OF CROTALARIA JUNCEA OVER TIME.

Table 3. Maize dry matter and nitrogen yield responses to inorganic fertilizer and <u>Crotalaria juncea</u> nitrogen sources and rates, ranked and separated by BLSD.

Dry matter yield (t/ha)						Nitrogen uptake (kg/ha)			
Grain		Stover		Grain + Stover		Grain		Grain + Stover	
GM	1.59 a	GM	2.63 a	GM	4.22 a	N150	21.5 a	N150	40.0 a
N150	1.52 ab	N150	2.36 a	N150	3.88 a	GM	21.1 a	GM	39.0 a
G180	1.29 bc	GMR	1.89 b	G180	3.04 b	G180	16.9 b	N100	28.6 b
N100	1.22 c	G180	1.75 bc	GMR	2.96 b	N100	16.6 b	G180	27.9 b
G120	1.08 c	N100	1.71 bc	N100	2.93 b	G120	14.4 bc	G120	25.3 b
GMR	1.06 c	G120	1.60 bcd	G120	2.68 bc	GMR	13.2 c	GMR	24.7 bc
GLMM	0.80 d	G60	1.51 cd	GLMM	2.24 cd	GLMM	10.5 d	GLMM	19.9 cd
G60	0.73 d	GLMM	1.49 cd	G60	2.23 cd	N50	9.4 d	G60	18.1 d
N50	0.70 d	N50	1.36 d	N50	2.06 d	G60	9.3 d	N50	18.1 d
NO	0.36 e	NO	1.00 e	NO	1.36 e	NO	5.2 e	NO	11.3 e
BLSD	0.24	BLSD	0.30	BLSD	0.45	BLSD	2.4	BLSD	5.1

Treatment means followed by the same letter are not significantly different from each other at 0.05 probability level.

Key to abbreviations: GM - in situ green manure; GMR - green manure below-ground residue; G_{60-180} - green leaf manure nitrogen rates, kg/ha; GLMM - green leaf manure mulch, 120 kg/ha N; N_{50-150} - urea nitrogen rates, kg/ha; N_0 - control, no nitrogen applied.

Figures 3, 4 and 5 show treatment means for total dry matter (grain plus stover), grain, and stover yields plotted against N applied; regressions are drawn for urea-N and GLM-N with the control common to both (GLMM is not included in the GLM regressions). Figure 3 includes the treatments excluded from the analyses of variance because of inadequate replication or replicate distribution; the BLSD given in Table 3 does not apply to these treatments. The nearly linear response to urea further emphasizes that nitrogen was the major limitation to growth for the yield levels encountered in this experiment.

The relatively flatter regressions for GLM treatments are a reflection of a less significant response by maize to the burial of legume tops as a nitrogen source. No one successive GLM rate produced significantly more stover than the other, and only the highest and lowest GLM rates were significantly different in total dry matter response. For grain production, G_{180} was equivalent to N_{150} but not significantly better than G_{120}, while G_{60} was significantly less than either of the higher rates. The G_{60} rate was by all considerations equivalent to 50 kg N as urea, and the two middle levels, G_{120} and N_{100}, were also equivalent.

The green leaf manure as mulch was not as good as the green leaf manure incorporated into the soil in terms of grain yield but the two were equivalent in terms of stover and total dry matter yields. For all three yield parameters, GLMM was in the same rank with the lowest rate of urea- and GLM-N.

GMR, the residues and below-ground portions of legumes grown in situ, produced yields ranked with the two highest GLM rates and N_{100}. In all respects it produced significantly greater responses than G_{60}

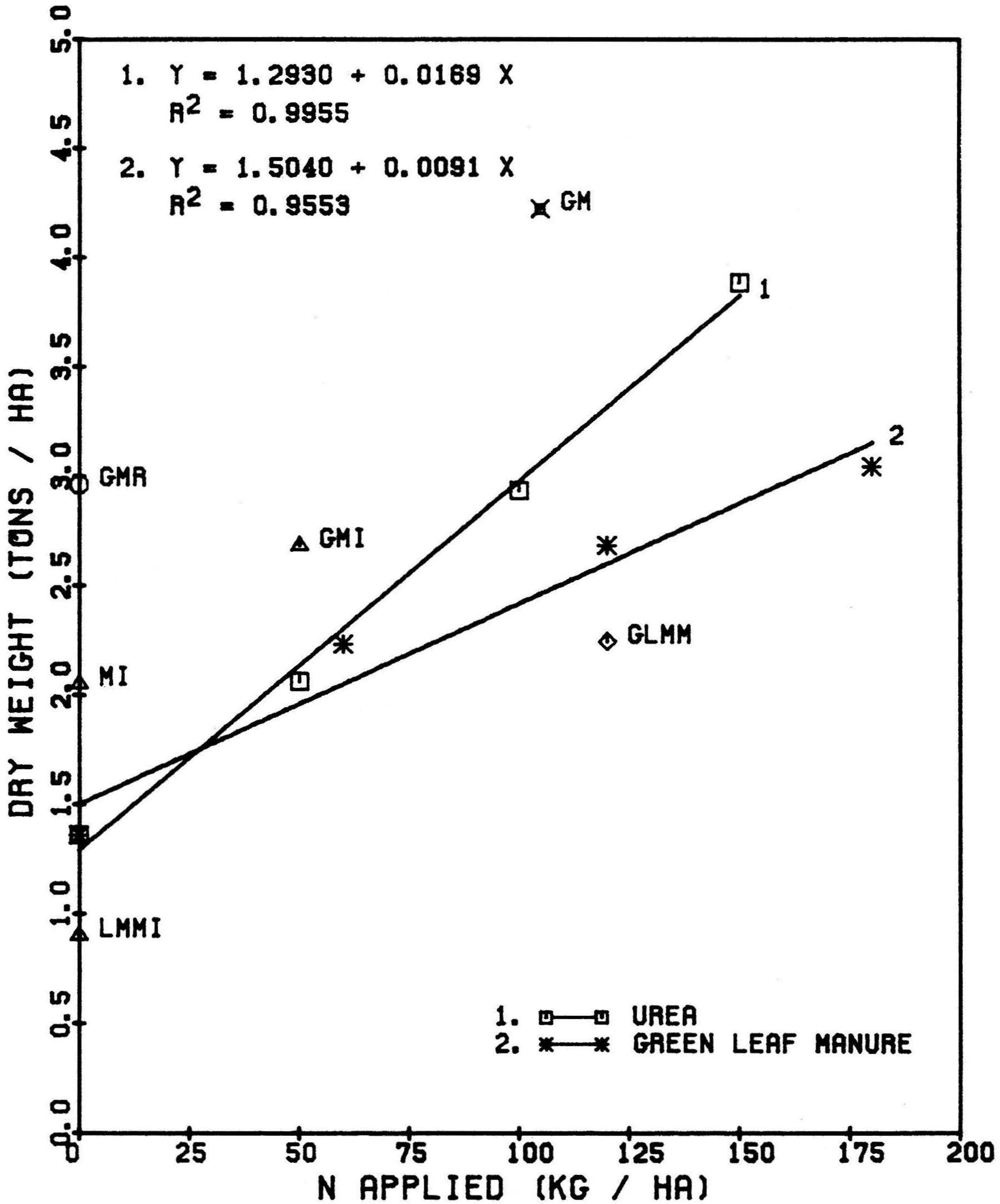


FIGURE 3.
TOTAL DRY MATTER YIELD OF MAIZE (GRAIN + STOVER) IN RELATION TO LEVELS OF N APPLIED AS INORGANIC FERTILIZER OR AS CROTALARIA JUNCEA.

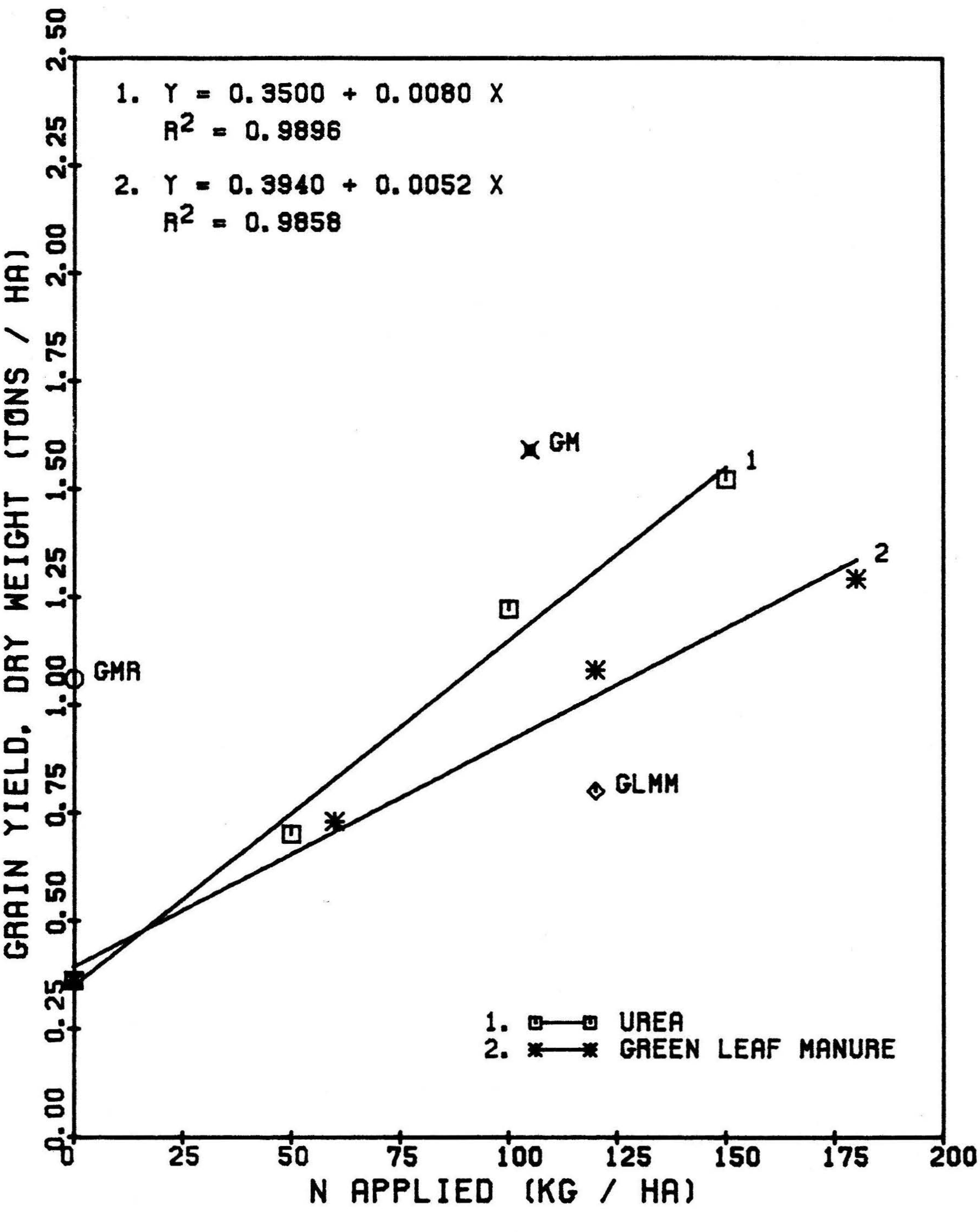


FIGURE 4.
GRAIN YIELD OF MAIZE IN RELATION TO LEVELS OF N APPLIED AS INORGANIC FERTILIZER OR AS CROTALARIA JUNCEA.

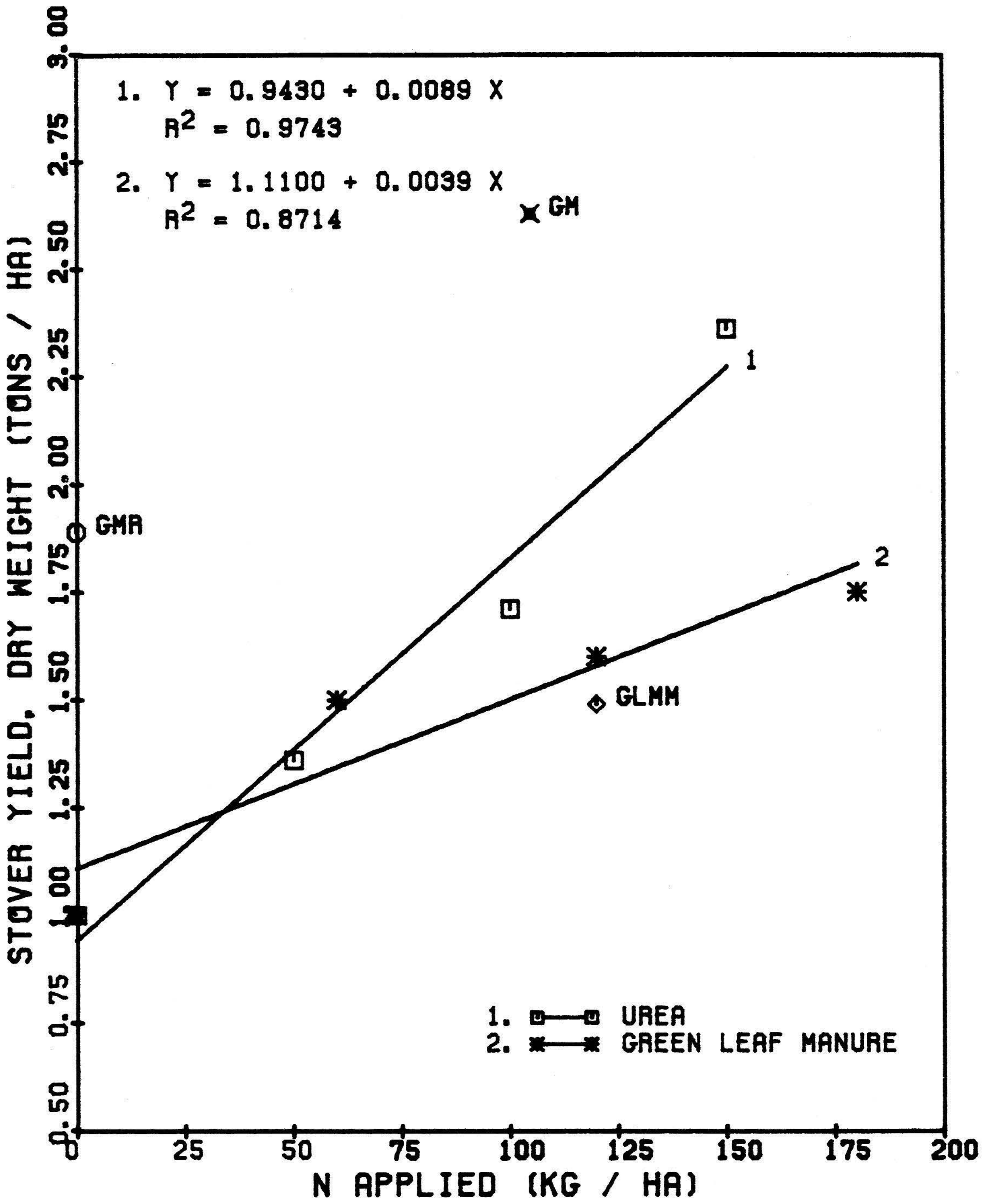


FIGURE 5.
STOVER YIELD OF MAIZE IN RELATION TO LEVELS OF N APPLIED AS INORGANIC FERTILIZER OR AS CROTALARIA JUNCEA.

and N_{50}. Since no direct estimation of root and nodule yield and N content was made, GMR yields are plotted on the y axis as zero N applied in all figures.

Grain and dry matter yields in this experiment were very low compared to the results of Jong et al. (1981) with hybrid maize at Waimanalo; grain responses to GM and N_{150} were about half the lowest yields they obtained. Their data showed that at Waimanalo yields were highly correlated with monthly incident light values, and that the short days and heavy cloud cover of winter months resulted in yields 70% lower than yields from summer plantings. The test crop in this experiment was sown in late November, the period of planting for which Jong et al. recorded their lowest yields. Low light apparently had a major effect limiting yield expression in this trial. Low levels of residual nitrogen on the site due to growth of three N-depletion crops obviously played a part in reducing yields, but it is not known why responses to high N rates were as low as they were.

3.3.2 Maize nutrient uptake.

3.3.2.1 Nitrogen uptake.

Nitrogen percentages of maize grain and stover dry matter are recorded in Table 4. Table 3 showed the ranking and separation of treatment means for grain N and total N uptake; they are plotted in Figure 6 and the ANOV are presented in Appendix 1. Mean separations for grain plus stover (total) N are similar to those shown for total dry matter in Table 3 except that G_{120} was significantly better than GLMM and GMR was not significantly different from GLMM in terms of N uptake.

Table 4. Maize nitrogen content as affected by inorganic fertilizer and *Crotalaria juncea* nitrogen sources and rates.

Treatment	N content	
	Grain	Stover
	%	
N0	1.44	0.62
GM	1.33	0.68
GMR	1.24	0.61
G60	1.27	0.59
G120	1.34	0.67
G180	1.31	0.63
GLMM	1.32	0.62
N50	1.36	0.63
N100	1.36	0.70
N150	1.42	0.77

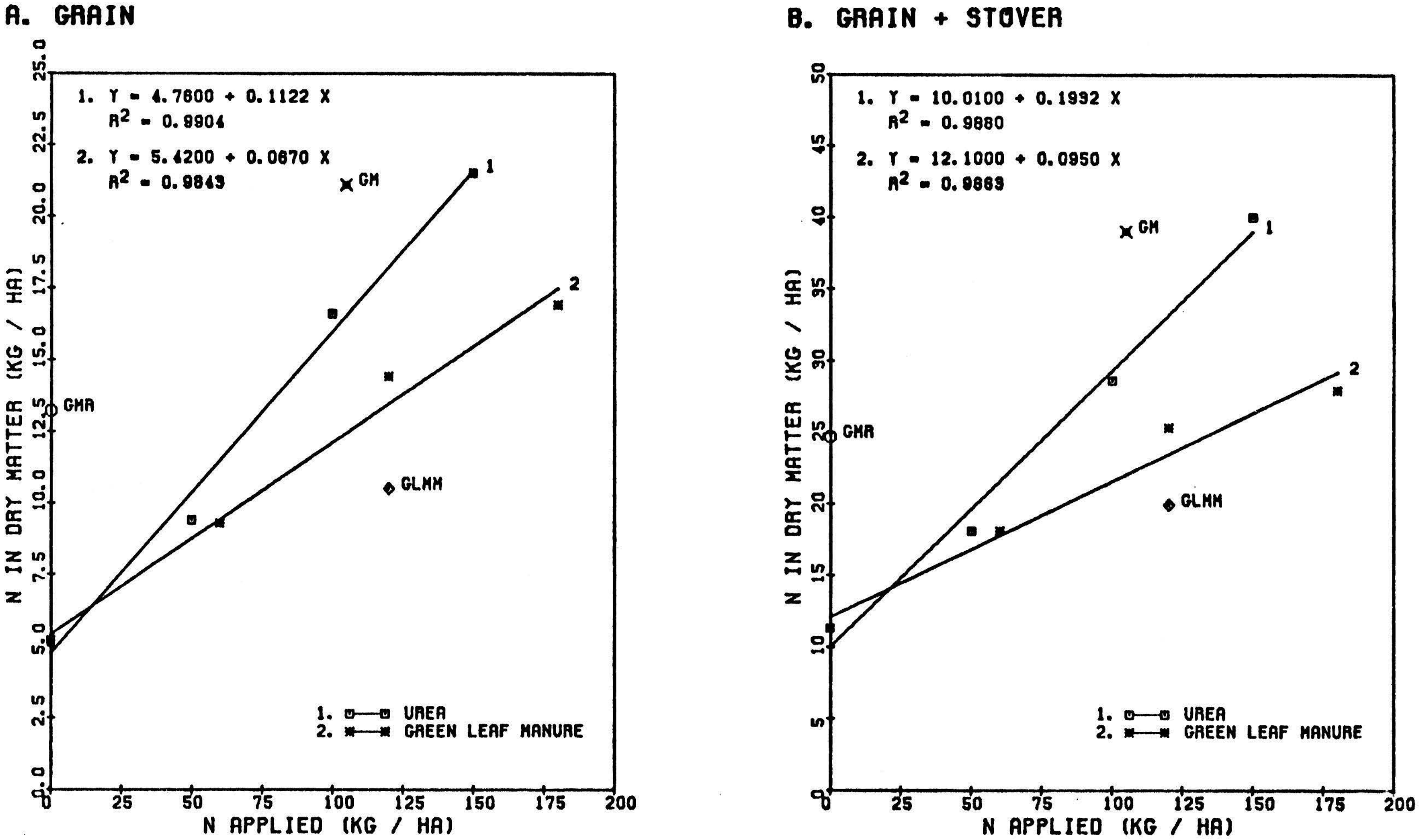


FIGURE 6.
N UPTAKE OF GRAIN AND TOTAL N UPTAKE OF MAIZE (GRAIN + STOVER)
IN RELATION TO LEVELS OF N APPLIED AS INORGANIC FERTILIZER
OR AS CROTALARIA JUNCEA.

GM and N_{150} produced similar maize N uptake responses, significantly more than the next rank grouping containing N_{100}, G_{180}, G_{120} and GMR.

Mean separations for grain N content show a similar pattern to whole-plant N except that the response to GMR is here statistically equivalent only to G_{120}, emphasizing its contribution to stover yield as opposed to grain yield. In the same manner, response to GLMM is here significantly less than to GMR, while they were equivalent in terms of total N uptake of grain plus stover.

3.3.2.2 Phosphorus and potassium uptake.

Phosphorus and potassium contents of grain and stover are ranked and separated by BLSD in Table 5, and the ANOV are in Appendix 1. Comparing treatments for P uptake in grain and stover reveals that when nitrogen is not in adequate supply, most of the P is in the stover. However, when more N is available for grain production, grain becomes a sink for plant P and as N uptake increases, the rankings show that increasing proportions of plant P are stored in the grain. Means for K in grain show a broad overlap, while there is a greater distinction among means for K in stover. The probably occurs because potassium is accumulated primarily in the leaves and stems of plants, not in grain. GM provided significantly higher stover K levels than other treatments.

3.3.3 Yield of maize seedlings.

Maize plants were harvested at five weeks, nine weeks from legume and inorganic N treatment applications, to obtain an indication of relative N availability from legume and urea N during early growth. The mean yields, N percentages and N uptake of seedlings are ranked and

Table 5. Phosphorus and potassium uptake of maize grain and stover in response to inorganic fertilizer and *Crotalaria juncea* nitrogen sources and rates, ranked and separated by BLSD.

Phosphorus				Potassium			
Grain		Stover		Grain		Stover	
			kg/ha				
GM	7.6 a	GLMM	6.2 a	GM	3.2 a	GM	30.1 a
N150	7.0 ab	G120	5.9 a	N150	2.9 ab	N150	24.8 b
G180	5.6 bc	GMR	5.8 a	G120	2.4 ab	G180	20.6 bc
G120	5.6 bc	G60	5.4 a	G180	2.3 ab	GMR	20.0 c
N100	5.3 bc	N150	5.2 a	N100	2.0 abc	N100	17.0 cd
GMR	4.8 c	N0	5.1 a	N50	1.8 bc	GLMM	15.4 d
G60	4.3 c	G180	5.1 a	GMR	1.7 bc	G120	14.5 de
GLMM	4.0 c	GM	5.0 a	G60	1.6 bc	G60	14.0 de
N50	3.9 c	N100	4.9 a	GLMM	1.6 bc	N50	10.9 ef
N0	1.9 d	N50	4.6 a	N0	0.7 c	N0	8.4 f
BLSD	1.8	BLSD	1.6	BLSD	1.4	BLSD	4.3

Treatment means followed by the same letter are not significantly different from each other at 0.05 probability level.

separated by BLSD in Table 6; the ANOV are in Appendix 1. Analyses of variance reveal highly significant treatment effects for each of these data sets.

Ranking of treatments is identical for yield and N uptake. Responses to urea N are higher than to legume N and are significantly different from one another. GLM rates are significantly superior to N_0, and equivalent to urea at 50 kg N. Response to GLMM is higher than to G_{120}, whereas GLMM was ranked below G_{120} in all of the final harvest yield parameters previously examined.

The yield and N uptake response to GM at seedling stage was, unlike at the final yield stage, equivalent to N_{100}, but once again was not significantly different from N_{150}. GMR effects were equivalent to N_{100} in dry matter yield and N uptake, and also to GLMM and G_{180}. This underscores the appreciable quantity of available nitrogen soon after incorporation in GM and GMR treatments.

N uptake of the maize seedlings is plotted against N applied in Figure 7. The same linearity of urea and GLM responses which characterized the harvest data is apparent at this stage. The greater difference in slope between these lines than between lines for harvest data probably reflects greater initial availability of urea N than of legume N.

3.3.4 Maize plant height.

Maize growth between the seedling and final harvest samplings is represented by plant height in Figure 8. Increases in height for the two lower urea-N treatments between 47 and 57 days were less than the increases for legume treatments, while control plants grew very little between 47 and 67 days. GLM-N may have become increasingly available

Table 6. Five-week-old maize plant yield, nitrogen content and nitrogen uptake in response to inorganic fertilizer and Crotalaria juncea nitrogen sources and rates, ranked and separated by BLSD.

Dry Matter Yield		Nitrogen Content		Nitrogen Uptake	
	gm/plant		%		mg/plant
N150	3.1 a	GM	2.25 a	N150	65 a
GM	2.8 ab	N150	2.13 ab	GM	63 ab
N100	2.6 bc	GMR	2.10 b	N100	53 bc
GMR	2.4 cd	N100	2.09 b	GMR	51 c
GLMM	2.2 de	G180	2.06 bc	GLMM	44 cd
G180	2.1 de	GLMM	2.00 bcd	G180	44 cd
N50	2.1 de	G120	1.99 bcd	N50	39 d
G120	1.9 e	N50	1.89 cd	G120	38 d
G60	1.8 e	NO	1.88 cd	G60	34 d
NO	1.3 f	G60	1.86 d	NO	23 e
BLSD	0.4	BLSD	0.19	BLSD	10

Treatment means followed by the same letter are not significantly different from each other at 0.05 probability level.

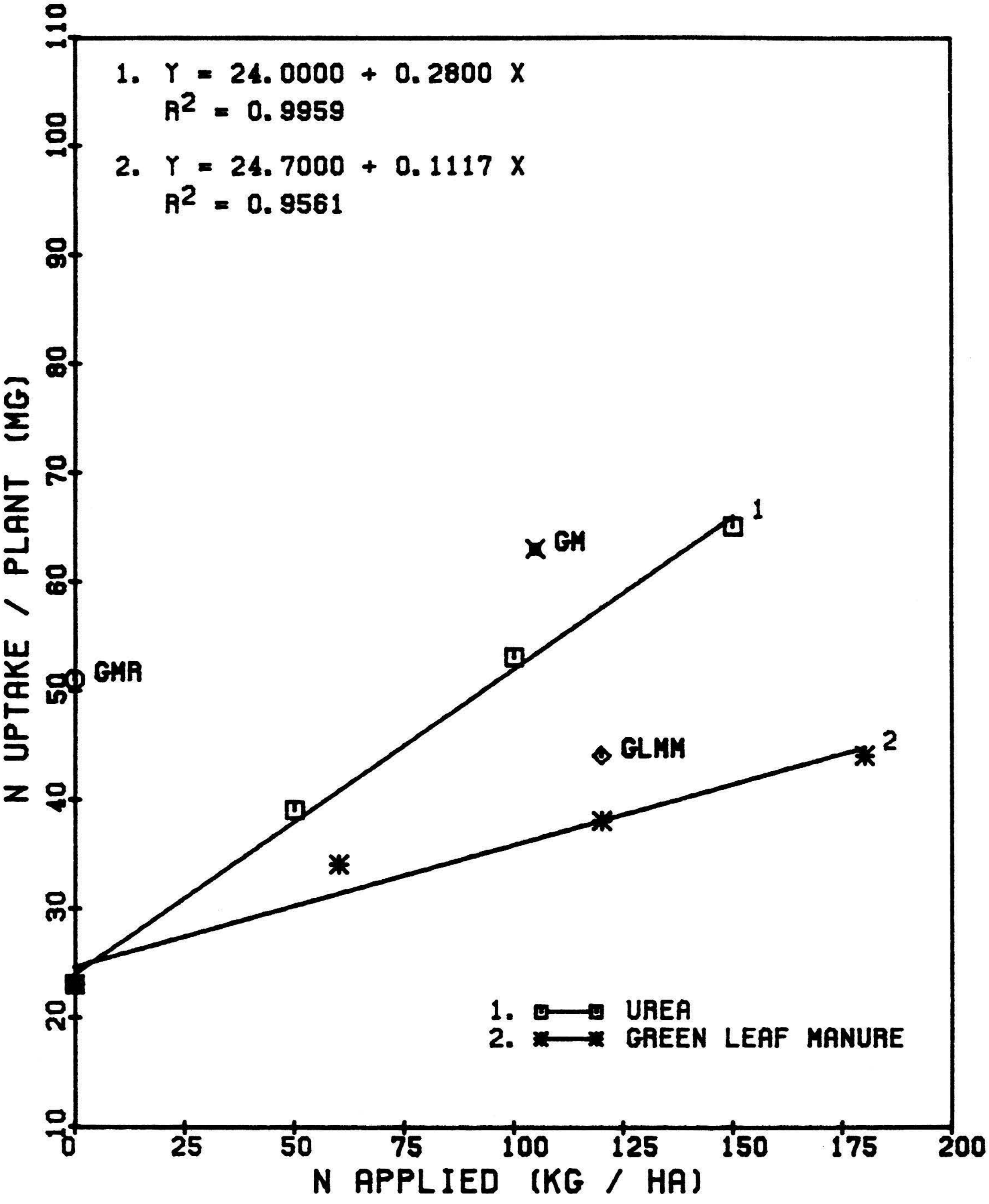


FIGURE 7.
N UPTAKE OF FIVE-WEEK-OLD MAIZE PLANTS IN RELATION TO N APPLIED AS INORGANIC FERTILIZER OR AS CROTALARIA JUNCEA.

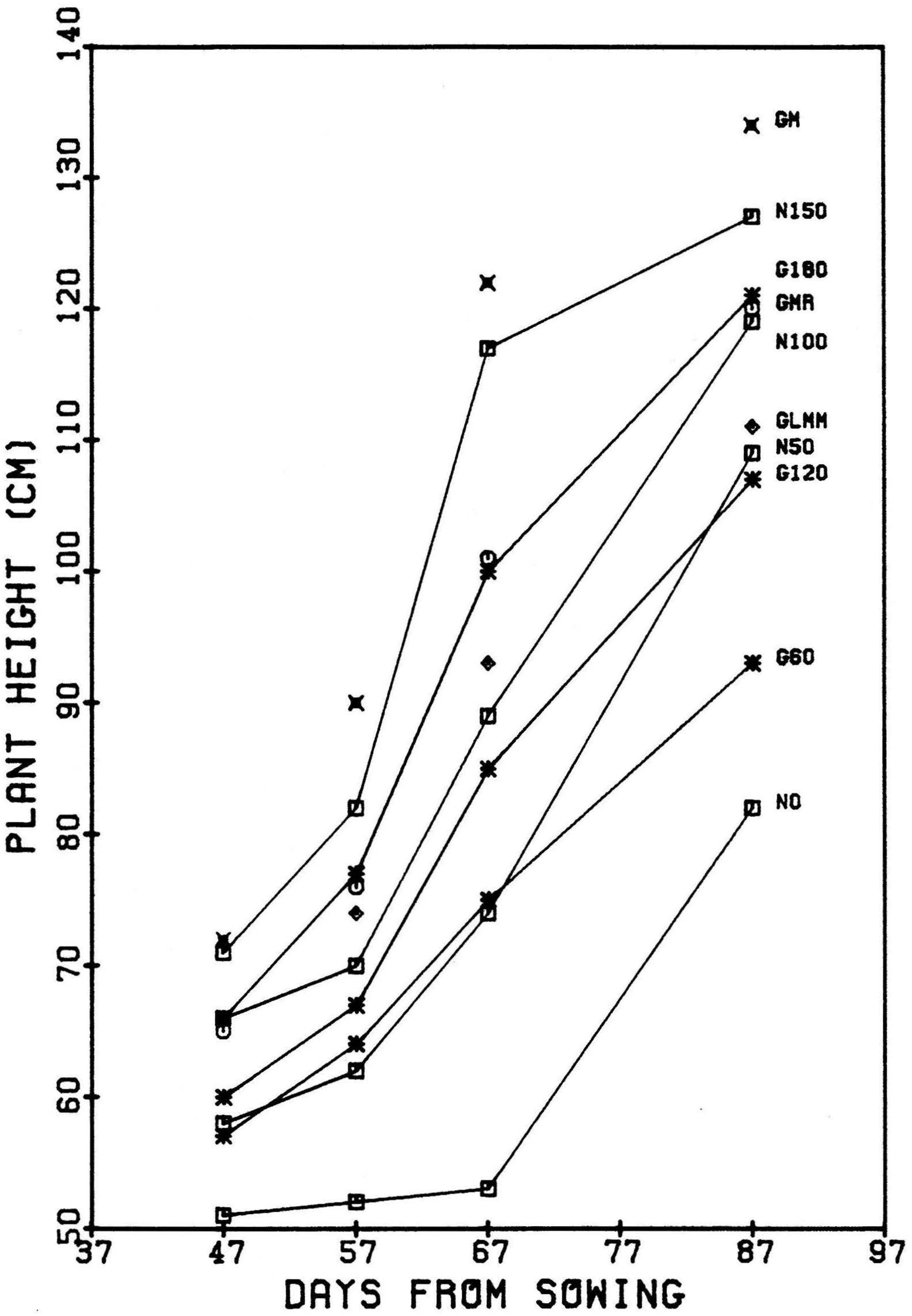


FIGURE 8.
INCREASE IN HEIGHT OF MAIZE, GIVEN DIFFERENT RATES AND SOURCES OF NITROGEN, OVER TIME.

during this first measured period. From 57 to 67 days, height increases for most treatments reflect a log phase growth increase prior to tasseling at about 67 days. It seems that maize following GM had entered this phase somewhat earlier than other treatments, and tasseling occurred earlier in GM and other high-N treatments than in low-N treatments and the control. Whatever the conditions influencing plant height during this period were, it is apparent that they were more or less uniform for the corresponding rates of urea and legume N sources. Parallelisms during this period were more or less maintained during the 67 to 87 day period, but N_{100}, N_{50} and N_0 plant heights increased somewhat more than other treatments. The plants in the GM and N_{150} treatments may have reached a plateau regulated by growth factors not monitored in the experiment.

3.4 Comparison of legume and inorganic nitrogen sources.

The effect of applied N in treatments is compared in two ways: (1) by the efficiencies with which maize took up applied nitrogen according to N uptake data, and (2) by the equivalents to inorganic urea-N application rates of the maize responses to legume-N, and their equivalent efficiencies, according to dry matter and N uptake data. In following sections, the different nitrogen sources are compared and discussed.

3.4.1 Efficiencies of applied nitrogen.

The efficiency with which maize plants utilized applied nitrogen, as represented by the percentage of applied N harvested in maize grain plus stover, is illustrated in Figure 9. Highest efficiencies are

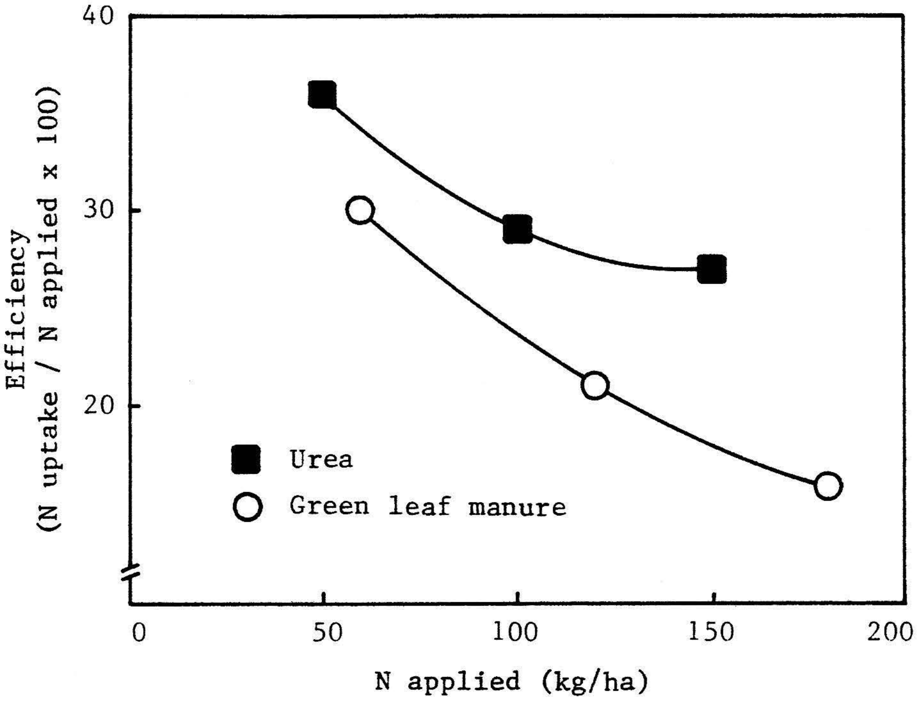


Figure 9. Efficiency of applied N from inorganic fertilizer and *Crotalaria juncea* sources at different levels of application.

associated with lower rates of N, in agreement with the conclusion of Fribourg (1954) in reviewing U.S. midwest maize trials, that as yields and nitrogen applications increase, fertilizer efficiency decreases. The decrease in efficiency of increasing N applications is more accentuated for the green leaf manure source and of less magnitude between the higher rates. Lohnis (1926) also found that small amounts of green manures generally resulted in higher efficiencies than larger quantities. The average of the efficiencies for the sources and rates shown in Fig. 9 is 27%. The average source efficiency for all rates is 31% for urea N and 22% for incorporated GLM-N. These values are low compared to the range of 50 to 75% recovery for inorganic N and 35 to 65% recovery for green manure N reported by Fribourg (1954).

At Waimanalo, a second maize planting was made following harvest of the test crop to find out how much of the unaccounted-for N is recoverable. Results of that planting are reported in Appendix 2.

3.4.2 Inorganic N-equivalents and equivalent efficiencies.

Inorganic nitrogen equivalents of the different legume N sources and rates as calculated from regressions of maize responses on urea application rates for various yield parameters are presented in Table 7, where yields for legume treatments were applied to the urea regressions, and values for x' are recorded as "I", the inorganic or urea N-equivalent. This is the amount of N as urea that would produce a yield identical to that of the particular source and rate in question. Generally, higher urea N-equivalents are associated with dry matter production (bases 1 and 4 in Table 7) than with N content of the dry matter (bases 2 and 3), which may mean that legume N was more available during the growth stage

Table 7. Inorganic nitrogen equivalents of legume treatments and their efficiencies in relation to applied nitrogen.

			Urea-N Equivalent $(I)^+$						I/N					
			Basis						Basis					
Treatment	N source	N Applied $(N)^{++}$	Total Dry Matter (1)	Total N (2)	Grain N (3)	Grain Dry Matter (4)	$\bar{X}$ (1-4)	N in Seedlings (5)	(1)	(2)	(3)	(4)	$\bar{X}$ (1-4)	(5)
		kg/ha	-------------------	-----	-----	kg/ha	-----	-------------------						
GM	tops plus residues*	105	174	150	145	155	156	139	1.65	1.43	1.38	1.48	1.49	1.32
GMR	residues	0	99	76	75	81	83	96	-	-	-	-	-	-
G_{60}	tops	60	56	42	40	48	47	36	0.93	0.70	0.67	0.80	0.78	0.60
G_{120}	tops	120	82	79	86	91	85	50	0.68	0.66	0.72	0.76	0.71	0.42
G_{180}	tops	180	104	93	108	118	106	71	0.58	0.52	0.60	0.66	0.59	0.39
GLMM	tops	120	56	51	51	56	54	71	0.47	0.43	0.43	0.47	0.45	0.59
$\bar{X}$			95	82	84	92	89	71						

+ Equivalents based on regressions of maize yield on urea applications as given in the following figures for the bases indicated: (1) Figure 3; (2) Figure 6B; (3) Figure 6A; (4) Figure 4; (5) Figure 7.

++ Nitrogen applied in legume tops to entire plot area.

* Residue nitrogen contribution not measured; residue = roots, nodules, litter, stubble, exudates.

determining dry matter yield, whereas uptake of urea N continued at higher rates than legume N through the maturation period, and there was perhaps more redistribution of plant N in the legume treatments than there was continued uptake. Within dry matter production, GM, GMR and G_{60} have their highest equivalents associated with total dry matter yield, while those for G_{120} and G_{180} are highest in respect to grain dry matter yield. This same pattern occurs to a lesser degree with nitrogen accumulation in total dry matter and in grain. This may be due to the availability pattern just mentioned, with the qualification that the larger amounts of incorporated material were delayed in providing available N. GMR and, to a remarkably greater extent, GLMM have high equivalents in terms of their effects on maize seedling N content; GM and GLM treatments, especially G_{120} and G_{180} show their lowest equivalents for this basis.

The average of urea N-equivalents for harvest bases 1 to 4 is also shown in Table 7. Green manuring in situ has an equivalent greater than the highest urea rate. Green manure below-ground residues are seen to have acted, on the average, like 83 kg of urea N.

3.4.3 Effect of green leaf manure.

Ratios of treatment urea N-equivalents to applied N are also presented in Table 7. The averages of equivalent efficiencies for harvest bases 1 to 4 for GLM incorporated treatments show that GLM-N was from 59 to 78% (average 69%) as efficient as urea N in terms of urea N-equivalents; when mulched, legume N was 45% as efficient as urea N in these terms.

Figure 10 graphically illustrates the urea N-equivalent efficiencies for GLM at successive rates for different harvest bases. Declines in efficiency in regard to grain yield and total nitrogen are greatest between G_{120} and G_{180}. This reflects the leveling off of responses to GLM between G_{120} and G_{180} as may be seen in the tendency toward curvilinearity in plots of yields (Figures 3, 4, 5, 6a and 6b), and the lack of significant differences between the rates for all yield parameters except K in stover.

GLM incorporations were a mixture of high C:N ratio stems and low C:N ratio leaves. Leaves generally have greater surface-to-volume ratios and moisture contents and decompose more rapidly than stems. Undecomposed stem materials were found in the incorporation sites of GLM plots six months after burial. The greater size of buried bundles of stems in the G_{180} treatments may have presented a greater impediment to maize root development. Later in the decomposition sequence from easily to less readily decomposed materials, after an initial flush and uptake of mineralized leaf N, the greater mass of low-N material in higher GLM treatments may have produced a greater demand on the soil environment for N for its decomposition, and may have immobilized soil N to a proportionately greater extent than lower application rates, thus decreasing efficiencies. On the other hand, it is also possible that some stem N was released during the later maize growth stage, accounting for the effect on grain yields in the higher GLM treatment rates. Decomposability is apparently an important factor in using legume N; Ramirez (1972) found a higher maize yield response to C. juncea grown to floral initiation (55 days, 108 kg/ha N) than to greater amounts of N incorporated as C. juncea at later growth stages.

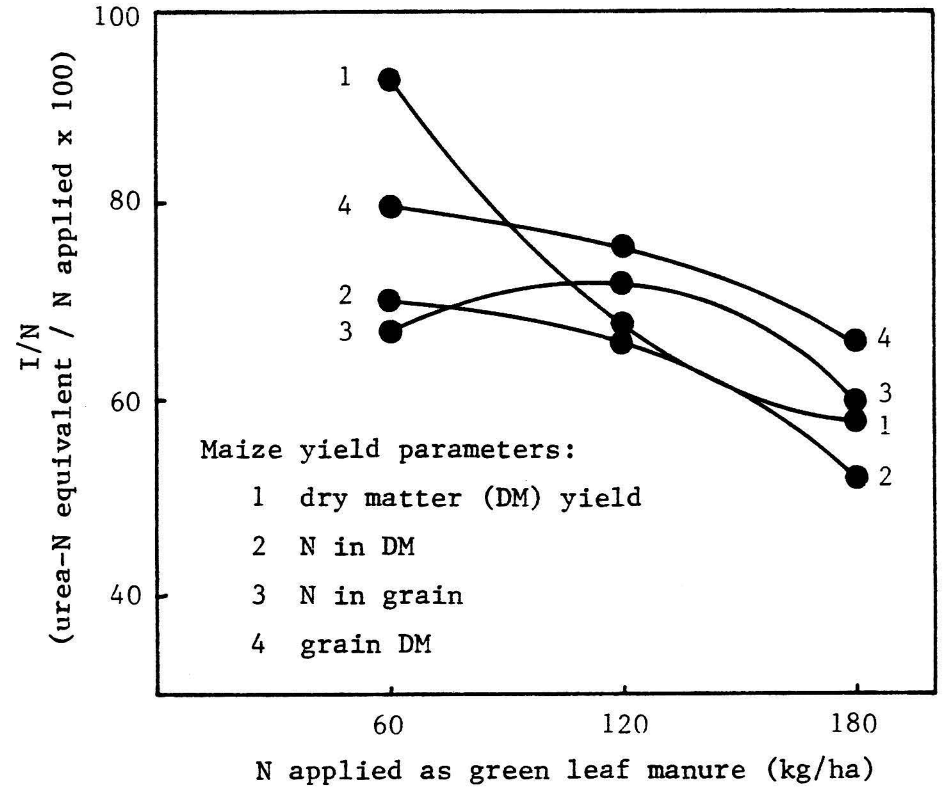


Figure 10. Efficiency of N applied as Crotalaria juncea green leaf manure in terms of the urea N-equivalents of application levels as determined on the bases of four maize yield parameters.

Urea N is rapidly available in most soils very soon after application. Even though GLM leaf N is quickly mineralized, there is a lag in its availability compared to urea. This was seen in data on 5-week-old seedling yield and N uptake, where no GLM rate was statistically different from N_{50}. Low rankings of GLM effects on seedlings may be due to a combination of a slower rate of availability of the legume nitrogen because of slower breakdown in the soil, and a lower quantity of available N because of storage of some of the N in stem tissues having a higher C:N ratio than the leaves.

Greater plant size at seedling stage confers an advantage which allows plants to intercept more light and exploit a larger soil volume. However, the GLM treatments showed a greater increase in plant height than urea treatments during the seventh week after sowing (Figure 8), and it was presumed that GLM-N was becoming increasingly available during this period. It is probable that GLM-N reached its peak availability during the seventh to tenth week of maize growth, and that availability declined thereafter compared to urea N (see Fig. 8). GLM-N was apparently available in comparable quantity for all GLM levels during the first 2.5 months, since it is during this period that stover yield is determined (Hanway, 1971), and GLM rates were not statistically different for stover yield at harvest. During the subsequent grain-filling stage, available N apparently declined for the low GLM level, while the two higher GLM rates maintained available N levels to the extent that grain yields and total N uptake were significantly greater than for G_{60}.

G_{180} produced yield responses higher than G_{120}, but it was not significantly better. Although it represented a greater N addition than

N_{150}, because of differences in N availability they were statistically similar only in grain yield response. Comparing the three GLM rates, it appears that G_{120} was the optimal rate for this experiment.

The N levels above which urea produced significantly greater maize yield responses than GLM are shown in Table 8. These levels were obtained by applying the BLSDs already presented to the regression lines in the appropriate figures. While these levels are in part a function of the dispersion of the data for the different parameters, they suggest that under the conditions of low levels of available soil nitrogen in this experiment, legume nitrogen can have a favorable effect on maize grain production. It may further be suggested that when low rates of nitrogen (100 kg/ha or less) are being applied, green leaf manure nitrogen can be as effective as urea on a kg-for-kg basis in producing maize grain.

3.4.4 Effect of mulched v.s. incorporated green leaf manure.

Mulched green leaf manure was 79% as effective as the same rate of buried GLM based on maize yield responses at final harvest. As mentioned previously, these treatments were reversed in their effect on five-week-old maize seedlings, and the GLMM effect on seedling yield and N content averaged 115% of G_{120}, although the differences between the two treatments were not significant. Since the methods of application have very different effects on the soil, especially soil physical conditions, it is difficult to relate these two treatments strictly on an N-applied basis. The experiment was not designed to explore soil physical effects, but a series of soil temperature measurements were made beginning 49 days after planting maize (11 weeks from mulch application) to compare soil temperature under mulch with that of bare soil in adjacent plots, with similar

Table 8. BLSD values applied to regressions of maize yield responses on urea and C. juncea green leaf manure levels.

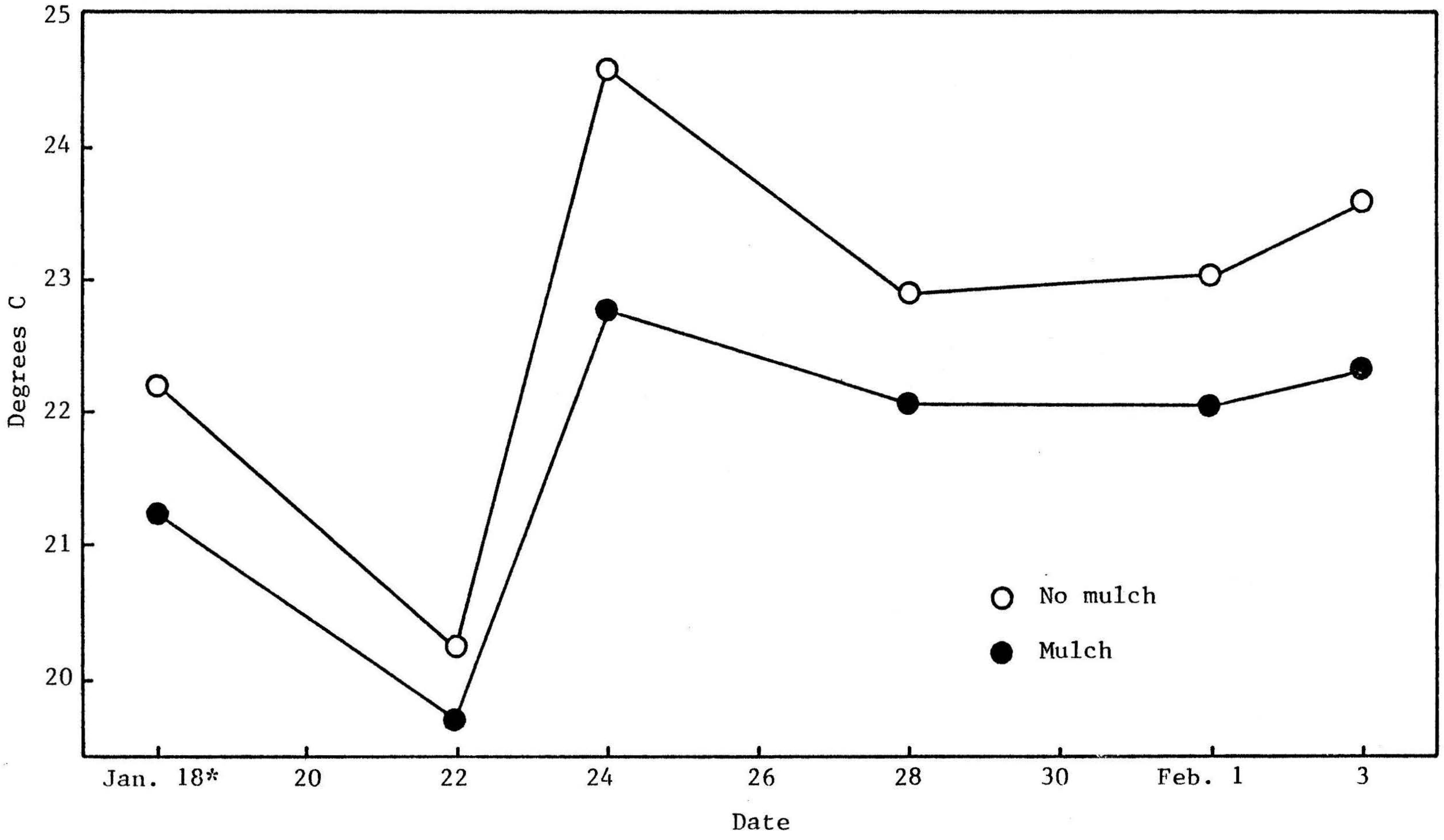
Maize Yield Parameter	N Level Above Which Urea Is Significantly Different From Green Leaf Manure *
	kg/ha
Grain dry matter	102
Stover dry matter	94
Total dry matter	85
Grain N uptake	70
Total N uptake	70
Seedling dry matter	60

* See Figures 3, 4, 5, 6A, 6B and 7 and their respective BLSD values.

maize stands, in which legumes had not been buried. The plot of these data, shown as Figure 11, reveals that mulch lowered late-afternoon soil temperature by an average of about one degree C over the period of observation, and that the degree of insulation by mulch was greater when soil temperatures were higher.

Mulching of green leaf manure resulted in similar dry matter yield but less grain yield and less total N uptake than incorporation of the same amount, once again indicating an early effect on maize, which subsequently diminished to a greater extent for GLMM than for G_{120}. Fresh material placed on the soil surface is more subject to N losses by ammonia volatilization than when buried. Joachim (1928) found that alternating wet and dry periods increased N losses from mulched GLM, but did not speculate on the fate of that N. IITA (1980) reported low utilization of N in _Leucaena_ leaf loppings applied as mulch to maize, but incorporation was said to constitute an intolerable erosion hazard under local conditions. While leaf N may have washed into the soil from the soil surface, N in _C. juncea_ stems probably did not become available in the mulched treatment, because stems lying on the surface decomposed only slightly.

Lack of differences among GLMM and G_{60} or N_{50} for any yield parameter measured indicates that where low rates of N are being applied or where incorporation of GLM is difficult or undesirable, mulching may be an acceptable alternative. Where biomass, or stover production are the objectives, results here indicate that mulching GLM is as effective, respectively, as G_{120}, or as G_{120} and G_{180}. There are also undoubtably cropping situations wherein advantages of mulching associated with its



* 11 wks from mulch application.

Figure 11. Soil temperature of maize plots at 15 cm depth under mulch and bare soil.

soil-covering and insulating properties, and perhaps with its effects on soil moisture conditions, would make it the preferred alternative. It is further possible that when applications of inorganic N, especially during the post-seedling stage, are combined with the use of GLM, further benefits of mulching would be revealed.

3.4.5 Effect of legume below-ground residue.

As noted previously, the average urea N-equivalent of the green manure below-ground residue treatment (GMR) is 83 kg/ha. The pronounced effect of the residues on early maize growth compared to green leaf manure is corroborated by the calculated equivalent of 96 kg urea N for GMR on the seedling-N basis (number 5 in Table 7). If the 83 kg urea N-equivalent of GMR is compared to total N uptake for the treatment as was done with actual rates for GLM and urea in Figure 9, an efficiency of 30% is obtained, which is more comparable to the average efficiency of applied N for urea (31%) than GLM (22%). These estimations made to characterize the response of maize to GMR cannot be construed to mean that it was solely an N response, or that any particular amount of N was contained in legume roots plus nodules plus exudations and litter; other factors may also have been operative, chiefly the ramification of the soil by the more deeply-penetrating legume roots, which may have allowed maize roots to exploit a larger soil volume than they could when tillage was confined to the soil surface and only maize had been grown.

Because the yield of C. juncea tops on GMR plots was identical to the G_{120} application rate, comparison of these two treatments is appropriate. The results of this experiment fall among those of other workers cited in the introduction who obtained considerable response to the below-ground component. GMR was here statistically equivalent to G_{120} in all respects. This is at variance with, for example, the results of Kute and Mann (1969b) who, growing C. juncea for the same period, found GLM significantly better than GMR by a 21% increase in wheat yields.

Inorganic N-equivalents and efficiencies as reported by Fribourg (1954) and Stickler et al. (1959) did not distinguish the below-ground component; although they measured the root N contribution, it was combined in the total N-applied as green manure.

In summary, green manure below-ground residues made a substantial contribution to maize, producing grain and stover yields and N accumulations statistically equivalent to 100 kg N as urea. At maize seedling stage, N was available in amounts equivalent to N_{100} and superior to that available from the incorporation of the tops as represented by G_{120}. The early contribution to yield of GMR is also seen in its effect on stover yields (Figure 5) and through stover on total dry matter (Figure 3). There was a tendency for the N supply in this treatment to decline during the later grain-filling period.

3.4.6 Effect of in situ green manure.

Maize yield response to incorporation of legume tops on the site where they were grown (GM) was not statistically different from N_{150} and was significantly greater than all other treatments. The GM treatment combined the below-ground component of the GMR treatment with approximately the same rate of tops as was incorporated in the G_{120} green leaf manure treatment. Similarity to the GMR treatment was apparent in high availablity of N during the early growth stages. GM had, like GMR, an effect on five-week-old seedling dry matter and N content equivalent to

N_{100}, but the GM response was significantly greater than GMR and was also statistically equivalent to N_{150}. The GM effect on stover yield was also quite pronounced, being very near to significantly greater than N_{150}. Maize plants in GM treatments were consistently taller than all others (Figure 8).

Both GMR and GLM treatments apparently failed to maintain adequate N levels into the maize growth stage where grain filling was occurring, but this was not the case for GM. It is possible that the readily available nitrogen of the GMR component combined with the easily decomposed leaf component to offset the high C:N ratios of stems and thus influence not only the rate but the quantity of available N. Whatever soil physical effects were favoring maize growth in the GMR treatment were also present with GM. Likewise, to the extent which incorporation of tops was physically beneficial to G_{120} treatments, GM was also so favored, and if there was a detriment, it may have been offset in the GM treatment by advantages associated with the GMR component.

Urea N-equivalents shown in Table 7 for GM generally were greater than N_{150}. Higher equivalents for GM (when urea = 1.00) are, however, an artifact of the unquantified GMR-N contribution not included in the value of 105 kg/ha N applied (as tops) in the GM treatment. If the estimated urea N-equivalent of GMR (83 kg) is added to the GM tops application rate, a value of 188 kg/ha N is obtained, which would shift the plot of GM yield responses in Figures 3, 4, 5, 6a and 6b to the right. Equivalent efficiencies would then equal urea N for stover yield, be slightly less for total dry matter yield, and be midway between urea and G_{180} for grain yield and for N uptake. These equivalent efficiencies would then correspond more closely with the urea N-equivalents given for GM.

A similar manipulation may be done with the efficiency of applied N. Had the GM treatment been calculated on the basis of N applied in tops as was done for GLM in Figure 9, its efficiency (total N uptake over N applied) would have been 37%. If the estimated value of 76 kg/ha N for GMR on the total N uptake basis (Table 7) is added to the 105 kg N applied as GM tops, an efficiency of 22% is obtained, equal to the average efficiency of GLM rates.

These estimations, in summary, imply in the first case that GM was somewhat better than GLM in terms of urea N-equivalents or equivalent efficiencies, and in the second case was equal to GLM in terms of efficiency of recovery of applied N.

Although C. juncea grown and incorporated in situ produced the highest yield responses of any legume-N treatment, significantly greater than 180 kg/ha N as green leaf manure and equivalent to 150 kg/ha N as urea, in situ green manuring may not be the best management alternative. Summing the yield responses to GMR and G_{120} given in Table 3 results in combined yields averaging 32% more than the yields for GM. This percentage represents yield increases significantly greater than GM or N_{150}, and may be low considering the lower rate of applied tops in the GM treatment caused when yield levels were diluted to application rates. One conclusion from these results is that when C. juncea is grown for two months under similar conditions, only half as much area need be sown if the trouble is taken to remove the tops for incorporation in another area.

3.5 Intercropping treatments.

3.5.1 Legume-sweet maize intercrops.

During the third N-depletion cropping period, some sweet maize was sown in wider (1 m) rows and interplanted with legumes; yields of intercropped sweet maize are given in Table 9. Whole plant yield of intercropped maize was 14.9 t/ha fresh, or 3.9 t/ha dry matter. These plots had not received preemergence herbicide as had the maize-only plots. *Sesbania* spp did poorly: the legumes failed to suppress weeds, which competed with them and with the maize. *C. juncea* did well: the legume grew rapidly, competing with the maize for light, and crowded out most of the weeds. *C. juncea* dry matter yields (Table 1) were 175% of those of maize on the same plots (5.6 v.s. 3.2 t/ha), and the legume accumulated five times as much nitrogen (106 v.s. 22 kg/ha).

S. cannabina was the only *Sesbania* spp to grow well as an intercrop. It was well and effectively nodulated with indigenous *Rhizobium* and the plants grew to about 1.5 m in height; their smaller, pinnate leaves allowed more light penetration and weed competition than the *C. juncea* intercrop. *S. cannabina* is very determinate throughout most of the year in Hawaii. It flowered within a few weeks of planting and by harvest time had dropped all leaves and senesced. Harvested stems and seeds were 39% dry matter and yielded 2.2 t/ha dry matter. About 1 kg of seed was obtained from the two plots. *S. cannabina* was not incorporated because of the low yield and the presence of many seeds.

Plots where *S. cannabina* was grown were the only plots to show an increase in available soil N between the soil samplings at time of planting and post-harvest; leaf litter may have been the cause, and a vigorous

Table 9. Sweet maize yield and N uptake when intercropped with green manure legumes during third N-depletion cropping period.

Legume Intercrop	Dry matter Yield *	N uptake **
	t/ha	kg/ha
Crotalaria juncea	3.28	22.2
Sesbania grandiflora	3.84	22.9
Sesbania speciosa	4.59	29.4
Sesbania cannabina	3.47	23.6
$\overline{X}$	3.79	24.5

* Sweet maize sown in rows 1 m apart in intercrop plots.

** Cf Table 1 for N uptake of sweet maize sown alone in rows 75 cm apart.

symbiosis may have contributed. *S. cannabina* may be useful as a short-term green manure sown in single stand. This experiment revealed disadvantages when sown as an intercrop, but delayed planting, planting during long-day periods, or use of less determinate varieties are possible management alternatives requiring further study.

S. grandiflora grew poorly, suffered from weed competition, and produced negligible biomass. It was observed to be nodulated, but the nodules were few and of a large, meristematic, staghorn type, located on lateral roots. Vigorous seedling growth of this species observed elsewhere in Hawaii has been associated with spheroidal nodules clustered around the taproot. Results here emphasize that it is not advisable to depend on indigenous *Rhizobium* spp. *S. speciosa* also grew poorly, and was not nodulated. Vigorous growth of this introduction has been observed in Hawaii on heavy, dark clay soils, although nodules have not been recovered, and infection with *Rhizobium* isolates from other *Sesbania* spp has not been achieved (personal observation; and Sheila May, unpublished data). Future trials utilizing effective inoculum and better information on appropriate planting densities may reveal potential for *S. grandiflora* and *S. speciosa* as green manure intercrops with maize.

3.5.2 C. juncea green manure intercrop.

Because of poor yields of the *Sesbania* treatments, green manure intercrop (GMI) treatments were performed only on the two *C. juncea* intercrop plots. When the above-ground plants were incorporated, the nitrogen harvest of the sample area (106 kg/ha) was spread over a larger area so that an estimated 50 kg/ha N was applied as tops. However, the residue portion of the legumes was within the sampling zone of the maize test crop (see Figure 1). Dry matter yield of the GMI treatment is plotted in Figure 3 for comparison with other treatments. Urea N-equivalents for yields from these plots averaged 93 kg/ha. Inadequate replication discourages speculation about this treatment, but yield responses and lack of a strongly deleterious competition effect on the companion sweet maize crop suggest that with properly calculated time of sowing the intercropping of _C. juncea_ and maize can be a valuable green manure management alternative.

3.5.3 Other intercrop treatments.

Yields of maize dry matter for other intercrop treatments tried during the test cropping period are also plotted in Figure 3. In the mulched intercrop (MI) treatment, _C. juncea_ interplanted in single rows at the same time as the maize test crop grew poorly with incomplete stands and provided little mulching material when cut at maize tasseling. It is not known why this planting did not perform as well as the earlier _C. juncea_ intercrop with sweet maize, but differences in row widths, planting densities, time of year, soil moisture conditions, and specific plot-site fertility factors could all have played a part. Maize yields on these plots were probably more strongly affected by the previous _S. cannabina_ intercrop than the concurrent _C. juncea_ intercrop.

Very low yields of the maize test crop grown with the live mulch manure intercrop (LMMI) treatment (0.89 t/ha dry matter containing 7.2 kg N) were the result of intense competition by weeds and legumes. _C. juncea_ planted before maize probably immobilized much of the available soil N, which was then not available when strips of young plants were tilled in for maize sowing. Legumes remaining in the interrows continued root zone competition and shaded the maize seedlings until topped. Topping at 15 cm height was too low and at an inappropriate growth stage. Kessler and Shelton (1980) found that *C. juncea* can effectively regrow only after topping at a height allowing about ten remaining leaves.

To summarize maize test crop responses to the intercrop treatments, LMMI plot yields were considerably less than N_0 because of severe competition from *C. juncea* plants and weeds. MI maize yields were in the same range as N_{50} and G_{60}, probably a response to residues from the preceeding *S. cannabina* intercrop. *C. juncea* GMI responses were of the same order as N_{100}, G_{120} and G_{180}.

3.6 Extractable soil nitrogen.

Three sets of soil samples were taken from each plot during the experiment: the first (8/80) during the seedling stage of the third (sweet maize) N-depletion crop, before the sowing of intercropped or solid stand legumes; the second (10/80) after harvest of the sweet maize and legumes and tillage of the plots preparatory to N treatment applications; and the third (5/81) after the harvest of the maize test crop. Pairs of samples were taken at the 5/81 sampling from all plots in which legumes had been buried in furrows: one sample from the incorporation site at about 20 cm depth which included undecomposed *C. juncea* stem materials, and the second from the surface 15 cm of the immediately adjacent area, i.e., between the incorporation furrows.

Table 10 presents the results of soil nitrogen analyses along with nitrogen removals in the form of maize grain plus stover and N additions either as urea or legume tops. Values for the 8/80 and 10/80 samplings are means of plot data grouped according to the treatments subsequently

Table 10. Budget of extractable soil ammonium plus nitrate nitrogen levels at three sampling times, with nitrogen additions as *C. juncea* tops or inorganic fertilizer and nitrogen removals by maize crops.

Treatment	Soil N 8/80	N Removed By Sweet Maize	Soil N 10/80	N Applied	N Removed By Maize Test Crop	Soil N 5/81	N Not Accounted For
				kg/ha			
N0	21	24	12	0	11	22	
N50	17	27	12	50	18	18	26
N100	23	30	13	100	29	17	67
N150	21	31	13	150	40	24	99
G60	22	26	15	60	18	24	33
G120	19	28	10	120	25	29	76
G180	21	29	12	180	28	31	125
GLMM	20	25	11	120	20	24	87
$\overline{X}$		28	12				
GM	18	120*	14	105	39	33	47
GMR	19	121*	14		25	23	
$\overline{X}$	20						

* N accumulated in *C. juncea* tops.

applied. Values for GM and G_{60-180} treatments for the 5/81 sampling are means of data from the two sampling zones; those data are presented in Table 11.

Extractable soil ammonium plus nitrate N averaged 20 kg/ha in the initial (8/80) sampling; sweet maize removed an average of 28 kg/ha N, reducing extractable soil N to an average 12 kg/ha. Plots on which C. juncea was grown in solid stand (GM and GMR) showed a slight N-enrichment immediately after the cropping period, averaging 14 kg/ha N.

N accumulation in legume tops was about 90 kg/ha more than in sweet maize during the same period, and it may be concluded that this represents fixed N if maize and C. juncea extracted similar amounts of soil N. This assumption must be qualified: plant density was higher in the legume plots; the legume rooting habit may have allowed exploitation of soil N to greater depth; supplementary fixed N may have allowed increased legume root growth resulting in more uptake of other nutrients, including soil N; on the other hand, the legume growth period was about three weeks shorter.

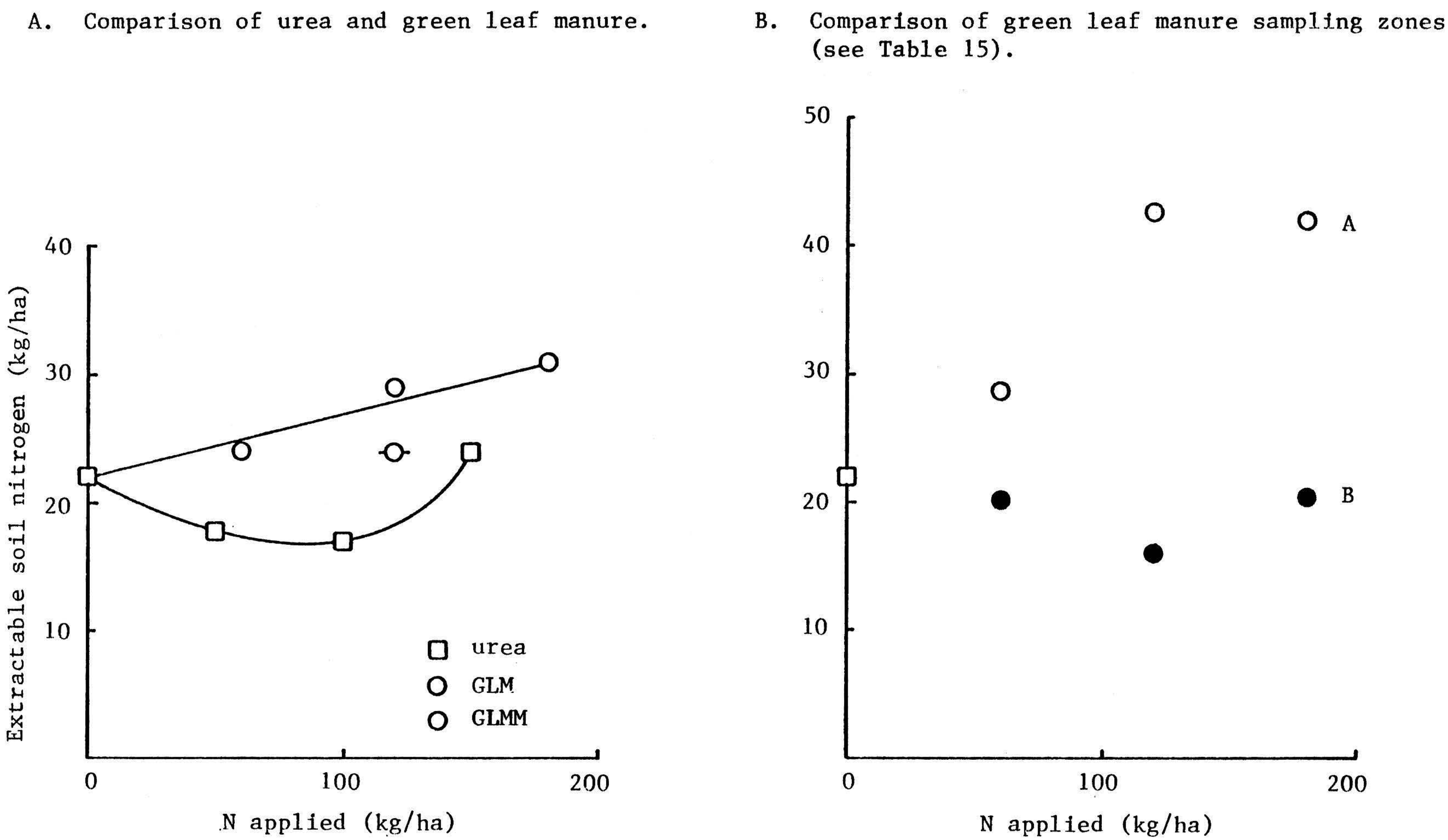
The relationship between N applied in treatments and extractable soil N at the 5/81 sampling is plotted in Figure 12, part A. Higher values for green leaf manure plots probably indicate mineralization of legume nitrogen late in the maize growth period and post-harvest, before sampling, and could be explained by the slow-release characteristic of legume N. These GLM values are means of samples A and B of Table 11 and are in part a function of the sampling bias which deliberately sought out N-enriched zones for half of the samples. Part B of Figure 12 shows that the surface, non-enriched samples of GLM plots have extractable N at levels similar to the urea plots. While comparison of N sources on the basis of

Table 11. Extractable soil ammonium plus nitrate nitrogen (5/81 sampling) in two sampling zones.

Treatment	A*	B**	A/B
	kg/ha		
GM	38.8	26.2	1.48
G60	28.6	20.2	1.42
G120	42.6	16.0	2.66
G180	42.0	20.4	2.06
$\overline{X}$	38.0	20.8	

* Site A: 15-20 cm depth in the zone of incorporation.

** Site B: surface 15 cm adjacent to A (away from the zone of incorporation.)



A. Comparison of urea and green leaf manure.

B. Comparison of green leaf manure sampling zones (see Table 15).

Figure 12. Extractable soil ammonium plus nitrate nitrogen after test crop in relation to N applied before test crop.

these composite GLM plot soil N values is tenuous, these data and the value for GM (5/81 sampling) in Table 10 indicate a higher residual N condition for legume tops than for inorganic fertilizer.

Nitrogen not accounted for by the observations made in this experiment is calculated in the final column of Table 10. These figures represent soil N at 10/80 plus N applied, minus N removed in the test crop, minus soil N at 5/81. Large amounts of N are thus unaccounted-for. Losses of N to the atmosphere and leaching to below the sampling zone are the most likely fates of this N. In addition to rainfall and irrigations during the cropping period, a storm occurred between the test crop harvest and the 5/81 sampling which deposited about 30 cm of rainfall in a two day period. Unaccounted-for nitrogen quantities are plotted against N applied in Figure 13. This plot is linear and shows that there is no difference in this relationship for the two N sources.

The foregoing data indicate that the soil at the experimental site is characterized by low extractable nitrogen levels, and is apparently able to maintain available ammonium plus nitrate N at about 20 kg/ha. Sweet maize was able to reduce available soil N by about half during an eleven week period at a time of year favorable to maize growth. During a less favorable season, hybrid maize grown to maturity did not take up much more N than did the sweet maize even when N was applied to the hybrid, and on the control plots where no N was applied, the hybrid took up less than half the amount taken up by sweet maize. N losses were high during the test crop period, but it is assumed that amounts of unaccounted-for N would have been less had the test crop been grown during a period allowing full yield expression. N losses were a function of the amount

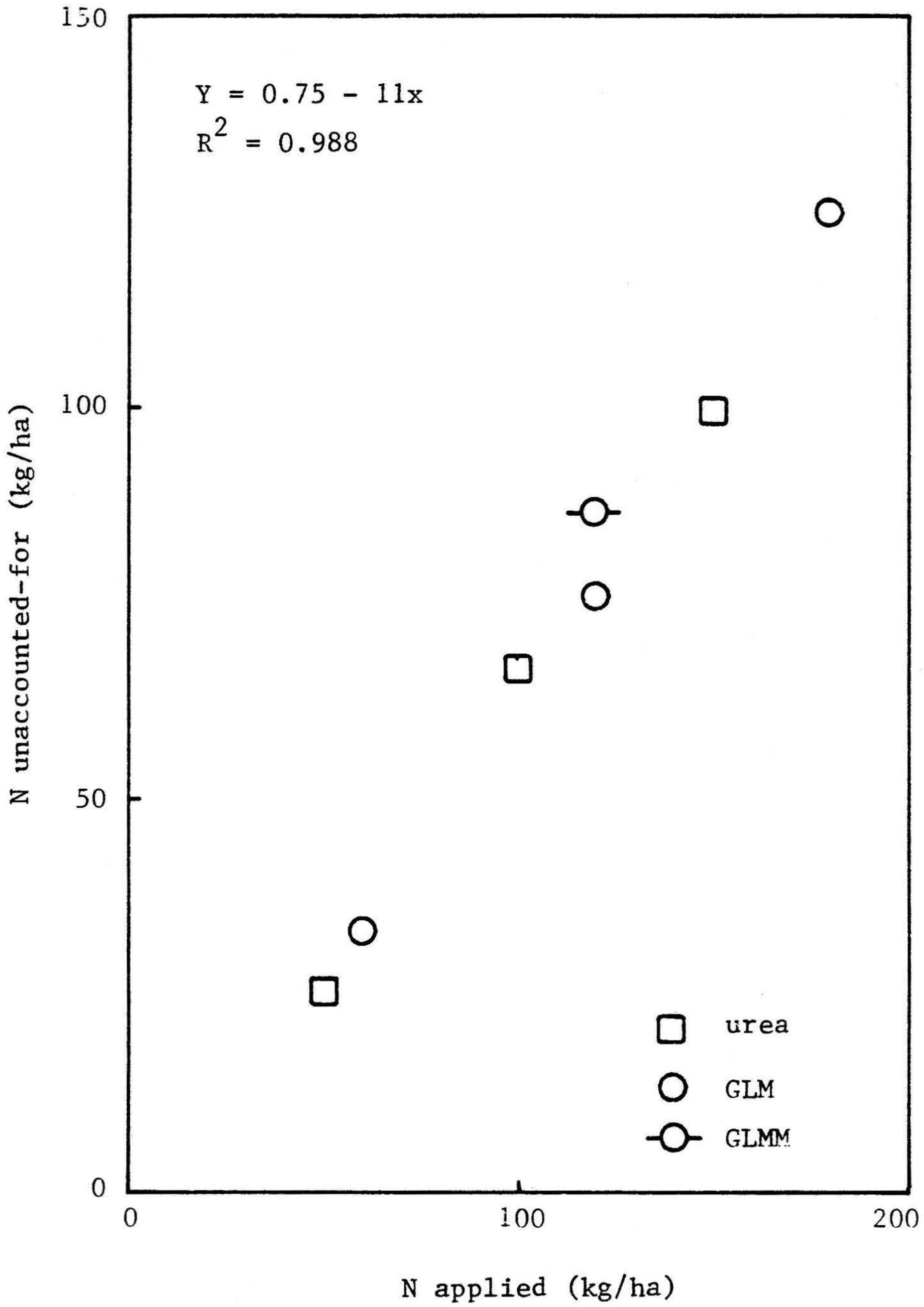


Figure 13. Relationship between nitrogen not accounted for in the nitrogen budget (Table 10) and rates of nitrogen applied.

of N applied rather than the source of the N. Residual extractable N after the test crop was higher in the plots where legume tops were buried, but areas enriched in residual N were localized according to placement sites.

SUMMARY

An experiment was conducted on a Vertic Haplustoll on coastal windward Oahu to compare the response of maize to nitrogen supplied as *Crotalaria juncea* or as inorganic fertilizer (urea). The soil had previously been depleted of N by three preceeding maize crops fertilized with P and K but not with N. Treatments compared were green manure grown and incorporated in situ (GM); the below-ground residue component of green manure grown in situ but tops removed (GMR); green leaf manure (GLM) grown elsewhere and incorporated as legume tops to provide the N rates G_{60}, G_{120} and G_{180} kg/ha, the intermediate rate also applied as a surface mulch (GLMM); three rates of urea providing the N rates N_{50}, N_{100} and N_{150}; and a control (N_0). Urea was broadcast and tilled in; legume tops were cut at ground level and buried by laying in furrows and earthing over. Maize was sown 4 weeks after treatment applications. *C. juncea* grown for 2 months yielded 22 t/ha fresh material as tops (5.8 t/ha dry matter) containing 121 kg/ha N. Yields of maize sown 4 weeks after treatment applications were generally low for all N levels and sources; it was thought that short, cool, cloudy winter days limited yield expression.

Responses to urea N were linear and significantly greater at each level. GM resulted in maize yields and N uptake equivalent to 150 kg N as urea. Neither G_{180} nor G_{120} were different from N_{100}; G_{60} and N_{50} were also equivalent. GLM as mulch was inferior to the corresponding incorporated rate for grain yield and N uptake but not for stover yield. Response to the below-ground legume component (GMR) was statistically similar to N_{100}, G_{120} and G_{180}.

Considering the yield and N uptake of 5-wk-old maize, maize height differences during growth, and stover yields, legume N was apparently slower in becoming available than urea N. It appeared that peak benefit to maize of C. juncea treatments occurred at about 14 weeks after incorporation, and that availability of N declined thereafter in all legume treatments but in situ GM. GM, GMR and GLMM had pronounced favorable effects on early maize growth.

Augments to the experiment suggested that intercropping of C. juncea or Sesbania cannabina with maize for GM to benefit succeeding maize crops may be a fruitful subject of further research.

It was concluded that under the experimental circumstances green manuring was as effective as moderately high urea rates (around 150 kg/ha N) for maize production, and that green leaf manure can produce yields equivalent to urea at low (under 100 kg/ha) N rates. The option to economize C. juncea green manure cropping area by incorporating the above-ground component on another, equal area was suggested as a green manure management alternative.

A second maize test crop compared residual effects of treatments with urea reapplications. Summer weather more favorable to maize growth apparently permitted more normal maize yields when the N supply was adequate; response to applied N was once again linear and significant, and the ratio of grain yield to urea N applied was six times that obtained in the first (winter grown) test crop. Residual effects of the urea and legume treatments applied before the first test crop produced maize yields of less than 1 t/ha grain, significantly less than the lowest rate (50 kg/ha N) of reapplied urea.

APPENDIX I

Analyses of variance for maize test crop yield parameters.

A. Dry matter yield.

Source	df	Mean Squares		
		Grain	Stover	Grain + Stover
Treatments	9	0.602 **	0.904 **	2.915 **
Blocks	3	0.010	0.221 *	0.305
Error	27	0.036	0.055^{+}	0.132^{+}
C.V.		18 %	14 %	13 %

B. Nitrogen uptake.

Source	df	Grain	Grain + Stover
Treatments	9	114.00 **	333.14 **
Blocks	3	2.49	25.84
Error	27	5.63	16.46^{+}
C.V.		17 %	16 %

C. Phosphorus and potassium uptake.

Source	df	P		K	
		Grain	Stover	Grain	Stover
Treatments	9	10.956 **	1.056	2.128 *	127.96 **
Blocks	3	0.029	8.248 **	0.588	47.00 *
Error	27	1.755	0.651^{+}	0.807	11.24^{+}
C.V.		27 %	15 %	45 %	19 %

D. Five-week-old seedlings.

Source	df	Dry matter Yield	N content	N uptake
Treatments	9	1.073 **	0.065 **	0.678 **
Blocks	3	1.075 **	0.245 **	0.215 *
Error	27	0.084	0.018	0.057
C.V.		13 %	7 %	17 %

*, ** denote statistical significance at 0.05 and 0.01 levels.

+ one df subtracted for missing plot calculation.

APPENDIX II

Test of residual effects of treatments.

To assess the residual effects of the treatments applied before the test crop, a second crop was planted on May 18, 1981, six weeks after the harvest of the first test crop, and grown for seventeen weeks. The plots were rotovated and the same maize variety, planting density, preemergence herbicide application and irrigation proceedures were followed. Plots to which urea had been applied before the test crop were split to form subplots 4.5 x 3.5 m, and urea was reapplied to half of each plot according to the previous rates. The treatments MI and LMMI, representing six plots, were not carried over into the residual crop phase but were given applications of 200 kg/ha inorganic N; three plots received urea and three received ammonium sulfate. Fertilizer reapplications were broadcast pre-planting and incorporated into the soil surface.

Dry matter yields of grain and stover from the residual test crop and inorganic N reapplications are plotted in Figures 14 and 15, and the treatment means are ranked and separated by BLSD in Table 12, with their analyses of variance.

N_{200} rates of urea and ammonium sulfate are plotted in the figures, but because they were replicated only three times they are not included in the analyses of variance. The range of grain yield responses to urea at 200 kg/ha N was from 6 to 8.1 t/ha (oven dry basis), and to ammonium sulfate from 6.4 to 7.7 t/ha. That these ranges include the mean response to N_{150} may be considered an indication that yield responses were beginning to level off in the $N_{150-200}$ range.

Increments of reapplied urea produced significant yield increases at all levels to N_{150}. In the range between N_{50} and N_{150}, mean responses were linear for both grain (r = 0.9971) and stover (r = 0.9998); within this range, each kilogram of added N produced an additional 50 kg of grain. This may be contrasted to the value for the previous test crop, grown at a period of sub-optimal solar radiation incidence, where a 1 kg increment of N produced only 8 kg of grain.

Residual effects of the previous N sources and rates were generally nonsignificant. The plotted data show trends for increased yields with increasing N rates, and a tendency for urea residual effects to be slightly higher than green leaf manure residual effects.

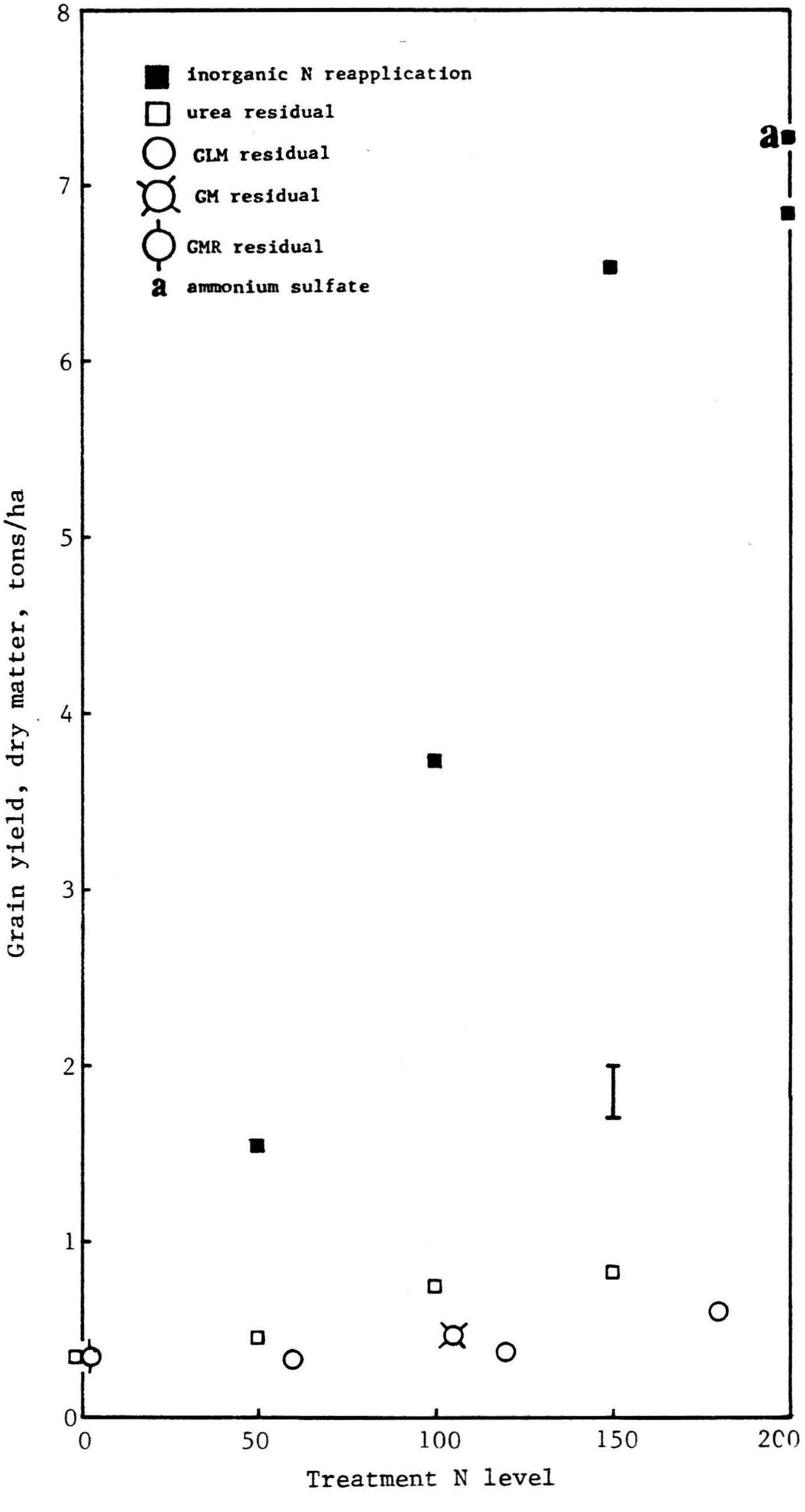


Figure 14. Maize grain yield response to residual effects of previous inorganic and legume N treatments and to inorganic N reapplication.

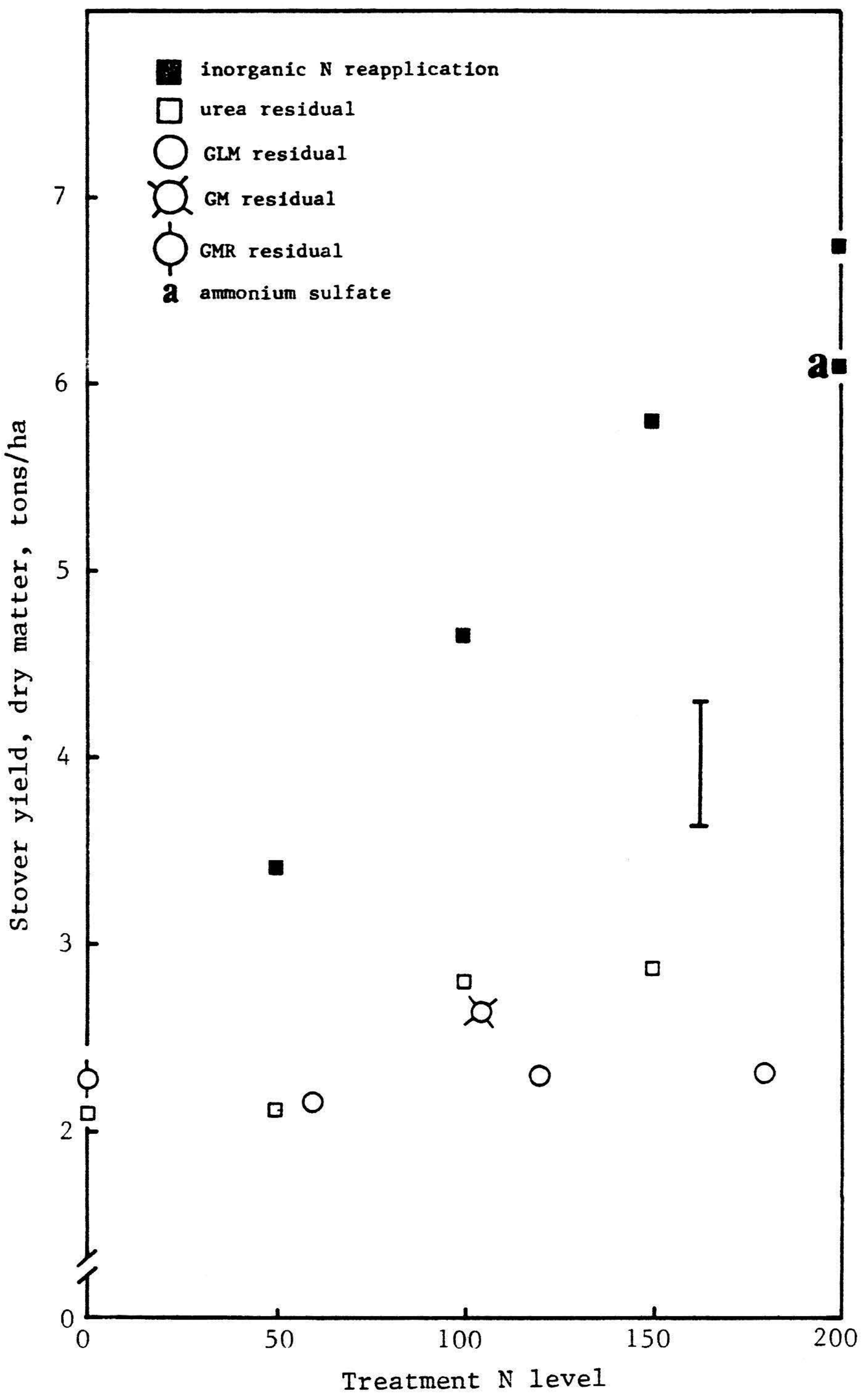


Figure 15. Maize stover yield response to residual effects of previous inorganic and legume N treatments and to inorganic N reapplication.

Table 12. Maize grain and stover response to residual effects of previous inorganic and legume N treatments and to inorganic N reapplication, ranked and separated by BLSD, with analyses of variance.

Grain dry matter, t/ha			Stover dry matter, t/ha		
N150 F*	6.53	a	N150 F	5.81	a
N100 F	3.72	b	N100 F	4.65	b
N50 F	1.57	c	N50 F	3.41	c
N150 R**	0.82	d	N150 R	2.87	cd
N100 R	0.77	de	N100 R	2.81	de
G180	0.60	def	GM	2.64	def
GM	0.48	ef	G180	2.32	def
N50 R	0.45	f	G120	2.30	def
GMR	0.38	f	GMR	2.28	def
GLMM	0.38	f	G60	2.16	ef
G120	0.37	f	N50 R	2.12	f
G60	0.34	f	N0	2.10	f
N0	0.34	f	GLMM	2.08	f
$BLSD_{.05}$	0.30		$BLSD_{.05}$	0.67	

* F = urea reapplication
** R = urea residual

Analyses of variance

Source	df	Mean Squares
Grain		
Treatments	12	13.3460 **
Blocks	3	0.0850
Error	33	0.0576
Total	51	
Stover		
Treatments	12	5.1337 **
Blocks	3	0.4336
Error	34	0.2415
Total	51	

** denotes significance at 0.01 probability level

LITERATURE CITED

Acharya, C.N. 1952. Legumes and the soil. Indian Farming 2(7):12-13.

Achorn, F.P. 1981. Cost effects of energy on fertilizers. p. 1-22 In Proceedings, 14th Hawaii fertilizer conference. University of Hawaii College of Tropical Agriculture and Human Resources, Research Extension Series 005.

Aldrich, S.R. 1980. Nitrogen in relation to food, environment and energy. Illinois Agricultural Experiment Station, Special Publication 61.

Ali, A.M., and Morachan, Y.B. 1974. Effect of irrigation levels and forms of manures on rice varieties IR8 and IR20. Madras Agricultural Journal 61(8):268-272.

Allan, R.G. 1915. Green-manuring in the Central Provinces, India. Agricultural Journal of India 10(4):380-394.

Allison, F. 1973. Soil organic matter and its role in crop production. Elsevier Scientific Publishing Co., Amsterdam.

Allison, F.E. 1966. The fate of nitrogen applied to soils. Advances in Agronomy 18:219-258.

Bally, W., and Legros, I. 1936. Use of leguminous plants in tropical countries as green manure, as cover and as shade. International Institute of Agriculture, Rome.

Barros, F. 1940. A comparative study of the effects on yield of corn of some leguminous crops used as green manure. Philippine Agriculturist 29(2):142-149.

Bhadauria, V.S., and Mathur, B.K. 1973. Problem of green manuring sugarcane--intercropping as solution. Indian Sugar 23(4):351-358.

Brown, P. 1958. The results of some short term experiments in Nyasaland. Rhodesian Agricultural Journal 55(6):626-633.

Burris, R.H. 1974. Biological nitrogen fixation, 1924-1974. Plant Physiology 54:443-449.

Dobbs, A.C. 1915. Green-manuring in India. Agricultural Research Institute, Pusa, Bulletin No. 56.

Eusebio, R.V., and Umali, D.L. 1952. A test of four green manure crops for corn. Philippine Agriculturist 36(2):251-258.

Foote, D.E., and Hill, E.L., Nakamura, S., Stephens, F. 1972. Soil survey of the islands of Kauai, Oahu, Maui, Molokai, and Lanai, State of Hawaii. USDA SCS, University of Hawaii Agricultural Experiment Station.

Fox, R.L. 1972. Symptoms of plant nutritional deficiency--visual symptoms and incipient malnutrition. Department of Agronomy and Soil Science, University of Hawaii, Illustrated Concepts in Tropical Agriculture No. 4.

Fox, R.L., and Yost, R.S. 1980. Estimating global fertilizer requirements: some tentative results. In Fertilizer raw material resources, needs and commerce in Asia and the Pacific, R.P. Sheldon, S. Ahmed, Y.H. Yang (eds.). East-West Center, Honolulu.

Fribourg, H.A. 1954. Comparison of leguminous green manures with inorganic nitrogen in rotations with corn. PhD dissertation, Iowa State College.

Fuggles-Couchman, N.R. 1939. Green manurial and cultivation trials made at Morogoro, Eastern Province, Tanganyika Territory. East African Agricultural Journal 5(3):208-210.

Guevara Calderon, J. 1958. The indirect influence of light and humidity in the damage by pests and plagues to tropical legumes associated with maize. (in Spanish) p. 318-325 In Memoria del Primer Congreso Nacional de Entomologia y Fitopatologia. Escuela Nacional de Agricultura, Chapingo, Mexico.

Guevarra, A.B. 1976. Management of Leucaena leucocephala (Lam.) de Wit for maximum yield and nitrogen contribution to intercropped corn. PhD dissertation, University of Hawaii.

Grove, T.L. (ed.) 1979. Nitrogen fertility in oxisols and ultisols of the humid tropics. Cornell International Agriculture Bulletin 36.

Hanway, J.J. 1971. How a corn plant develops. Iowa State University Cooperative Extension Service, Special Report No. 48.

Huang, K.M., and Wang, T.S.C. 1974. A study on the decomposition of organic manure and the formation of humus in soils with the 14C tracer method. Report of the Taiwan Sugar Research Institute No. 63, p. 45-58. Soils and Fertilizers in Taiwan 1974, 31.

Inforzato, R. and Mascarenhas, H.A.A. 1967. Root system of Dolochos lablab in a reddish-yellow podzol soil. (in Portugese) Bragantia 26(16):213-217.

Iyer, S.S. and Tandon, R.K. 1960. A review of sugarcane manurial trials in Uttar Pradesh. Indian Journal of Sugarcane Research and Development 4(3):160-165.

IITA. 1980. Annual Report for 1979, International Institute of Tropical Agriculture, Ibadan, Nigeria.

Jacoby, E.H. 1974. Structural changes in third world agriculture as a result of neocapitalistic developments. The Developing Economies 12(3):201-213.

Jadhav, B., Tekale, N.S., and Joshi, R.N. 1979. Green-manure crops as a source of leaf protein. Indian Journal of Agricultural Science 49(5):371-373.

Joachim, A.W.R. 1925. A review of scientific investigations on green manuring in India. Tropical Agriculturist (Ceylon) 65(6):325-331.

Joachim, A.W.R. 1928. Losses of nitrogen from green manures and tea prunings through drying under field conditions. Tropical Agriculturist (Ceylon) 71(6):348-351.

Joffe, J.S. 1955. Green manuring viewed by a pedologist. Advances in Agronomy 7:145-187.

Jong, S.K., Brewbaker, J.L. and Lee, C.H. 1981. Effects of solar radiation on the performance of maize in 41 successive monthly plantings in Hawaii. Crop Science, in press.

Joshi, N.V. 1922. Comparative manurial value of the whole plants and different parts of green manures. Agricultural Research Institute, Pusa, Bulletin 141.

Joshi, N.V. 1919. Rate of nitrification of different green manures and parts of green manures and the influence of crop residues on nitrification. Agricultural Journal of India 14:395-413.

Joshi, N.V. 1928. An economical method of manuring with sann-hemp. Agricultural Journal of India 23(2):87-94.

Kanwar, R.S., and Singh, H. 1959. Manurial value of sanhemp (Crotalaria juncea)--its effect on soil composition, juice quality and yield of sugarcane. Indian Journal of Sugarcane Research and Development 3(4):194-201.

Kessler, C.D.J., and Shelton, H.M. 1980. Dry-season legume forages to follow paddy rice in NE Thailand. III. Influence of time and intensity of cutting on Crotalaria juncea. Experimental Agriculture 16:207-214.

Khanna, S.S., and Mahajan, K.K. 1969. Study on the role of inorganic phosphorus added in a legume-wheat cropping sequence. Indian Journal of Agricultural Science 38(4):757-765.

Kurup, K.R., and Kaliappan, R. 1969. The influence of phosphate fertilization on legumes. Madras Agricultural Journal 56(1):12-15.

Kute, S.B., and Mann, H.S. 1969a. Effect of green manuring on the composition of soil and wheat crop, and the balance of major plant nutrients in the soil after the crop. Indian Journal of Agricultural Sciences 39(1):10-17.

Kute, S.B., and Mann, H.S. 1969b. Effect of green manuring on the yield attributes of the succeeding crop of wheat. Indian Journal of Agricultural Sciences 39(1):18-24.

Lappe, F.M., Collins, J., and Fowler, C. 1978. Food First. Institute for food and development policy. Ballantine, New York.

Litzenberger, S.C. (ed.) 1974. Guide for field crops in the tropics and subtropics. Technical Assistance Bureau, U.S. Agency for International Development.

Lohnis, F. 1926. Nitrogen availability of green manures. Soil Science 22(4):253-290.

Mahalingam, P.K., Kandaswamy, P., Krishnamoorthy, K.K., and Mathan, K.K. 1975. Efficacy of calcium ammonium nitrate compared to other sources of nitrogen for paddy. Madras Agricultural Journal 62(2): 77-78.

Manshard, W. 1979. Tropical agriculture. Longman, Inc., New York.

McCall, W.W. 1975. Soil classification in Hawaii. University of Hawaii Cooperative Extension Service, Circular 476.

McKee, R. 1946. Crotalaria culture and utilization. USDA Farmers' Bulletin 1980.

Mudaliar, V.T.S. 1960. South Indian field crops. S. Viswanathan, Madras.

Panse, V.G., Abraham, T.P., and Leelavathi, C.R. 1965. Green manuring of crops (review of experimental results in India). Indian Council of Agricultural Research, Technical Bulletin No. 2.

Panse, V.G., and Ayachit, G.R. 1954. A note on the artificial assessment of additional production from green manuring. Ninth meeting of the Crops and Soils Wing, Board of Agriculture, New Delhi, India, 1952.

Patnaik, S., and Rao, N.V. 1979. Sources of nitrogen for rice production. In Nitrogen and rice. International Rice Research Institute, Los Banos, Philippines. p. 25-44.

Paul, W.R.C. 1938. A comparison of different seed rates of sunnhemp on the yield of green material and seed. Tropical Agriculturist (Ceylon) 91(6):345-348.

Peregrina, R.P., de Toro, J., and Laird, R. 1955. Hubam clover as a green manure. (in Spanish) Agricultura Tecnica en Mexico 1(2):543.

Pieters, A.J. 1917. Green manuring: a review of the American experiment station literature. Journal of the American Society of Agronomy 9(2):62-82.

Pieters, A.J. 1927. Green manuring, principles and practice. John Wiley & Sons, New York.

Ramirez, R. 1972. Comportamiento de tres abonos verdes y su efecto en el rendimiento de maiz. Agronomia Tropical 22:3-17.

Rao, B.V.V., and Sadasivaiah, T. 1968. Studies on nitrogen mobilisation through phosphate fertilising of a legume in the Bangalore red soil. Mysore Journal of Agricultural Science 2(4):251-256.

Rattray, A.G.H. 1950. Annual report of experiments, 1948-49, Agricultural Experiment Station, Salisbury. Rhodesia Agricultural Journal 47(2):126-151.

Rattray, A.G.H., and Ellis, B.S. 1952. Maize and green manuring in Southern Rhodesia. Rhodesia Agricultural Journal 49(4):188-197.

Relwani, L.L., and Ganguly, B.D. 1959. Effects of green manuring in conjunction with fertilizers on paddy yields. Indian Journal of Agricultural Science 29(2+3):1-13.

Rojas, C.A., and Lotero, J. 1970. Comparative study of forage, roots, nodulation and nitrogen fixation in 13 legumes. (in Spanish) Revista Instituto Colombiano Agropecuario 5(3):221-242.

Ruiz, M.J., and Laird, R.J. 1961. Tres leguminosas tropicales para abono verde. Agricultura Tecnica en Mexico 11:14-15.

Russell, E.W. 1973. Soil conditions and plant growth. Longman Group, Ltd., London and New York.

Schuman, G.E., Stanley, M.A., and Knudson, D. 1973. Automated total nitrogen analyses of soil and plant samples. Soil Science Society of America Proceedings 37(3):480-481.

Sharma, R.P.R., and Singh, A. 1970. Effect of growing winter legumes on certain properties of an alluvial soil of northern India. Indian Journal of Agricultural Sciences 40(1):45-53.

Shende, N.K., and Sen, S. 1958. Phosphate manuring of legumes. VIII. Manuring of guar (Cyamopsis tetragonoloba) with phosphate and micronutrients and its effect on physical and chemical properties of the soil. Indian Journal of Agronomy 3:89-97.

Singh, A. 1962. Studies on the modus operandi of green manures in tropical climates: I. A critical review of literature. Indian Journal of Agronomy 7:69-79.

Singh, A. 1975. Use of organic materials and green manures as fertilizers in developing countries. p. 19-30 In Organic materials as fertilizers. Food and Agriculture Organization of the United Nations, Soils Bulletin 27, Rome.

Singh, B.N., and Singh, S.N. 1936. Analysis of Crotalaria juncea with special reference to its use in green manuring and fibre production. Journal of the American Society of Agronomy 28:216-227.

Singh, P.P., and Gautam, D.P. 1973. Effect of double cropping on soil moisture and yield of barley under rain-fed conditions. Indian Journal of Agricultural Sciences 43(11):988-992.

Singh, R., Singh, N., Sidhu, G.S., and Bhatia, I.S. 1970. Symbiotic nitrogen fixation by some summer (kharif) legumes of the Punjab. III. Residual effect of nitrogen fixed on the subsequent non-legume crop (wheat) and overall nitrogen status of the soil. Journal of Research, Punjab Agricultural University 7(4):495-500.

Sornay, P. de. 1916. Green manures and manuring in the tropics. John Bale, Sons & Danielsson, Ltd., London.

Staker, E.V. 1958. Green manure crops in relation to paddy rice production in south-east Asia. International Rice Commission Newsletter (FAO Bangkok) 7(4):1-20.

Stangel, P.J. 1979. Nitrogen requirement and adequacy of supply for rice production. p. 45-69 In Nitrogen and rice. International Rice Research Institute, Los Banos, Philippines.

Stickler, F.C., Shrader, W.D., and Johnson, J.J. 1959. Comparison of leguminous green manures with inorganic nitrogen for corn production. Agronomy Journal 51(3):157-160.

Stokes, W.E., Barnette, R.M., and Hester, J.B. 1936. Effects of summer cover crops on crop yields and on the soil. I. Yields of corn and sweet potatoes following summer cover. II. Influence of summer cover on nitrate and organic matter content of a poor grade of Norfolk soil. University of Florida Agricultural Experiment Station Bulletin 301.

Suehisa, R. 1980. Total nitrogen--continuous digestion method. p. 480, Appendix II, In Sugarcane crop-logging and crop control. H.F. Clements. University Press of Hawaii, Honolulu.

Swaminathan, K., and Singh, M. 1960. Value of growing kharif legumes with or without phosphatic fertilizers in influencing yield of succeeding potato crop. Indian Potato Journal 2(2):83-93.

Tisdale, S.L., and Nelson, W.L. 1975. Soil fertility and fertilizers. Macmillan Publishing Co., Inc., New York.

USDA-SCS. 1979. Management and uses of sunn hemp (Crotalaria juncea) in Hawaii. Honolulu.

van der Giessen, C. No date (ca. 1942). Rice culture in Java and Madura, Ch. 3 in Green manuring of sawah rice in Java and Madura. Contribution No. 11 of the Chuo Noozi Sikenzyoo, Bogor, Indonesia.

van der Giessen, C. 1947. Green manuring of sawah rice. Landbouw 19:195-209.

van de Goor, G.A.W. 1954. The value of some leguminous plants as green manure in comparison with Crotalaria juncea. Netherlands Journal of Agricultural Science 2(1):37-43.

Vieira, C. 1961 Effect of interplanted legumes for green manure on corn yields. (in Portugese) Experientiae 1(1):1-24.

Walunjkar, W.G., Singh, A.N., and Balagopal, K. 1968. Green manuring in black-cotton soils with flue cured tobacco. Indian Journal of Agronomy 13(1):57-63.

Whyte, R.O., Nilsson-Leissner, G., and Trumble, H.C. 1953. Legumes in agriculture. Food and Agriculture Organization of the United Nations, FAO Agricultural Studies No. 21, Rome.

Wittwer, S.H. 1976. Biological nitrogen fixation. p. 249-256 In Proceedings, First review meeting I.N.P.U.T.S. project (Increasing productivity under tight supplies), S. Ahmed, M. Sadiq and L. Kobayashi (eds.). East-West Food Institute, East-West Center, Honolulu.

Yadav, J.S.P., and Agarwal, R.R. 1961. A comparative study on the effectiveness of gypsum and Dhaincha (Sesbania aculeata) in the reclamation of a saline-alkali soil. Journal of the Indian Society of Soil Science 9:151-156.

Yost, R.S., Evans, D.O., Saidy, N.A., and Fox, R.L. 1981. Green manuring--renewed interest in an old concept. Department of Agronomy and Soil Science, University of Hawaii, Illustrated Concepts in Tropical Agriculture No. 25.