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IMPACT OF LEGUME AND FERTILIZER NITROGEN
ON SMALLHOLDER MAIZE (*Zea mays* L.) CROPPING SYSTEMS
IN NORTHERN ZIMBABWE

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IMPACT OF LEGUME AND FERTILIZER NITROGEN ON SMALLHOLDER MAIZE (*Zea mays* L.) CROPPING SYSTEMS IN NORTHERN ZIMBABWE

By

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ABSTRACT

IMPACT OF LEGUME AND FERTILIZER NITROGEN ON SMALLHOLDER MAIZE (*Zea mays* L.) CROPPING SYSTEMS IN NORTHERN ZIMBABWE

By

Peter Jeranyama

Growing maize (*Zea mays* L.) in rotation or intercropped with legumes may maintain soil fertility and prevent yield declines associated with smallholder cropping systems of Zimbabwe. This research was conducted in Zimbabwe on a Typic Kandiustalf to (i) evaluate the impact of relay-intercropping a food legume (cowpea; *Vigna unguiculata* L.) and a tropical forage legume (sunnhemp; *Crotalaria juncea* L.) into maize, and (ii) assess the effects of a systematic rotation of maize with groundnut (*Arachis hypogaea* L.) on maize yields and economic returns.

Relay intercropping legumes into maize fertilized at 60 kg N ha^{-1} did not result in yield reductions of the companion maize crop. However, relay-intercropping legumes into maize fertilized at 120 kg N ha^{-1} was associated with yield declines of 20-34% for a companion maize crop. In the subsequent year, maize grain yields were increased by 20% following maize-legume intercrops relative to continuous maize when no fertilizer was used. Maize grain yield increases following maize and legume intercrops were sufficient to pay legume seed outlays in the intercropping year. The research suggests that intercropped annual herbaceous legumes when integrated with

small amounts of inorganic N fertilizer offers a strategy to meet the N needs on smallholder farms of Zimbabwe.

Maize grain yields were 0.1-2.2 Mg ha^{-1} higher following groundnut than following maize. Fertilizer needs of maize following groundnut were reduced by up to 72 kg N ha^{-1} compared to continuous maize. However, these results were sensitive to rainfall distribution. A marginal benefit cost analysis showed that continuous maize at 92 kg N ha^{-1} optimized marginal benefits when compared to rotation in a scenario where family labor had an opportunity cost. The low groundnut yields and little yield improvements for maize following groundnut on-farm, and the high labor costs associated with groundnut made the rotation less profitable than continuous maize, especially when maize was grown with some fertilizer. The results for groundnut-maize rotation underline the need for research to (i) increase the yield of groundnut on smallholder farms and (ii) reduce the associated labor costs in producing groundnut without adding much to cash costs.

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PREFACE

Chapters 1 and 2 of this dissertation are written in the style required for publication in the *Agronomy Journal*. Chapter 3 is written in the style required for publication in the *Agricultural Systems*.

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CHAPTER ONE

RELAY-INTERCROPPING OF ANNUAL LEGUMES INTO A MAIZE (*Zea mays* L.) SYSTEM IN ZIMBABWE

ABSTRACT

Declining maize (*Zea mays* L.) yields in the smallholder cropping systems of northern Zimbabwe present the need to develop a more sustainable production system. Increased maize production will continue to emphasize the use of inorganic fertilizers. However, rising real prices of inorganic fertilizers is driving smallholder maize production towards lower levels of inorganic fertilizer inputs. Meanwhile, legume intercrops are a source of plant N that can be produced within local environments and offer a practical complement to inorganic fertilizers.

This article evaluates the impact of relay-intercropping a food legume - cowpea (*Vigna unguiculata*), and a tropical forage legume - sunnhemp (*Crotolaria juncea*) into smallholder maize in Zimbabwe. Field studies were conducted on a loamy sand (Typic Kandiustalf) soil at a mid altitude site for two years. The objectives of the study were to quantify (i) biomass and N yield of legumes intercropped into maize, (ii) the impact of the legumes on companion maize grain yield and N uptake, and (iii) the response of the subsequent maize crop to relay-intercropped legumes.

Herbage biomass as dry matter yield ranged from 0.6 to 4.6 Mg ha^{-1} for

cowpea and 0.9 to 2.9 Mg ha^{-1} for sunnhemp, over the two years. Highest above-ground N yield for cowpea was 154 kg N ha^{-1} compared to 82 kg N ha^{-1} for sunnhemp. Companion maize grain yields were not reduced when legumes were relay-intercropped into maize fertilized at zero and 60 kg N ha^{-1} in each of the two years. However, maize yields were reduced 20 to 34 % when maize-legume intercrops were fertilized at 120 kg N ha^{-1}. In the subsequent year, maize grain yields were increased by 20% following maize-legume intercrops when no fertilizer N was applied, compared to maize following maize. From fertilizer replacement value calculations, legumes reduced fertilizer needs of a subsequent maize crop by up to 36 kg N ha^{-1}.

This study suggests that annual herbaceous legumes relay-intercropped into moderately fertilized (>0-60 kg N ha^{-1}) maize can maintain yields of the companion maize crop while enhancing yields in a subsequent maize crop. The study did not assess long-term effects of the increased crop diversity and cover crops.

INTRODUCTION

Declining maize (*Zea mays* L.) yields in the smallholder cropping systems of Zimbabwe present the need to develop a more sustainable production system. To continue to increase maize production will require emphasis on the use of inorganic fertilizers (Waddington and Heisey, 1997). However, legume cover crops are a source of plant nutrients that can be produced within local environments and they offer a practical complement to inorganic fertilizers.

In Zimbabwe, green manures were heavily researched from the 1920's to 1940's (Metelerkamp, 1988), and large-scale commercial farms (the second sector in a dichotomous agriculture) used green manures widely. Although there was no deliberate effort (with documented evidence) to promote the use of green manures by the smallholder sector, there were informal reports that some smallholders did use some green manures such as sunnhemp (*Crotolaria juncea* L.) to maintain soil fertility (Hikwa et al., 1997). This practice continued until real prices of inorganic fertilizers fell in the 1950's and green manures became uneconomic (Tattersfield, 1982). However, rising real prices of inorganic fertilizers in the recent past and concerns about the sustainability of current smallholder cropping systems have once again attracted interest in green manures (Hikwa and Mukurumbira, 1995).

Although green manures have once again become popular among agricultural scientists, the growing of legume sole-crop green manures in fallows have been rejected by smallholders because of labor and land constraints. At current fertilizer costs, most smallholders will grow maize with very little or no fertilizer. There remains potential to integrate legume cover crops in the existing cropping systems as intercrops. If legumes are intercropped in a timely manner, competition with the maize crop for resources (light, water, nutrients) can be minimized while legume herbage N can be accumulated. This technology is unlikely to directly benefit the companion crop, but has potential to increase the yields of a subsequent maize crop (Jeranyama, 1995).

If food legumes are not to be a net drain on N from the system, they must fix at least as much N as is removed from the field in grain or other produce when the legume is harvested (Giller et al., 1994). When an abundant supply of mineral N is available in the soil profile, legumes preferentially utilize soil N at the expense of N_2-fixation (Allos and Bartholomew, 1956). In such cases, the legume removes more nitrogen from the soil than it fixes from the atmosphere, which results in a net loss of available nitrogen for the companion crop. However, as soils in the smallholder farms have low inherent fertility (Grant, 1970; Mashiringwani, 1983), percent N from N_2-fixation tends to be high and legumes often contribute N to the system in excess of their own requirements.

When food legumes are used to supply biological N to soil, those with a low N harvest index (N in harvested grain per unit total above-ground N) will be most valuable as they are associated with less N removal from the field in harvestable grain. Values of the N harvest index vary from 90% in soybean to only 25-40% in some genotypes of cowpea, groundnuts (*Arachis hypogea*), and pigeon pea (*Cajanus cajan*) (Giller et al., 1994). Unlike food crops, forage legumes are usually not intercropped with cereals in the region (Okigbo and Greenland, 1976), probably because forages do not contribute directly to the food security of farmers (Kumwenda et al. 1996). There is often a direct conflict between the need to assure immediate food supply and the need to assure future food supply by building up soil fertility over a long period. Kumwenda et al. (1996) noted that farmers discount the value of a benefit that will only be achieved several years from when investments were made. The most suitable legumes from a soil fertility perspective are often the most difficult to adopt and usually offer no value for human consumption.

Smallholder farmers rarely plant crops solely for use by livestock. Producers cannot afford to take risks in subsistence agriculture, so priority of resources, such as labor, is given to staple food crops. Accordingly, and ironically, legume forages currently have little place in crop-based systems even though these systems potentially offer the best opportunities for legume introduction (Thomas and Sumberg, 1995).

The percent of nitrogen from N_2-fixation in intercropped legumes is generally higher than that of legume monocrops in a given environment as the supply of soil N available to the legume is reduced by competition for N from the cereal crop (Rerkasem and Rerkasem, 1988). However, total yield of fixed N is often reduced as the grain legume occupies less land area and is subject to competition for resources, particularly for light, from the taller cereal crops (Nambiar et al., 1983).

Two common methods of assessing the N contribution by legume to a cropping system are total N content in legume herbage biomass and fertilizer replacement value (FRV) (Hesterman, 1988). The method based on total N legume biomass assumes that all legume N produced is mineralized and is available to the subsequent cereal crop. In fact some studies suggest that only 10-30% of the N incorporated in the legume material is absorbed by the following crop (Ladd et al., 1983; Harris and Hesterman, 1987), with the excess accounted for in soil organic matter, in the inorganic soil N pool and by losses due to denitrification and leaching.

Fertilizer replacement value (FRV) is defined as the quantity of N fertilizer required to produce a yield in a crop that does not follow a legume that is identical to that produced by incorporation of a legume (Hesterman, 1988). Reported FRV's for maize-cowpea or maize-black gram (*Vigna mungo*) intercrops in the subsequent year ranged from 31 to 54 kg N ha^{-1} (Nair et al., 1979; Singh, 1983).

There remains controversy as to whether cereals benefit directly from N_2 fixed by intercropped legumes, or whether the enhanced N uptake sometimes observed in intercrops is simply due to a 'sparing' of soil N by the legume for use by the cereal (Agboola and Fayemi, 1972; Remison, 1978; Pandey and Pendleton, 1986).

Legume cover crops are included in cropping systems because they reduce soil erosion (Giller and Cadisch, 1995), suppress weeds (Exner and Cruse, 1993) and fix biological N (Giller et al., 1994). However, legume cover crops can also deplete soil moisture necessary for grain production in semi-arid areas (Baduruddin and Meyer, 1989) and compete for light and nutrient with the main crop (Ofori and Stern, 1987). There is therefore a need to develop cover crop strategies that comply successfully with the overarching necessity of water conservation in dryland cropping systems. Moisture conservation is however, not the major thrust of this study.

Annual herbaceous legumes may provide opportunities for cover crops that provide biological N and at the same time generate fewer water deficit problems than longer-lived legumes such as the woody perennials currently being promoted in agroforestry. However, herbage biomass N from herbaceous plants may be insufficient to overcome soil N deficiencies in smallholder farms. The integration of small amounts of inorganic N fertilizer with the organic materials (legume cover crop) offers a strategy to meet the N needs of smallholder farms (Jama et al., 1997; Waddington and Heisey, 1977).

Objectives. The objectives of this study were to (i) quantify legume herbage biomass and N accumulation of a food and a forage legume relay-intercropped into maize, (ii) evaluate impact of relay-intercropped legumes on the companion maize crop, and (iii) evaluate response of a subsequent maize crop to relay-intercropped legumes and compare this with the response to fertilizer N.

MATERIALS AND METHODS

This study was conducted in 1996 and 1997 at Domboshava (elevation approx. 1500 masl), 31 km north east of Harare. The area has Typic Kandiustalf which is generally infertile with coarse-grained loamy sand soil. Trophic soil properties were characterized at the beginning of the study (Table 1.1).

Maize (*Zea mays* L. 3-way cross hybrid R215) was hand-planted at two seeds per station on tractor disc-plowed land. Designated plots were received 22 kg N ha^{-1}, 28 kg P ha^{-1} and 19.5 kg K ha^{-1} applied as Compound D (8 14 7) before planting. Additional fertilizer of 0, 60 and 120 kg N ha^{-1} as NH_4NO_3, was applied in designated plots as a dollop next to each station about 48 days after planting (V6 growth stage of maize) when the soil moisture level in the ground was at field capacity. Maize plant spacing was 0.9 m between rows and 0.5 m within row giving a plant population density of 44, 444 plants per hectare. Each plot was 10 m x 6.4 m.

Weeds were removed by hand as necessary. Two legumes, cowpea (*Vigna unguiculata* L.) - a food legume, and sunnhemp (*Crotalaria juncea* L.) - a forage legume, were relay-intercropped into maize (two legume rows between adjacent maize rows) in each of two years. Legumes were planted as intercrops at about 28 days after maize planting (V4 stage) in pre-assigned plots. Legumes were seeded at in-row spacings of 10 cm, achieving a plant population of 111, 000 plants per hectare.

The legume seeds were not inoculated with rhizobia before planting, which corresponds to local farmer practice. Also, an unfertilized plot with maize alone was included in each replication as control.

Above-ground herbage biomass of legumes was sampled at 45, 60 and 75 days after planting (DAP) the legumes using hand secateurs from a 0.09 m^2 quadrant. Weeds were hand separated from legumes and legume herbage was dried at 60 C temperature for at least three days for dry matter yield.

Photosynthetically active radiation (PAR) was measured in 1997 at 50 and 75 DAP (legume) using a Licor sensor meter. Readings were taken just above the maize canopy, just above understory legume and on the ground under the legume.

Maize grain was harvested from a 1.8 m x 4 m section of the center two rows in each plot so that the area harvested was 7.2 m^2. Grain yields were adjusted to 125 g kg^{-1} moisture content. Maize stover was harvested from a single center-most row in a 0.9 m x 4 m section and yields were expressed as dry matter per hectare.

In the subsequent year, maize following maize-legume intercrops was established on the same plots. This crop was fertilized with two split applications of 0, 46, 92 and 138 kg N ha^{-1}, initially as Compound D at planting and NH_4NO_3 as side dress at about V6-V8 maize growth stage.

Plant and Chemical Analysis. Total N in maize grain, stover and legume herbage was determined by a modified micro-Kjeldahl method. Dry plant materials were ground in a Wiley mill to pass through a 2-mm screen. Plant samples of 0.1 g were digested in 4 ml of 18 M H_2SO_4 with 1.5 g K_2SO_4 and 0.075 g Se catalyst. Following digestion total NH_4^+ was determined by spectrophotometry. Total N yield was calculated as the product of dry matter yield and nitrogen concentration.

Statistical Analysis.

In the relay-intercropping year, the experiment was planted as a randomized complete block design (RCBD) with treatments replicated three times. Analysis of variance (ANOVA) was used to analyze treatment differences for grain yield, total above-ground biomass, grain N content and total N uptake of maize. When N applied was significant, response was further partitioned into linear and quadratic trends from single degree of freedom comparisons and regression equations determined in Proc Reg of SAS (SAS, 1997).

Legume herbage biomass was analyzed as a repeated measures experiment with a first order auto-regression correlation type [AR(1)] over sampling periods in Proc Mixed of SAS (SAS, 1997). Due to a significant ($P \leq 0.05$) three way interaction of legume x N applied x sampling period, a reduced model of herbage biomass and N yield was used within a sampling period. In the reduced model, herbage biomass and N yield was analyzed as an RCBD, with treatments replicated three times.

In the subsequent year, experiment was a RCBD with a split-plot arrangement, replicated three times. The first year cropping system [maize + 1st-yr. N or maize-legume + 1st-yr. N] were whole plots and 2nd-yr. N rates were subplots. Analysis of variance using Proc GLM (SAS, 1997) was used to identify treatment effects.

Response to N fertilizer rate in the 2nd-yr. were determined by evaluating linear and quadratic trends from single degree of freedom comparisons. Whenever trends were significant, regression equations were calculated to determine fertilizer replacement values (FRV) of relay-intercropped legumes in the preceding year.

RESULTS AND DISCUSSION

Legume herbage biomass. A significant legume x nitrogen interaction was observed in both years for herbage biomass and N yield. Hence legumes herbage biomass (as dry matter, DM) and N yields are presented separately for each N rate (Tables 1.2 and 1.3). Herbage biomass ranged from 0.6 to 4.6 Mg ha^{-1} for cowpea and from 0.9 to 2.9 Mg ha^{-1} for sunnhemp. These herbage biomass yields are similar to those recorded with pigeon pea (*Cajanus cajan* L.) when grown alone (2.07-3.21 Mg ha^{-1} , Kwatpata 1984) and when intercropped with maize in Malawi (3.0 Mg ha^{-1} Sakala, 1994).

Response of legumes to N fertilizer were determined by evaluating linear and quadratic trends from a single degree of freedom comparisons. In 1996, only sunnhemp was linearly related to N applied. Sunnhemp herbage biomass yield was positively correlated ($r = 0.55$; $P \leq 0.1$) with N rate. However, cowpea and N applied were not significantly correlated ($P \leq 0.1$), but herbage biomass was lowest at the maximum N applied (Table 1.2). Differences in response by the two species are mainly due to different growth habits. Cowpea will get more shade from fast covering high N rate maize, but sunnhemp grows up (erect) into the maize canopy and intercepts more light. In 1997, both cowpea and sunnhemp linearly responded to N applied and were negatively correlated with N rate, with r = -0.55 and -0.41

respectively, at P≤ 0.1. Herbage biomass tended to decline with increased N rate (Table 1.3).

The negative correlation of herbage biomass to applied N could be explained by the direct effects of shading by associated maize on dry matter production by the legume. Because dry matter production in crops depends on the efficiency of interception of photosynthetically active radiation (PAR) (Biscoe and Gallagher, 1977; Monteith, 1977), shading of the legume understory resulted in low herbage biomass. In this study, PAR recorded in 1997 shortly before tasselling were 87, 78 and 61 percent for understory legume in maize-legume intercrops fertilized with 0, 60 and 120 kg N ha^{-1} , respectively (data not shown). The PAR recorded indicated a fair amount of shading in the understory legume at 120 kg N ha^{-1}.

Legume N yield. Legume N yields ranged from 15 to 154 kgN ha^{-1} for cowpea and 23 to 82 kg N ha^{-1} for sunnhemp (Tables 1.2 and 1.3). Giller and Wilson (1991) have shown that tropical legumes grown in pure cultures can often accumulate 100-200 kg N ha^{-1} in 100-150 days. The range of N yields reported in our study are somewhat lower, partly because the legumes were intercropped and were allowed to grow for a maximum of only 75 days. Legume N yields in intercrops are usually lower than those from sole legumes because intercrops occupy less land area and are subject to competition for resources, particularly for light, from the taller cereal crop (Nambiar et al. , 1983).

In 1997, N yields of cowpea and sunnhemp were negatively correlated to N rate (r = -0.56 and -0.52 ; P≤ 0.1, respectively). Giller and Cadisch (1995) reported a decrease in N_2 fixation by legumes due to the 'problem' of excessive plant-available N. Our results suggest that N yields are reduced in the presence of an increased inorganic N pool and due to the shade effects by maize fertilized at high N rates (<60 kg N ha^{-1}. Furthermore, Eaglesham et al. (1983) concluded from pot studies that fertilizer N applications in excess of 25 kg N ha^{-1} would be likely to inhibit N fixation of cowpea under field conditions.

Relay-intercropped maize yields. Due to a significant (P≤ 0.05) cropping system x nitrogen rate interaction, data are presented as response of maize to cropping system and fertilizer N. Because legume x nitrogen interactions were not significant, and main effects of cowpea and sunnhemp were not significantly (P≤ 0.05) different, data were averaged across the two legumes. Least square equations for maize grain yield, grain N content and total above-ground biomass in response to applied nitrogen in maize-legume intercrop systems and sole maize were calculated (Table 1.4).

Relay-intercropping cowpea and sunnhemp into maize fertilized with zero or 60 kg N ha^{-1}, was not associated with a significant (P≤ 0.05) grain yield reduction (Figs 1.1 and 1.2). However, relay-intercropping legumes into maize fertilized with 120 kg N ha^{-1} resulted in significant grain yield reductions of 18% in 1996 (Fig 1.1) and 32% in 1997 (Fig 1.2), respectively compared to unfertilized sole maize.

Results for zero and 60 kg N ha^{-1} which are representative of the range of N rates that smallholders in Zimbabwe often use suggests that legumes could be relay-intercropped into maize without decreasing maize grain yields. In fact, yields were slightly improved at these N rates, however, not significantly so. Also, our results agree with those of Haizel (1974) working with maize-cowpea, and Andrews (1972) and Rees (1986) with sorghum-cowpea intercrop systems, in which no maize yield suppressions nor increases were observed.

Maize grain yield reductions at 120 kg N ha^{-1} likely resulted from competition for resources such as moisture, light and nitrogen with the legume. The maize grain yield reduction of 18-32% when maize was relay-intercropped with legumes in our study corresponds to those by other researchers reporting declines in unfertilized maize yields when intercropped with cowpea of 31% (Haizel, 1974), 33% (Wanki et al. 1982) and 18% (Ofori and Stern, 1986). However, unfertilized cereal yields have been increased in some studies by 11% (Agboola and Fayemi, 1971) and 45% (Remison, 1978) in maize-cowpea intercrop systems in West Africa.

Competition between species in intercropped systems for growth-limiting factors is regulated by basic morpho-physiological differences and agronomic factors such as the proportion of crops in the mixture, fertilizer applications and relative time of planting (Harper, 1961; Trenbath, 1976).

Maize grain N uptake. Maize grain N uptake was similar or slightly greater with the intercrop than with the control (sole maize) when no N fertilizer was applied (Figs 1.3 and 1.4). At 60 kg N ha^{-1}, intercropped maize was associated with a significantly higher grain N uptake in both years. At 120 kg N ha^{-1}, grain N uptake in the intercrop system was reduced by 20% in 1996 and 34% in 1997 (Figs 1.3 and 1.4).

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In cereal-legume intercropping, the legume component is capable of fixing atmospheric N_2 under favorable conditions and this is thought to reduce competition for N with the cereal (Trenbath, 1976). In the absence of an effective N_2-fixing system, both the cereal and intercropped legume compete for available soil N (Ofori et al. 1987). Another theory states that in the presence of adequate to excessive soil N, legumes switch off N_2 fixation and utilize the readily available soil N. This theory seems to adequately explain the grain N uptake pattern in our study. Our results suggest that legumes were actively fixing N_2 when plots were fertilized with zero or 60 kg N ha^{-1}, but N_2-fixation was reduced by the higher N rate. Decreased N_2 fixation resulted in competition for soil N, hence reducing maize grain N uptake.

Subsequent Maize Response to Legume and Fertilizer Nitrogen

Maize Yields: No Nitrogen Applied. Maize following maize that had been relay-intercropped with a legume produced 20% higher grain yields than maize following maize with no legumes (continuous maize) (Fig 1.5). There was no significant legume x nitrogen fertilizer interaction on subsequent maize grain yield and total above-ground biomass. Therefore data presented are means of two legumes (cowpea and sunnhemp). Most studies of maize-cowpea intercropping conducted in Zimbabwe have not assessed effect in a subsequent year, in spite of reporting either an intercrop advantage (e.g. Mariga, 1990) or disadvantage (e.g. Shumba et al., 1990; Natarajan and Shumba, 1990) in the intercropping season. This study is an attempt to provide an assessment on effects of intercropped legumes in the subsequent season.

Maize improvements of 33% following pigeon pea in Malawi (Kwatpata, 1984) and 21% following sunnhemp in Tanzania (Temu, 1982) have been reported. Agboola (1980) working with one season fallows of pigeon pea, mucuna (*Calopogium mucunoides* L.) and cowpea in a sub humid province of Nigeria observed increases of subsequent maize crop yields of 10-30%. Nair et al. (1979) found a maize grain yield increase of 34% in the year following a maize-cowpea intercrop.

Grain N content in the subsequent year was significantly affected by the legume type. Maize following maize intercropped with cowpea was associated with a 16% higher grain N content, while sunnhemp reduced maize grain N uptake by 50% when no N fertilizer was applied (Fig 1.6). Increased maize grain N uptake associated with the previous cowpea crop seems to be a response to an enlarged soil N pool. A decline of about 50% with sunnhemp may be due to a net soil N immobilization. However, we cannot make formal conclusion, as soil N pools were not measured in this study.

<u>Maize response to Fertilizer and Legume Nitrogen</u>. There was a positive response of maize grain yield (GR), grain N content (GRN) and total above-ground N uptake (TN) to fertilizer N and legume from the previous year. Fitted regression equations were calculated for maize grain yield, grain N content and total N uptake as a function of fertilizer N applied (Table 1.5).

Maize grain yields were greater at all fertilizer N levels following a maize-legume intercrop compared to continuous maize, but not significantly so at the highest

N level. Maximum yield benefits of the maize-legume intercrop in the subsequent year appeared to be realized when maize was fertilized with 46-92 kg N ha^{-1} , while at higher N levels diminishing returns were apparent (Fig 1.5). Lack of maize response to higher N rate in 1996/97 was due to incessant and excessive rainfall received especially in the months of January and February (rainfall data is presented in Fig 2.1).

Grain N content of maize following the maize-cowpea intercrop was always higher than that of the continuous maize, but not always at a statistically significant level ($P \leq 0.05$). However, with maize following the maize-sunnhemp intercrop, grain N content was always lower than that of continuous maize (Fig 1.6). A possible explanation of this response is (i) immobilization of sunnhemp, absorbing inorganic sources of N or (ii) lack of synchrony between legume N release and maize grain N uptake. However, if the latter occurred, then we would expect grain N uptake of the maize following maize-sunnhemp intercrop to be similar to that of continuous maize, but this was not the case in our study.

Fertilizer Replacement Values. For the cropping systems under study to be acceptable to both the farmers and researchers, there must be a convincing yield or N uptake improvement in the subsequent year, with no yield reduction in the intercropping season.

One way to assess improvements in the subsequent year is to evaluate fertilizer replacement values (FRV). For an FRV to be valid, yield of a subsequent crop following the legume should be significantly higher than that of the non-legume control. Based on this criterion, FRV could only be calculated based on grain yield, grain N content and total N uptake of maize.

Highest FRV's were calculated based on grain N content and the least on grain yield (data not shown). Because the lowest FRV of 18 kg N ha^{-1} was obtained with grain yield, this suggests modest residual N benefits derived from the cropping system. Singh (1983) estimated N benefits to subsequent cereal crops after cereal-legume intercrops. He obtained N fertilizer equivalents of 3 kg ha^{-1} with soybean, 31 kg ha^{-1} with greengram, 46 kg ha^{-1} with grain cowpea and with groundnut, and 54 kg ha^{-1} with forage cowpea.

Table 1.1. Trophic soil properties at the beginning of study at Domboshava.

Soil texture	Loamy sand
pH ($CaCl_2$)	4.5
C (%)	0.46
Mineralizable N (ppm)	24.13
P_2O_5 ($\mu g\ g^{-1}$)	9.10
CEC† (me %)	1.92
TEB‡ (me %)	5.17

† Cation exchange capacity
‡ Total exchangeable bases

Table 1.2. Effect of fertilizer N on legume herbage biomass (DM) and N yield at 75 DAP in 1996.

N applied (kg ha^{-1})	Cowpea		Sunnhemp	
	DM (Mg ha^{-1})	N yield (kg ha^{-1})	DM (Mg ha^{-1})	N yield (kg ha^{-1})
0	1.05	27.21	0.89	22.71
60	1.93	50.42	2.34	57.02
120	0.60	15.28	2.92	76.66
CV (%)	32	24	40	22
LSD (0.05)	0.84	22.45	1.21	24.58

Table 1.3. Effect of fertilizer N on legume herbage biomass (DM) and N yield at 75 DAP in 1997.

N applied (kg ha^{-1})	Cowpea		Sunnhemp	
	DM (Mg ha^{-1})	N yield (kg ha^{-1})	DM (Mg ha^{-1})	N yield (kg ha^{-1})
0	4.57	154.32	2.86	82.07
60	2.72	104.46	1.80	51.01
120	2.01	73.28	1.32	44.24
CV (%)	28	25	32	19
LSD (0.05)	1.68	31.54	1.36	24.34

Table 1.4. Fitted Regression Equations for Maize grain yield (GR), grain N content (GRN) and total above-ground biomass (TDM) in Maize-Legume Intercrop Systems as a function of N fertilizer applied (x).

Cropping system	Equation†	R^2	Sign
	Intercropping year : 1996		
Maize alone	GR = 1.36 + 0.01(x)	0.75	0.003
	GRN = 15.88 + 0.13(x)	0.73	0.003
	TDM = 3.05 + 0.019(x)	0.61	0.01
Maize + legume	GR = 1.45 + 0.025(x) - 0.0002(x^2)	0.78	0.01
	GRN = 16.72 + 0.29(x) - 0.002(x^2)	0.79	0.01
	TDM=3.54 + 0.04(x) - 0.0003(x^2)	0.68	0.03
	Intercropping year: 1997		
Maize alone	GR = 2.12 + 0.04(x)	0.63	0.01
	GRN = 21.2 + 0.5(x)	0.62	0.01
	TDM = 7.75 + 0.04(x)	0.44	0.05
Maize + legume	GR = 1.92 + 0.103(x) - 0.0007(x^2)	0.74	0.0001
	GRN = 17.38 + 0.98(x) - 0.006(x^2)	0.73	0.0001
	TDM=7.54 + 0.116(x) - 0.0008(x^2)	0.42	0.017

†Linear equations were based on 7 degrees of freedom, while quadratic equations were based on 6 degrees of freedom.

Table 1.5 : Regression equations for maize grain yield (GR), grain N content (GRN), total above-ground biomass (TDM) and total N in above-ground biomass (TN) as a function of N fertilizer applied (x) in the subsequent year (maize + legume-maize).

Cropping system	Equation†	R^2	Sign
Maize - Maize	GR = 1.22 + 0.045(x) - 0.002(x^2)	0.63	0.01
	GRN =15.41 + 0.334(x)-0.0013(x^2)	0.71	1e-04
	TN =37.45 + 0.24(x)	0.58	0.001
Maize + cowpea - Maize	GRN = 22.78 + 0.153(x)	0.51	0.001
	TN = 41.28 + 0.228(x)	0.48	0.01
Maize + sunnhemp-Maize	GRN = 5.99 + 0.48(x) - 0.0022(x^2)	0.75	0.002
	TN = 32.11 + 0.519(x) - 0.0024(x^2)	0.78	0.001
Maize + legumes‡ - Maize	GR = 1.94 + 0.039(x) - 0.0002(x^2)	0.7	1e-04

†Linear equations were based on 10 degrees of freedom, while quadratic equations were based on 9 degrees of freedom.

‡Refers to combined effect of cowpea and sunnhemp and equation is based on 21 degrees of freedom.

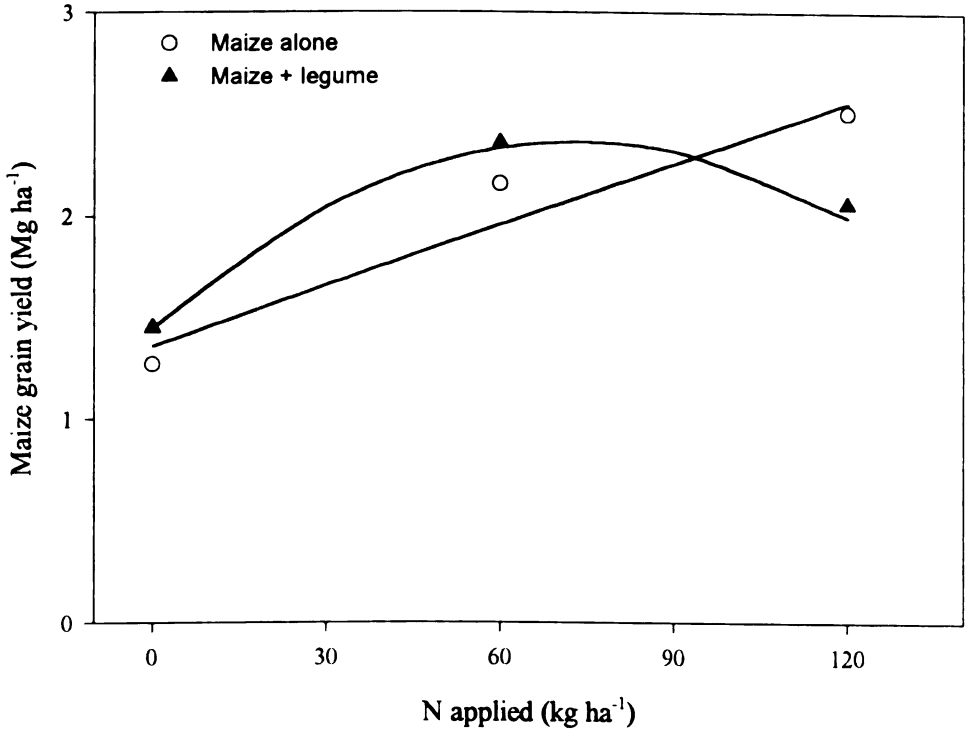


Figure 1.1 Effect of relay-intercropped legumes and fertilizer N on maize grain yield in the interseeding year (1996).

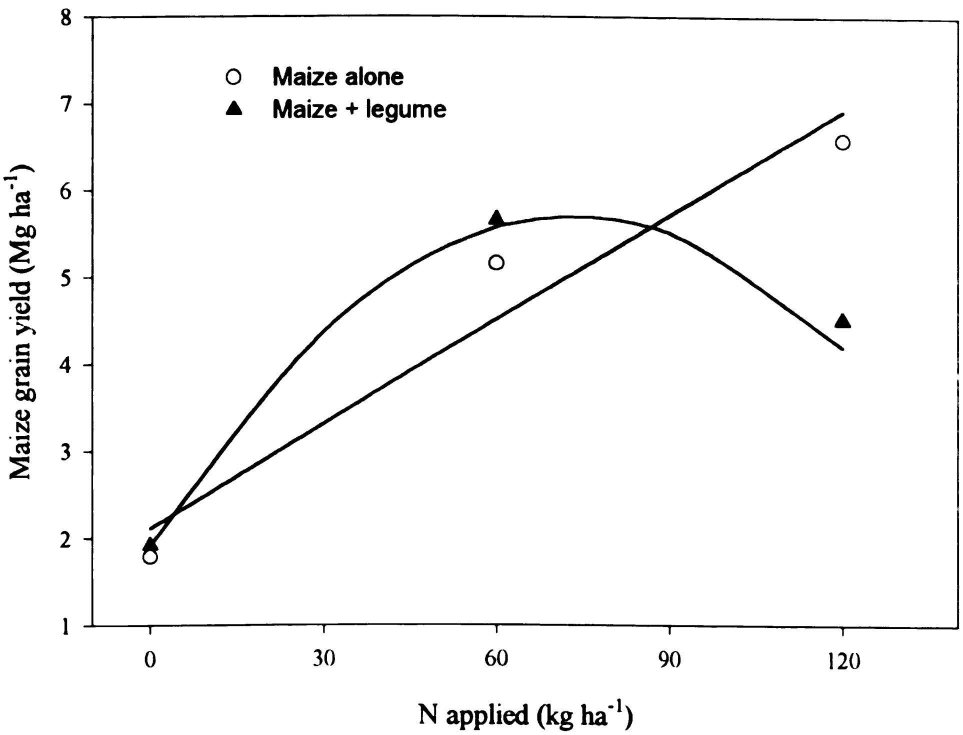


Figure 1.2 Effect of relay-intercropped legumes and fertilizer N on maize grain yield in the interseeding year (1997).

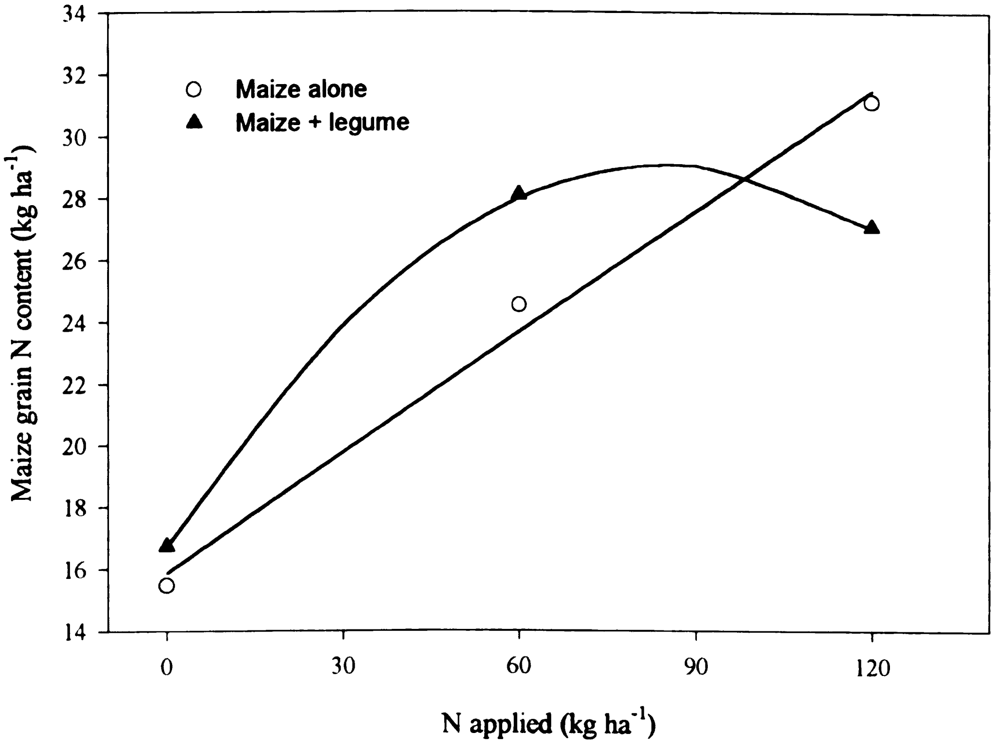
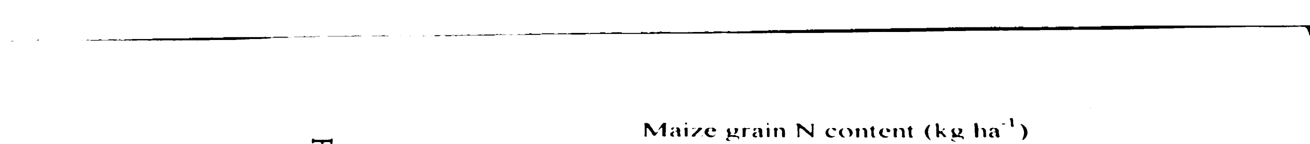


Figure 1.3 Effect of relay-intercropped legumes and fertilizer N on maize grain N content in the interseeding year (1996).


Maize grain N content (kg ha^{-1})

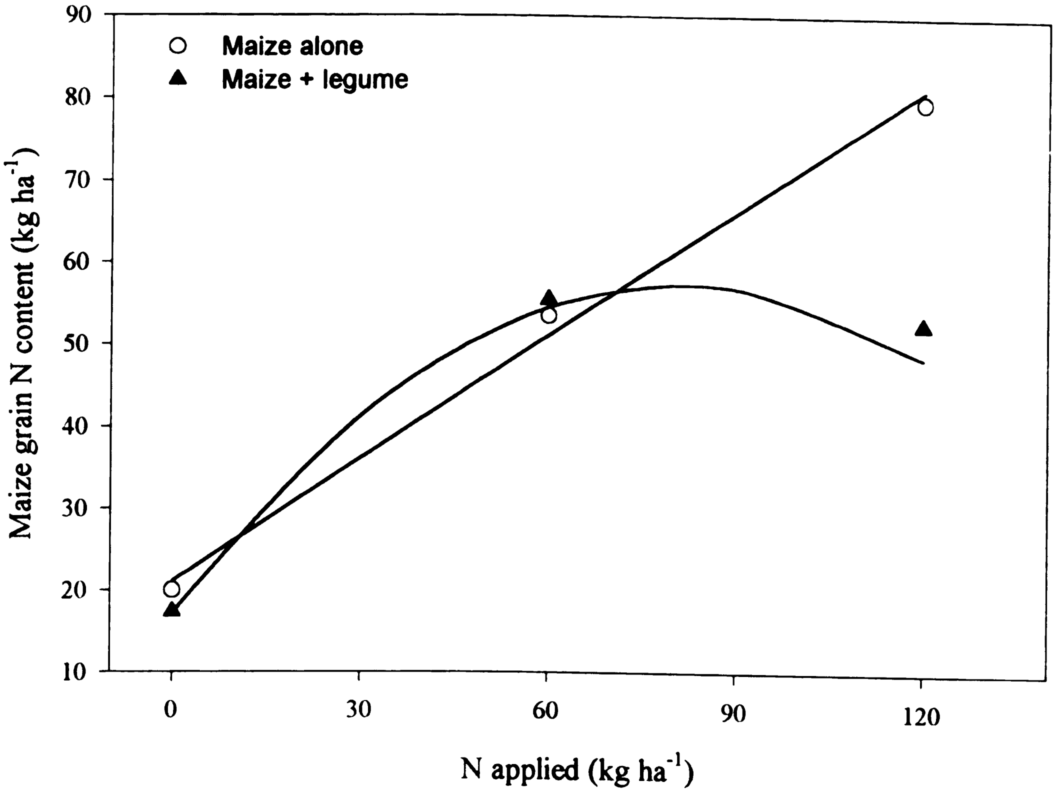


Figure 1.4 Maize grain N content response to relay-intercropped legumes and fertilizer N in the interseeding year (1997).

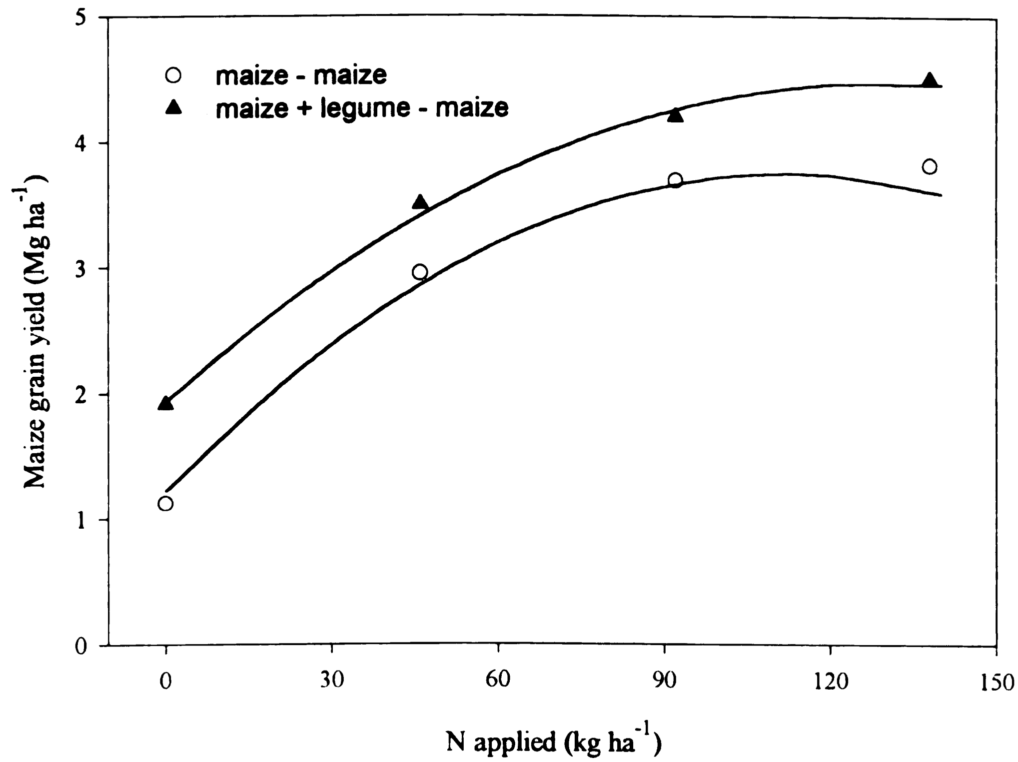


Figure 1.5 Subsequent maize grain yield (1997) response to fertilizer N and previous year's cropping system.

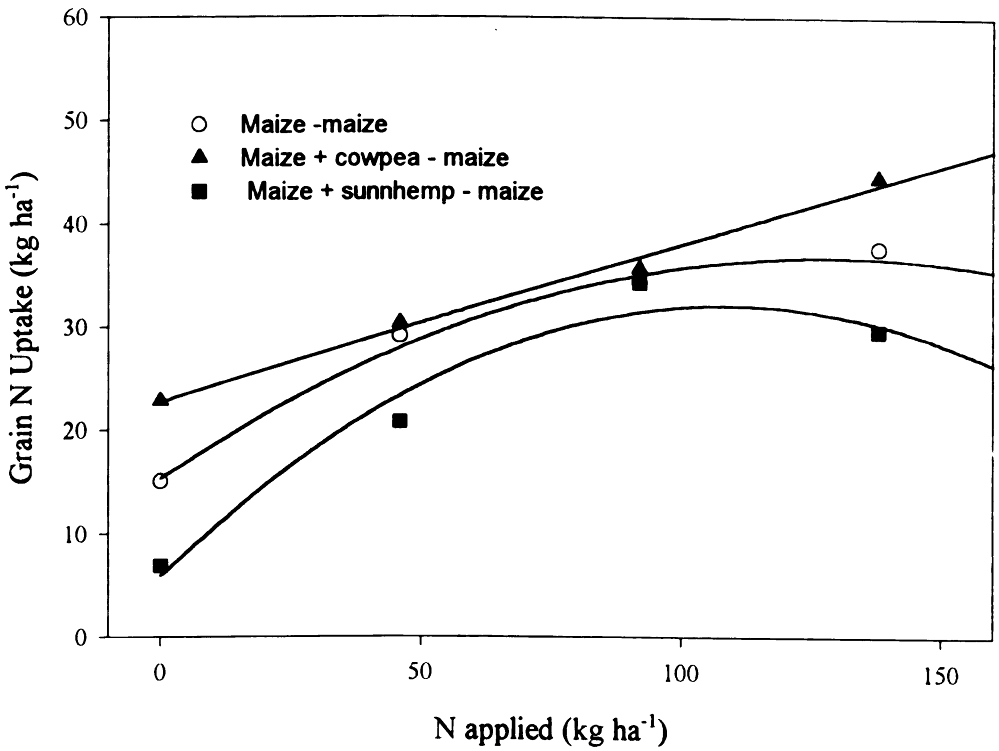


Figure 1.6. Effect of relay intercropped legumes on subsequent maize grain N uptake

CONCLUSIONS

Herbage biomass and N yield of intercropped legumes were influenced by N application. A high fertilizer N rate (120 kg ha^{-1}) was associated with decline in legume herbage biomass and subsequent N yields compared to 60 kg N ha^{-1} .

Companion maize grain yields were not reduced when legumes were relay-intercropped into maize fertilized with zero and or 60 kg N ha^{-1}. However, at 120 kg N ha^{-1}, yields were reduced by 18-32%. Also, grain N uptake was not reduced at zero and 60 kg N ha^{-1} fertilizer levels in the intercropping system, but were reduced by 20-34% at 120 kg N ha^{-1}.

In the subsequent year, maize grain yields were increased by 20% following legume intercrops compared to continuous maize. Maize grain N uptake following the maize-cowpea intercrop was increased by 16% while grain N uptake following the maize-sunnhemp intercrop was reduced by as much as 50%. Overall, legumes reduced fertilizer needs of subsequent maize crop by up to 36 kg N ha^{-1}.

This research suggests that annual herbaceous legumes have a unique niche in smallholder farms in Zimbabwe. If they are relay-intercropped into moderately fertilized (>0-60 kg N ha^{-1}) maize, the yields of companion maize can be maintained, at the same time that subsequent maize crop yields are enhanced.

REFERENCES

Agboola, A.A, and A.A. Fayemi. 1971. Preliminary trials on the intercropping of maize with different tropical legumes in Western Nigeria J. Agric. Sci.77: 219-225.

Agboola, A.A., and A.A. Fayemi. 1972. Fixation and excretion of nitrogen by tropical legumes. Agron J. 64: 409-412.

Agboola, A.A. 1980. Effect of different cropping systems on crop yield and soil fertility in the semi-humid tropics. In Organic recycling in Africa (Rome: FAO) p. 87-105.

Andrews, D.J. 1972. Intercropping with sorghum in Nigeria. Exp. Agric. 8: 139-150.

Allos, H.F. and W.V. Bartholomew. 1956. Relacement of symbiotic fixation by available nitrogen. Soil Science 87, 61-66.

Baduruddin, M., and D.W. Meyer. 1989. Water use by legumes and its effect on soil water stress. Crop Sci. 29: 1212-1216.

Biscoe, P.V., and J.N. Gallagher. 1977. In J.J. Landsberg and C.V. Cutting (eds.). *Environmental Effects of Crop Physiology*. pp. 75-100. Academic Press, New York.

Eaglesham, A.R.J., S.Hassouna, and R. Seegers. 1983. Fertilizer-N effects on N_2 fixation by cowpea and soybean. Agron. J. 75: 61-66.

Exner, D.N, and R.M. Cruse. 1993. Interseeded forage legume potential as winter ground cover, nitrogen sourse, and competitor. J. Prod. Agric. 6: 226-231.

Giller, K.E. and K.J. Wilson. 1991. *Nitrogen Fixation in Tropical Cropping Systems*. CAB International, Wallingford.

Giller, K.E, J.F. McDonagh and G. Cadisch. 1994. Can Biological Nitrogen Fixation Sustain Agriculture in the Tropics? In J.K. Syers and D.L. Rimmer (ed.) Soil Science and Sustainable Land Management in the Tropics. Dep. of Agricultural and Environmental Sci., University of Newcastle upon Tyne, UK.

Giller, K.E. and G. Cadisch. 1995. Future benefits from biological nitrogen fixation: An ecological approach to agriculture. Plant and Soil 174: 225-277.

Grant, P.M. 1970. Restoration of productivity of depleted sands. Rhod. Agric. J. 67: 131-137.

Haizel, K.A. 1974. Maize-cowpea intercropping study in Kumasi. Ghana J. Agric. Sci. 7: 169-178.

Harper, J.L. 1961. Approaches to the study of plant competition.Symp. Soc. Expl. Biol. 15: 1-39.

Hesterman, O.B. 1988. Exploiting forage legume for nitrogen contribution in cropping systems. p. 155-166. In W.L. Hargrove (ed.). Cropping strategies for sefficent use of water and nitrogen. ASA-CSA-SSSA Spec. Publ. 51, ASA-CSA-SSSA. Madison, WI.

Harris, G.H, and O.B. Hesterman. 1987. Recovery of nitrogen-15 labelled alfalfa residue by a subsequent corn crop. In: J.F. Power (ed.) The role of legumes in conservation tillage systems. Soil Cons. Soc. Am. Ankey, IA. pp 58-59.

Hikwa, D. and L. Mukurumbira. 1995. Highlights of previous, current, and proposed soil fertility research by Department of Research and Specialist Services (DR&SS) in Zimbabwe. In S.R. Waddington (ed.), Report on the First Meeting of the Network Working Group, Soil Fertility Rsearch Network for Maize-Based Farming Systems in Selected Countries of Southern Africa. Lilongwe, Malawi, and Harare, Zimbabwe. The Rockefeller Foundation Southern Africa Agricultural Sciences Program and CIMMYT. Pp. 44-50.

Hikwa, D., M. Murata, F. Tagwira, C. Chiduza, H. Murwira, L. Muza, and S. Waddington. 1997. Performance of green manure legumes on exhausted soils in northern Zimbabwe: A soil fertility network trial. In: S.R. Waddington et al. (eds), Proceedings of the Soil Fert Net Results and Planning workshop. Africa University, Mutare, Zimbabwe.

Jama, B., R.A. Swinkels, and R.L. Buresh. 1997. Agronomic and Economic Evaluation of Organic and Inorganic sources of Phosphorus in Western Kenya. Agron. J. 89:597-604.

Jeranyama, P. 1995. Medic planting date effect on dry matter and nitrogen accumulation when clear-seeded or intercropped with corn. MS thesis, Dept. of Crop and Soil Science, Michigan State University.

Kwatpata, M.B. 1984. Shifting cultivation problems and solutions in Malawi. In: The future of shifting cultivation in Africa and the task of Universities (Rome: FAO) pp. 77-85.

Kumwenda, J.D.T., S.R. Waddington, S.S. Snapp, R.B. Jones, and M.J. Blackie. 1996. Soil Fertility Management Research for the Maize Cropping Systems of Smallholders in Southern Africa: A Review. NRG Paper 96-02. Mexico, D.F.: CIMMYT.

Ladd J.N, J.M. Oades, R.B. Jackson and J.H.A. Butler. 1983. Utilization by wheat crops of nitrogen from legume residues decomposing in soils in the field. Soil Biol Biochem 13: 251-238.

Mariga, I.K. 1990. Effect of cowpea planting date and density on performance of a maize-cowpea intercrop. Zimbabwe J. Agric. Res. 28: 125-131.

Mashiringwani, N.A. 1983. The present nutrient status of the soil in communal areas of Zimbabwe. Zimb. Agric. J. 80: 73-75.

Metelerkamp, H.R.R. 1988. Review of crop research relevant to semiarid areas of Zimbabwe. In Cropping in the Semiarid Araes of Zimbabwe. Proceedings of a workshop. Harare, Zimbabwe: Agritex, Department of Research and Specialist Services (DR&SS), and Gemeinschaft fur Technische Zusammenarbeit (GTZ). Pp. 190-315.

Monteith, J.L. 1977. Climate and the efficency of crop production in Britain. Philos. Trans. R. Soc. London Ser. B. 281: 277-294.

Nair, K.P.P., U.K. Patel, R.P. Singh, and M.K. Kaushik. 1979. Evaluation of legume intercropping in conservation of fertilizer nitrogen in maize culture. J. Agric. Sci. 93: 189-194.

Nambiar, P.T.C., M.R. Rao, M.S. Reddy, C.N. Floyd, P.J. Dart, and R.W. Wiley. 1983. Effect of intercropping on nodulation and N_2-fixation by groundnut (*Arachis hypogea*).Expl. Agric. 19: 77-86.

Natarajan, M., and E.M. Shumba. 1990. Intercropping research in Zimbabwe: Current status and outlook for the future. In: S.R. Waddington, A.F.E. Palmer, and O.T. Edje (eds.) Research Methods for Cereal/Legume Intercropping. Mexico, D.F.: CIMMYT pp. 190-193.

Ofori, F. and W.R. Stern. 1987. Cereal-legume intercropping systems. Advances in Agronomy, vol 41: 41-90.

Okibgo, B.N. and D.J. Greenland. 1976. Intercropping in tropical Africa. p. 63-101. In R.I. Papendick, P.A. Sanchez, and G.B. Triplett (ed.) Multiple cropping. ASA 'Spec. Publ. 27, Madison, WI.

Pandey, R.K., and J.W. Pendleton. 1986. Soybeans as green manure in a maize intercropping system. Exp. Agric. 18: 125-138.

Rees, D.J. 1986. Crop growth, development and yield in intercropping sorghum with cowpea in semi-arid conditions in Botswana. II. Exp. Agric. 22: 169-177.

Remison, S. U. 1978. Neighbour effects between maize and cowpea at various levels of N and P. Exp. Agric. 14: 205-212.

Rerkasem, K. and B. Rerkasem. 1988. Yields and nitrogen nutrition of intercropped maize and ricebean (*Vigna umbellata* (Thumb) Ohwi and Ohashi). Plant and Soil 108: 151-162.

Sakala, W.D.M. 1994. Crop management interventions in traditional maize pigeon pea intercropping systems in Malawi. MSc thesis. Lilongwe, Malawi: Bunda College of Agriculture, University of Malawi.

SAS Institute, Inc 1997. SAS/STAT Users Guide, Release 6.12 Ed. Cary NC.

Singh, S.P. 1983. Summer legume intercrop effects on yield and nitrogen economy of wheat in the succeeding season. J. Agric. Sci. 101: 401-405.

Shumba E.M., H.H. Dhliwayo, and O.Z. Mukoko. 1990. The potential of maize-cowpea intercropping in low rainfall areas of Zimbabwe. Zimbabwe Journal of Agricultural Research 28: 33-38.

Tattersfield, J.R. 1982. The role of research in increasing food crop potential in Zimbabwe. Zim Sci. News vol. 16 no. 1 : 6-11.

Thomas, D., and J.E. Sumberg. 1995. A review of the evaluation and use of tropical forage legumes in sub-Saharan Africa. Agriculture, Ecosystems and Environment 54: 151-163.

Trenbath, B.R. 1976. In Mutliple cropping (R.I Papendick, P.A. Sanchez, and G.B. Triplett. eds.) pp. 129-169. Spec. Publ. ASA. Madison, WI.

Temu, A.E.M. 1982. Rotational green manuring with Crotolaria in the Southern highlands of Tanzania. Southern Highlands Maize Improvement Program, Progress Report, Tanzania. Mimeo.

Waddington, S.R., and P.W. Heisey. 1997. Meeting the nitrogen requirements of maize grown by resource-poor farmers in southern Africa by integrating varieties, fertilizer use, crop management and policies. In G.O. Edmeads, M. Banziger, H.R. Mickelson, and C.B. Pena-Valdivia (eds). Developing drought-and-low N-tolerant maize. Proceedings of a symposium, March 25-29, CIMMYT, El Batan, Mexico, D.F.: CIMMYT.

CHAPTER TWO

MAIZE (*Zea mays* L.) YIELD AND NITROGEN UPTAKE FOLLOWING GROUNDNUT (*Arachis hypogaea* L.) ON SMALLHOLDER FARMS IN NORTHERN ZIMBABWE

ABSTRACT

The more systematic rotation of maize (*Zea mays* L.) with groundnut (*Arachis hypogaea* L.) has been proposed as a way of maintaining soil fertility and preventing maize productivity declines associated with smallholder cropping systems of Zimbabwe. The objectives of this study were (i) to evaluate the impact of a groundnut crop on subsequent maize yield and N uptake, (ii) to evaluate the response to fertilizer-N for maize in rotation with groundnut compared to continuous maize and (iii) to determine the fertilizer replacement value of groundnut. Treatments included continuous maize and a maize-maize-groundnut rotation, receiving variable fertilizer-N rates in a split-plot arrangement. Maize yields were improved by 0.1-2.2 Mg ha^{-1} following groundnut compared to continuous maize. The low groundnut yield on farm were associated with little yield improvements for a subsequent maize crop. In a second maize crop after groundnut on station, yields were increased by 0.8 Mg ha^{-1} and grain N uptake was increased by 53% relative to continuous maize. Fertilizer needs were reduced by 72 kg N ha^{-1} when maize followed groundnut.

INTRODUCTION

Declining soil fertility in the smallholder farms of Zimbabwe is partly a result of continuous maize (*Zea mays*) production and partly due to inadequate nutrient inputs and management, exacerbated by unreliable rainfall distribution and marginal economics. Traditionally, African agricultural systems restored soil fertility lost during cropping by extended fallows with natural vegetation (Araki, 1993; Blackie and Jones, 1993). Increasing population pressure on limited agricultural land has rendered fallowing a non-viable option, while continuous maize has become a common cropping system in Zimbabwe (Kumwenda et al., 1996). Continuous cropping of maize at reasonable levels of productivity (>1 Mg ha^{-1} grain yields) can likely not be sustained without substantial additions of nutrients (Grant, 1970; MacColl, 1989). One alternative to reduce over-dependence on chemical fertilizers is to grow maize in rotation with a legume such as groundnut (*Arachis hypogaea*).

Although maize remains the major crop and a staple food, groundnuts are important in the diets of smallholder farmers. Groundnuts are the second most important crop in sub-humid smallholder farmers in Zimbabwe and are widely recognized for their nutritive value, particularly for young children. The kernels are eaten raw, boiled or roasted, and made into confectionery and snack foods. They are also used in soups or made into sauces for meat, rice or maize meals. The vegetative residues from groundnut are excellent forage. However, despite the benefits of groundnut as a crop, its production in the smallholder farms has declined (Shumba, 1983; Dendere, 1987).

Reasons for groundnut production declines includes a government policy of over-promoting maize for a long time by making maize pricing and marketing more favorable and the lower priority placed on groundnut by male farmers because of the high labor demand in processing (and as such the crop is referred to as a "female crop" (Shumba, 1983)). Farmers also have taste preferences and perceptions of profitability that seem to favor maize.

Legume-cereal rotations in the region have long been recognized for restoring soil fertility and increasing crop productivity (MacColl, 1989; Mukurumbira, 1985). Rotations shift biological balance in the soil, reducing build up of specific pests and diseases and sustains productivity of the cropping system (Kumwenda et al., 1996). In a long-term maize-legume rotation trial in South Africa, unfertilized maize grain yields were improved by 2 Mg ha^{-1} in rotation with field pea (*Pisum arvense* Poir) compared to unfertilized continuous maize (Nel et al., 1996).

Legume residues are particularly useful as organic green manures due to their high N content and because this N is more readily available for plant uptake than N from non-legumes (Giller et al., 1994). The capabilities of grain legumes to contribute to soil fertility differ among species. The greater the efficiency of the legume in translocating N to the harvested components (such as grain) the smaller the contribution of N to the soil profile. Giller et al. (1994) showed that groundnut which contains large amounts of N in its residues at harvest and prior leaf-fall can supply more N for subsequent crops than other grain legumes such as soybean. McDonagh et al. (1993) found that groundnut residues containing 100-130 kg N ha^{-1}, when incorporated into the soil reduced fertilizer needs of a subsequent maize crop by 60 kg N ha^{-1}.

For grain legumes to play an important role in the maintenance of soil fertility, they must leave behind substantially more N from N_2-fixation than the amount of soil N that was removed in the harvested portion of the crop. Clearly the two purposes served by the legume crop, one to provide forage and grain yield and the other to leave residual N are somewhat contradictory. The role of grain legumes in contributing N to cropping systems is bound to be compromised by the breeding priority of optimizing the efficiency of conversion of N into the grain removed (Hanzell and Vallis, 1977). A smaller grain yield of legume may be the price to pay if the amount of legume N restituted to the soil profile is to be increased.

In the current study, the effect of including a groundnut crop in rotation with maize was evaluated. Specific objectives were: (i) to evaluate the impact of a groundnut crop on subsequent maize yield and N uptake, and response to fertilizer-N of maize in rotation with groundnut compared to continuous maize and, (ii) to determine the fertilizer replacement value of groundnut.

MATERIALS AND METHODS

Since the 1992/93 cropping season, the CIMMYT Maize Program in Harare has conducted a set of long-term trials on crop productivity and soil fertility trends in maize-groundnut systems under current smallholder management (Waddington et al., 1996). Two distinct agro-ecological zones, natural regions (NR) II[1] and III (Vincent and Thomas, 1961), were chosen for this study. These typical represent sub-humid maize cropping areas of Zimbabwe.

This experiment was established at Chinyika and Domboshava (both NR II) and Chiduku (NR III) smallholder areas. Soils in these locations are predominantly sandy soils derived from granite and classified as Typic Kandiustalf. The sites have been cropped for various length of time, ranging from 14 years at Chinyika to over 60 years in Chiduku. Trophic soil properties were characterized at the beginning of the study in 1994 at each site (Table 2.1).

The experiment was arranged in a randomized complete block design replicated three times at each site. The treatments (and cropping systems) in this study were ;

1. Continuous maize - Fertilizer level of 275 kg ha^{-1} Compound D (8-14-7) as basal and a side dress of 70 kg N ha^{-1} as NH_4NO_3 so that total N applied was 92 kg ha^{-1}

2. Continuous maize - no fertilizer applied

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[1]A broad classification of Natural regions is based on rainfall: NR I 900-1200mm p.a NR II 750-900mm p.a; NR III 650-750mm p.a; NR IV 450-650mm p.a and NR V < 650mm p.a.

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3. Maize-Maize-Groundnut rotation - fertilizer applied to maize only as in treatment 1

4. Maize-Maize-Groundnut rotation - no fertilizer applied.

In year four (maize after groundnut), cropping systems 1 and 3 were further split into sub-plots and subjected to fertilizer applications of 0, 46, 92 or 138 kg N ha^{-1}.

Maize (*Zea mays* L. var. 'R215') was hand-planted at two seeds per planting station on plots that had been moldboard plowed. Each sub-plot was 5 x 5.4 m with 6 rows of maize, planted at 0.9 m between rows and 0.5 m within rows, giving a plant population density of 44, 440 plants per hectare. Initial fertilizer was applied as Compound D at about one week after plant emergence (corresponding to farmer practice). Additional fertilizer was applied in the form of NH_4NO_3 as a surface dollop next to each plant station at V6 maize growth stage when the soil moisture level approximated field capacity.

Groundnut (*Arachis hypogaea* var. 'Spanish') were planted in rows of 0.45 m apart and 0.25 m between planting stations in a row. Groundnut were planted at two seeds per station, giving approximately 160 000 plants per hectare. Because the Spanish cultivars exhibit promiscuous nodulation in the soils under study and because farmers do not inoculate, seeds were not inoculated with rhizobia before planting.

Maize grain and groundnut kernels were harvested from a 2.7 x 3 m section of the three center rows of each plot, so that the area harvested was 8.1 m^2. Grain yields were adjusted to 125 and 100 g kg^{-1} moisture content for maize and groundnut, respectively. Total above-ground biomass of maize was measured from two adjacent middle rows from an area of 2.7 m^2.

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Plant Chemical Analysis.

Total N in maize grain and stover was determined by a modified micro-Kjeldahl method. Dry plant materials were ground to pass through a 2-mm screen in a Wiley mill. Plant samples of 0.1 g were digested in 4 ml of 18 M H_2SO_4 with 1.5 g K_2SO_4 and 0.075 g Se catalyst. Following digestion, total NH_4^+ was determined by spectrophotometry. Total N yield was calculated as the product of dry matter yield and nitrogen concentration.

Statistical Analysis.

ANOVA in Proc GLM (SAS, 1997) was used to analyze treatment effects with respect to maize grain yield, grain N content and total above-ground biomass in the fourth year. Experiment was a RCBD with treatments arranged in a split plot, cropping systems were main plots and fertilizer-N rates subplots. Cropping systems were also compared using orthogonal contrasts (=1 df comparisons). Subsequent maize responses to fertilizer-N rates within a cropping system were determined by evaluating linear and quadratic trends from single degree of freedom comparisons. Whenever trends were significant, regression equations were calculated to determine fertilizer replacement values (FRV) of groundnut in rotation with maize.

RESULTS AND DISCUSSION

Groundnut yields. Groundnut kernel yields (harvestable portion) for the three locations ranged from 0.16 to 0.34 Mg ha^{-1} and the vegetative biomass (haulms) ranged from 0.65 to 1.6 Mg ha^{-1} (Table 2.2). Because kernels are harvested and removed from the field, net plowdown N is therefore primarily based on the haulms and fallen leaves. One of the signs of kernel physiological maturity is the browning and senescence of leaves. Plowdown N values tend to underestimate actual contribution of groundnut to soil N because only the green or intact vegetative material is measured. In this study, plowdown N was between 16 and 40 kg N ha^{-1} (Table 2.2). Our values of plowdown N compare well to those calculated from Suwanarit et al. (1986) and Dakora et al. (1987), of 42 and 38 kg N ha^{-1}, respectively.

Maize yields following groundnut (No Fertilizer). Because of significant ($P \leq 0.05$) treatment x location interactions, data are presented as treatment effects within location (Table 2.3). Unfertilized maize grain yields following groundnut were improved by 2.2, 0.3 and less than 0.1 Mg ha^{-1} at Domboshava, Chinyika and Chiduku respectively (Table 2.3). However, yield increase at Chiduku of 8% was not significantly ($P \leq 0.05$) better than unfertilized continuous maize. Although there were positive yield increases in maize grain yield following groundnut at Chinyika and Chiduku, these yields remained low (less than 1 Mg ha^{-1}) and were only 16% of those obtained at the more fertile Domboshava site.

In Zimbabwe, Mukurumbira (1985) evaluated maize grain yields following several food legumes which included groundnut and fallow. Yield of maize was greater following groundnut (6.2 Mg ha^{-1}) than unplanted fallow (4.3 Mg ha^{-1}) or maize (3.9 Mg ha^{-1}). Maize grain yield after groundnut represented a 60% improvement over continuous maize. Our results at Chinyika and Domboshava corroborate those of Mukurumbira (1985).

In a second maize crop following groundnut, grain yield was increased by 0.8 Mg ha^{-1}, representing a 69% improvement over continuous maize when no fertilizer was applied (Table 2.4). Grain N uptake and total above-ground biomass were each improved by 53% over continuous maize (Table 2.4). Although maize grain yields were higher in the second crop following groundnut relative to continuous maize, these yields were considerably smaller than yields of the first maize crop following groundnut. Yields at the highest fertilizer level of 138 kg ha^{-1} were about 1 Mg ha^{-1} lower than the unfertilized first maize crop after groundnut (data not shown).

In an attempt to explain treatment x location interaction, grain yield differences between maize following groundnut and continuous maize were correlated to soil pH, soil phosphorus, mineralizable N, cation exchange capacity, total exchangeable bases, groundnut haulm biomass and plowdown N, combined January and February rainfall, and total rainfall as suggested by Matlon (1984) and accomplished by Shumba et al. (1992) in Zimbabwe. Multiple regression was not used in this analysis. Combined January and February rainfall was negatively correlated ($r = -0.8$ $P \leq 0.05$) to yield differe

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differences. This parameter (combined January and February rainfall) explained 56 percent of the variability in yield differences (r^2=0.56 p≤ 0.05) and the other parameters were not significantly correlated to grain yield differences. Effects of including groundnut in rotation with maize were offset at locations that received more than 530 mm in the months of January and February. Incessant and excessive rains that characterized the 1996/97 season throughout January and the first half of February promoted widespread waterlogging that affected growth of maize. Our results corroborate findings of Shumba et al. (1992) who concluded in a tillage study in NRII[1] that tillage x location interaction was mostly explained by January rainfall (r^2=0.76) and that tine tillage increased maize grain yields at locations that received less than 240 mm of rainfall in January and depressed yield at those locations that received more than 240 mm. However, in our study it was the combined January and February rainfall that explained most of the variability, further suggesting that rainfall distribution plays a key role on the effectiveness of smallholder technologies in Zimbabwe. Rainfall data for the study areas is presented in Figure 2.1.

Maize yields following groundnut (Variable N applied). There was not always a positive maize response to groundnut in rotation when fertilizer-N was applied. Regression equations for each cropping system for maize grain yield (GR), grain N content (GRN) and total above-ground biomass (TDM) as a function of fertilizer N applied were obtained at Domboshava and Chinyika (Table 2.5). At Domboshava response of a second maize crop following groundnut was also evaluated.

[1]Natural region II 70-900mm rainfall per annum.

Maize grain yields following both groundnut and continuous maize linearly responded to increasing N rates at Domboshava (Figure 2.2). At all N rates, yields were significantly ($P \leq 0.05$) higher following groundnut than following maize.

At Chinyika, continuous maize showed a quadratic response while maize following groundnut linearly responded to variable N rates. At $N \geq 30$ kg N ha^{-1}, continuous maize was always associated with a yield higher than that of maize following a groundnut crop (Figure 2.4).

Maize grain N content for the two cropping systems and at both locations linearly responded to increasing N rates (Figures 2.5 and 2.6). At Domboshava, grain N content following groundnut was increased by 41% at each N rate relative to continuous maize. However, the reverse was true for Chinyika at which grain N content for continuous maize increased more than grain N content for maize following groundnut as N rates increased (Figure 2.6). Results for Chinyika show that the common assumption that a groundnut crop improves N availability and enhances yield in a subsequent year may not always be correct, on smallholder fields where soil fertility is low.

Total above-ground biomass of maize following groundnut at Domboshava was 2 Mg ha^{-1} higher than following continuous maize when no fertilizer was applied (Figure 2.7). Differences in total above-ground biomass for the two cropping systems narrowed and became non significant as fertilizer N rate increased (Figure 2.7). At Chinyika, total above-ground biomass for continuous maize showed a quadratic response to increasing N rates while that following groundnut was linear (Figure 2.8).

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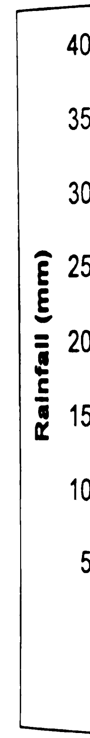
response to increasing N rates while that following groundnut was linear (Figure 2.8). Continuous maize produced significantly ($P \leq 0.05$) higher biomass yields than maize following groundnut at all N rates except at 138 kg N ha^{-1}.

Fertilizer Replacement Value. Fertilizer replacement values of first year maize following groundnut was 72 kg N ha^{-1} based on grain yield and 18 kg N ha^{-1} based on total above-ground biomass (Table 2.6). We note that groundnut residual effects increased yields of a second maize crop following groundnut. Fertilizer replacement values for this second maize crop ranged from 31 to 49 kg N ha^{-1}. In each year, the highest FRV's were based on grain yield. MacColl (1989) also presented a beneficial effect on the second and even a third maize crop following groundnut in central Malawi.

Fertilizer replacement values obtained in our study are similar to those reported by other researchers for groundnut using maize as a test crop. In northern Ghana, groundnut and cowpea (*Vigna unguiculata*) had FRV's of 60 kg N ha^{-1} (Dakora et al., 1987). Jones (1974) evaluated residual effects of groundnut on a subsequent maize crop in savanna areas of Nigeria and obtained an equivalent of 43-73 kg N ha^{-1} when no fertilizer nitrogen was applied to maize. Maize yields in short rotations with legumes at Bunda, Malawi were found to be better after legumes with poor grain yield but vigorous vegetative growth such as lablab (*Lablab purpureus*) and these generally left more residual N than groundnut or soybean (*Glycine max*) (MacColl, 1989). Legume equivalent values were 52, 26 and 0-14 kg N ha^{-1} for lablab, groundnut and soybean, respectively in that study.



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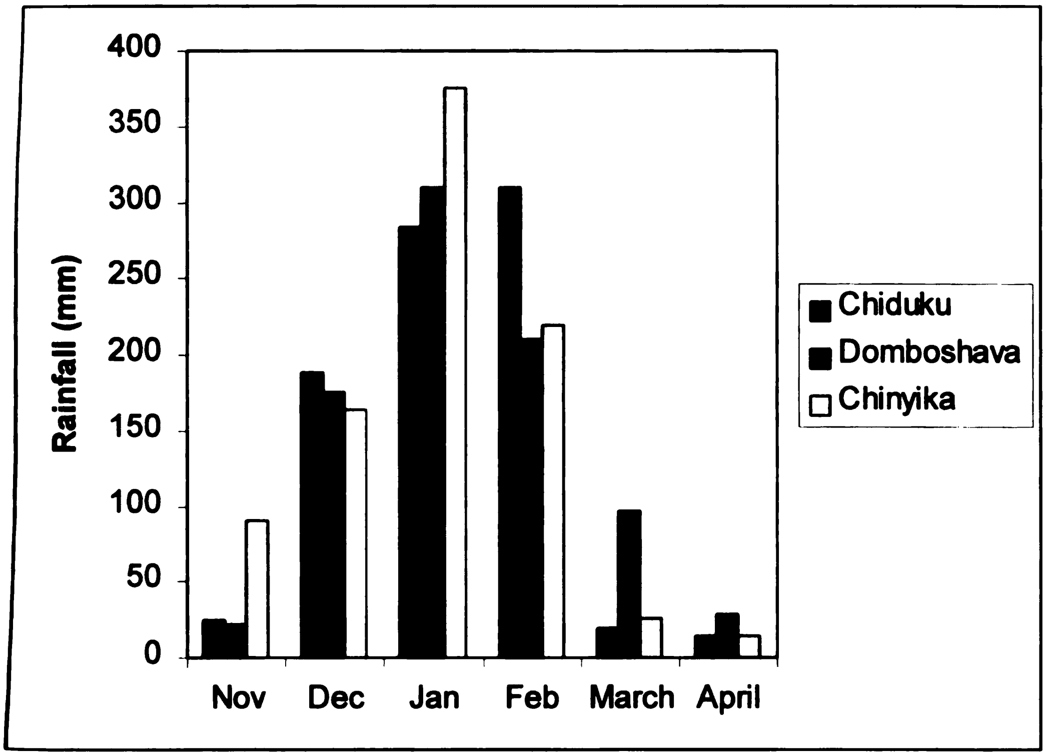

Fig. 2.1. Rainfall data for Chiduku, Chinyika and Domboshava for the 1996/97 season.

Table 2.1. Trophic soil properties at Chinyika and Chiduku in Zimbabwe at the beginning of the study

Characteristic	Chinyika	Chiduku
Soil texture	loamy sand	sandy clay loam
pH ($CaCl_2$)	4.3	4.7
C (%)	0.52	1.35
Mineralizable N (ppm)	18.63	41.63
P_2O_5 (µg g^{-1})	9.76	8.20
K (µg g^{-1})	3.00	8.25
CEC† (me %)	3.01	8.25
TEB‡ (me %)	6.38	8.48

† Cation exchange capacity
‡ Total exchangeable bases

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Table 2.2. Groundnut kernel, haulm and plowdown N yield at three locations in Zimbabwe.

Parameter	Chinyika	Chiduku	Domboshava
	------------------kg ha^{-1}	------------------	
Kernel	161	193	337
Haulms	650	980	1600
Plowdown N	16	22	40

Table 2.3. Effect of cropping system on unfertilized maize grain yield at three locations in northern Zimbabwe.

Cropping system[†]	Chinyika	Chiduku	Domboshava
	------------------Mg ha^{-1}------------------		
Mz-Mz-Mz-Mz	0.39	0.71	2.46
Mz-Mz-Gn-Mz	0.68	0.77	4.61
CV (%)	26	4	20
Contrast			
Mz-Mz-Mz-Mz vs Mz-Mz-Gn-Mz	*	NS	*
Percent increase[‡]	74	8	87

[†]Underlined letter indicates year for yield. Mz=maize, Gn=groundnut
* Significance at P≤ 0.05. NS=non significant at P≤ 0.05.
[‡] Refers to increase due to rotation over continuous maize.

Table 2.4. Effect of cropping system on unfertilized second maize crop following groundnut at Domboshava, Zimbabwe.

Cropping system†	Grain Yield ($Mg\ ha^{-1}$)	Grain N Content ($kg\ ha^{-1}$)	Total biomass‡ ($Mg\ ha^{-1}$)
Mz-Mz-Mz-Mz-Mz	1.20	13.16	3.19
Mz-Mz-Gn-Mz-Mz	2.03	20.12	4.89
CV (%)	18	24	16
Contrast			
Mz-Mz-Mz-Mz vs Mz-Mz-Gn-Mz	*	*	*
Percent increase¶	69	53	53

†Underlined letter indicates year for yield. Mz=maize, Gn=groundnut
* Significance at P≤ 0.05. NS=non significant at P≤ 0.05.
‡ Total above-ground biomass of maize
¶ Refers to increase due to rotation over continuous maize

Table 2.5. Fitted Regression Equations for maize grain yield (GR), grain N content (GRN) and total above-ground biomass (TDM) in two maize cropping systems as a function of N fertilizer applied (x).

Cropping System[†]	Regression Equation[‡]	R^2	Signif
	Domboshava		
Mz-Mz-Mz-Mz	GR=2.46 + 0.03(x)	0.59	0.05
	TDM=7.65 +0.03(x)	0.95	0.03
Mz-Mz-Gn-Mz	GR=4.61 + 0.04(x)	0.98	0.01
	TDM=8.2 + 0.03(x)	0.96	0.02
Mz-Mz-Mz-Mz-Mz	GR=1.33 + 0.01(x)	0.75	0.05
	GRN=13.96 + 0.18(x)	0.72	0.01
	TDM=3.93 + 0.03(x)	0.65	0.02
Mz-Mz-Gn-Mz-Mz	GR=1.92 + 0.01(x)	0.84	0.001
	GRN=19.68 + 0.18(x)	0.83	0.002
	TDM=5.75 + 0.02(x)	0.48	0.05
	Chinyika		
Mz-Mz-Mz-Mz	GR=0.25 + 0.02(x)-0.00007(x^2)	0.96	0.001
	GRN=3.8 + 0.15(x)	0.89	0.01
	TDM=2.74 + 0.069(x)-0.0004(x^2)	0.82	0.01
Mz-Mz-Gn-Mz	GR=0.34 + 0.009(x)	0.88	0.001
	GRN=2.87 +0.12(x)	0.87	0.001
	TDM=2.76 + 0.027(x)	0.79	0.003

† Underlined letter represent the crop and year for reported yields. Mz=maize, Gn=groundnut.
‡ Linear equations are based on 6 degrees of freedom, while quadratic equations are based on 5 degrees of freedom

Table 2.6. Fertilizer replacement values of a maize and groundnut rotation cropping system at Domboshava.

Parameter	Mz-Mz-Gn-Mz[†]	Mz-Mz-Gn-Mz-Mz
	---------kg N ha^{-1}-----------	
Grain yield	72	49
Grain N content	-	31
Total above-ground biomass	18	32

[†] Underlined letter shows the test crop from which data is derived. Mz=maize, Gn=groundnut

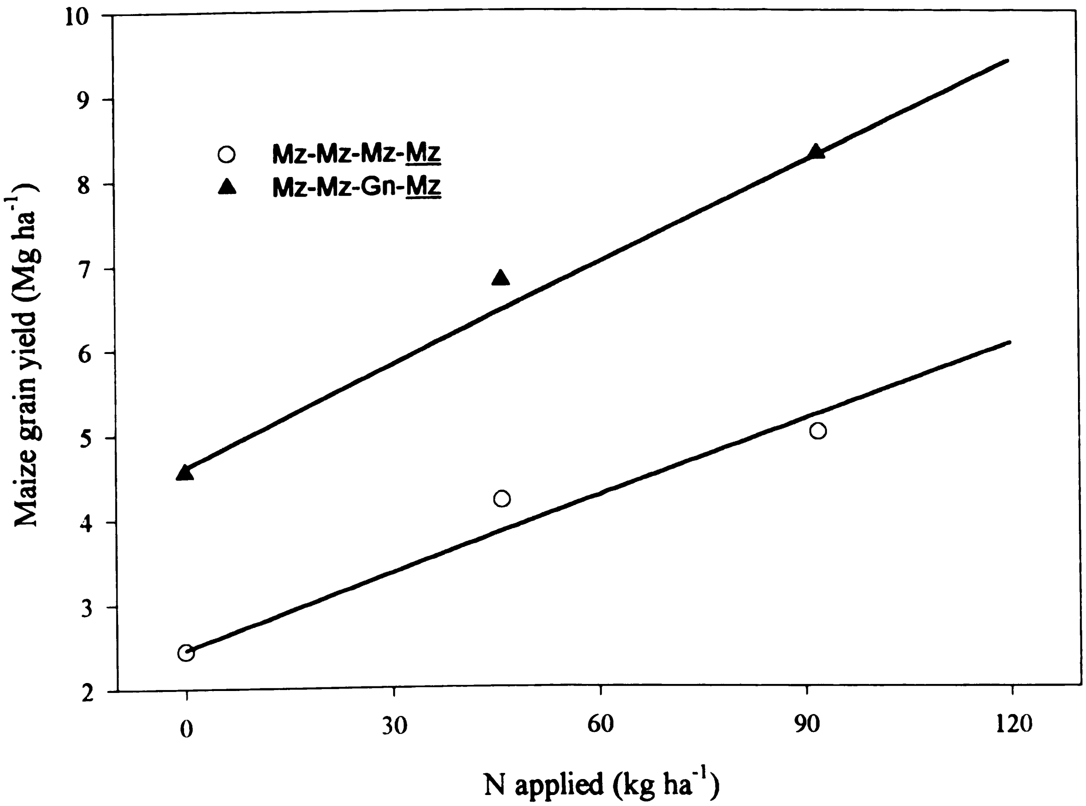

Figure 2.2 Subsequent maize grain yield response to N and rotation with groundnut at Domboshava

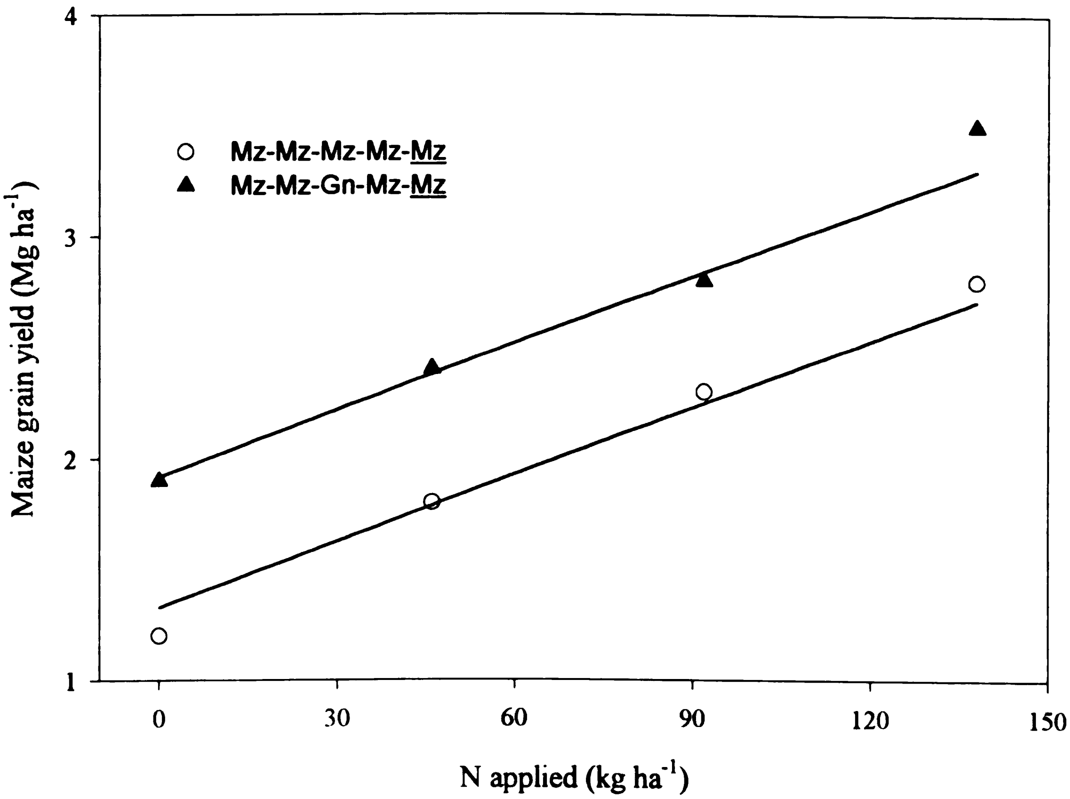

Figure 2.3 Maize grain yield response to N and rotation with groundnut at Domboshava

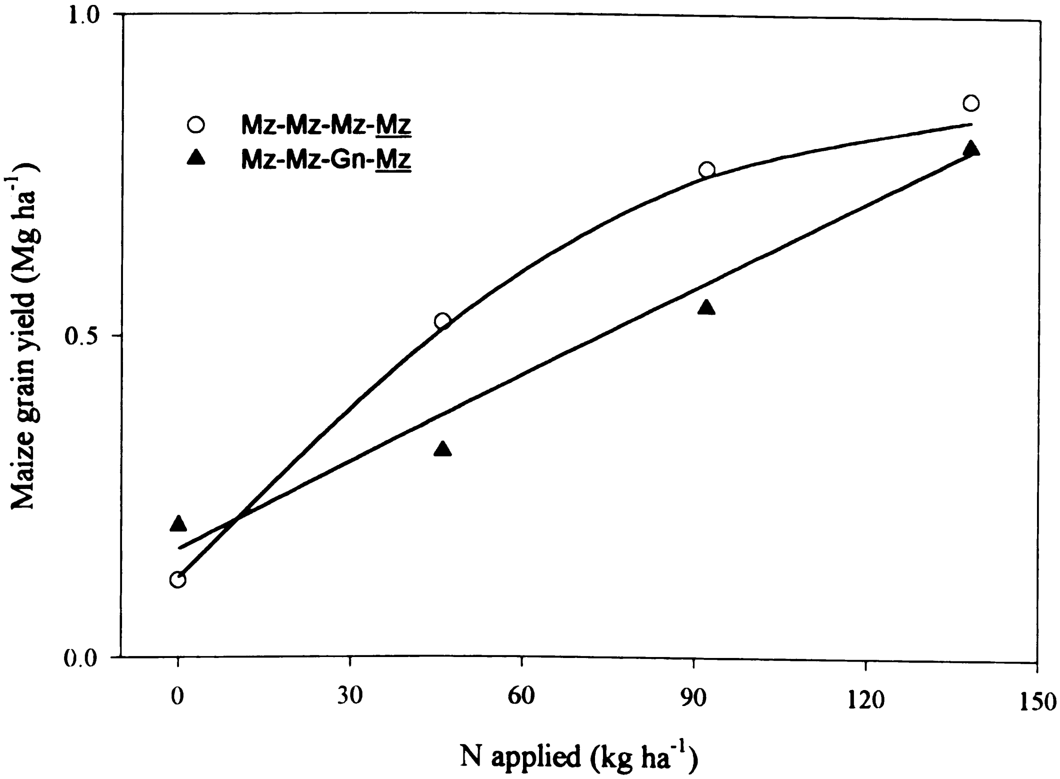

Figure 2.4 Maize grain yield response to N and rotation with groundnut at Chinyika

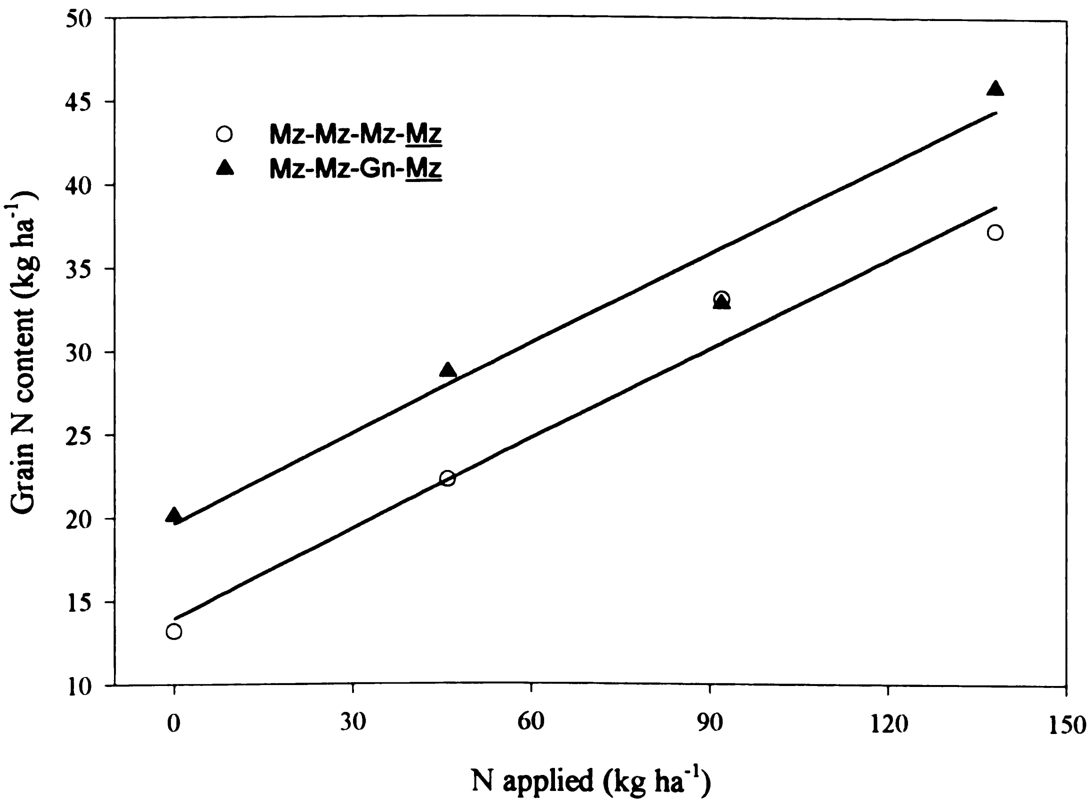

Figure 2.5 Maize grain N content response to N and rotation with groundnut at Domboshava.

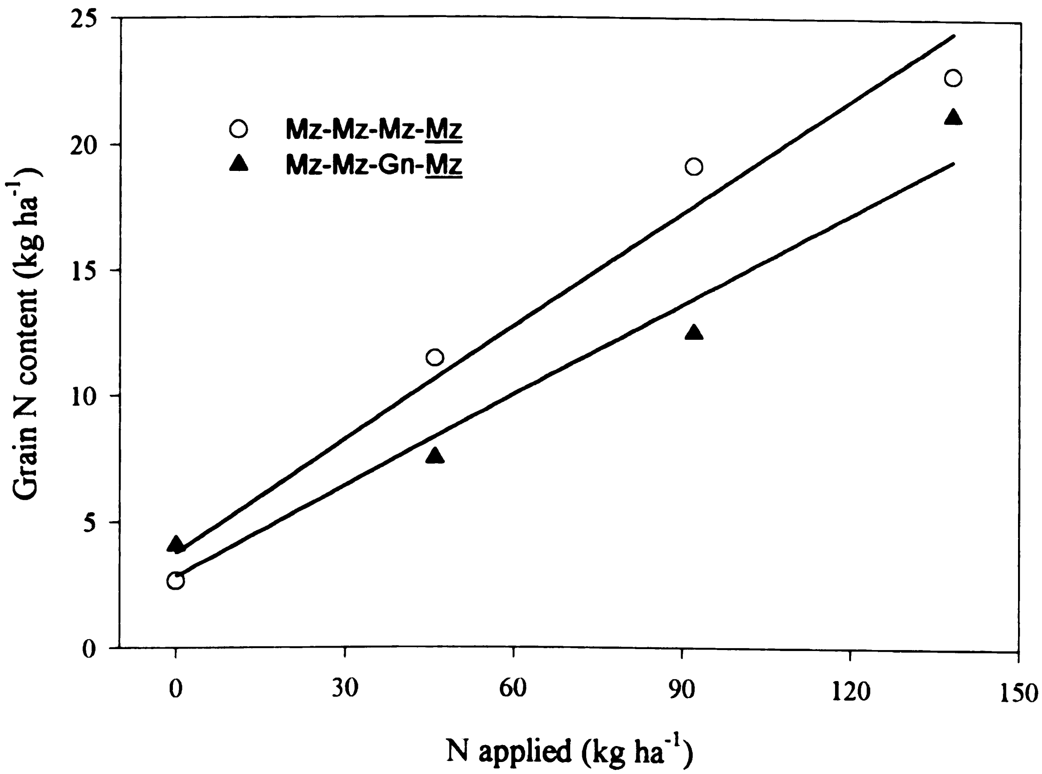

Figure 2.6 Maize grain N content response to N and rotation with groundnut at Chinyika.

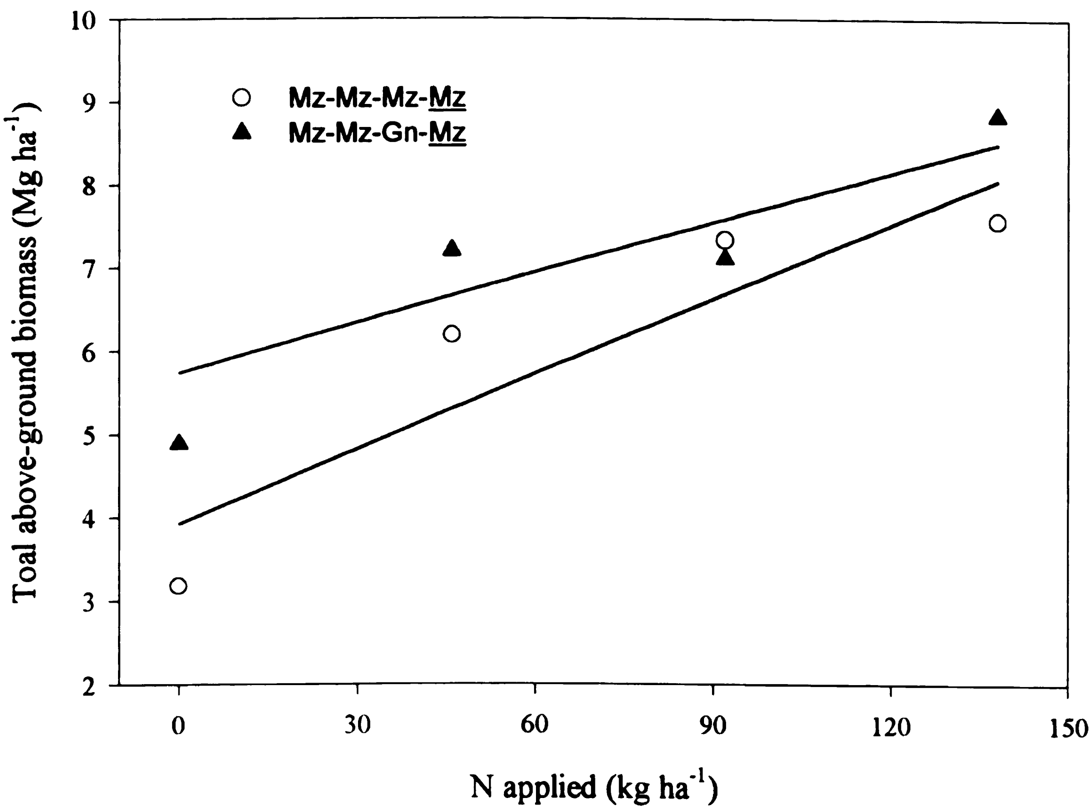

Figure 2.7 Maize total above-ground biomass response to N and rotation with groundnut at Domboshava.

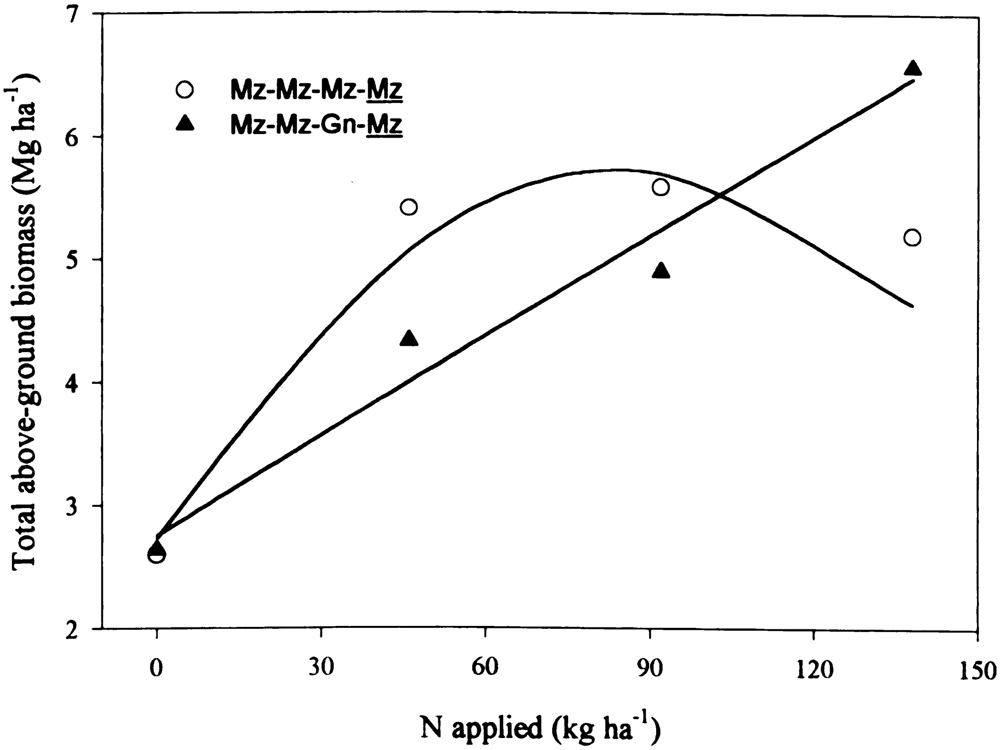

Figure 2.8 Maize total above-ground biomass response to N and rotation with groundnut at Chinyika

CONCLUSIONS

This research showed that maize yields were improved in rotation with groundnut compared to continuous maize in Zimbabwe. Unfertilized maize grain yields were improved by 0.1-2.2 Mg ha^{-1} following groundnut compared to continuous maize. For a second maize crop following groundnut, legume residual benefits were of 0.8 Mg ha^{-1}. However, improvements over continuous maize were not observed at two of the three sites when maize was fertilized at the recommended N level due to incessant and excessive rains received at those sites.

The groundnut crop reduced fertilizer needs of a subsequent maize crop by up to 72 kg N ha^{-1} and by 49 kg N ha^{-1} in a second maize crop at one site. Benefits of including groundnut were less pronounced at the other two sites.

Our results suggest that benefits of including groundnut in rotation with maize are sensitive to rainfall events in the smallholder farms of Zimbabwe. Maximum benefits were obtained at sites with reasonably well distributed rainfall (slightly less than 530 mm rainfall in the months of January and February, a period that coincide with anthesis). However, at sites with poorly distributed rainfall benefits were modest or non-existent.

REFERENCES

Araki, S. 1993. Effect on soil organic matter and soil fertility of the chitemene slash-and-burn practice used in northern Zambia. In K. Mulongoy and R. Merckx (eds.) *Proceedings: Soil Organic Matter Dynamics and Sustainability of Tropical Agriculture. Chiscester*, U.K.: Wiley-Sayce. pp. 367-375.

Blackie, M.J., and R.B. Jones. 1993. Agronomy and increased maize productivity in southern Africa. Biological Agriculture and Horticulture 9: 147-160.

Dakora F.D., R.A. Aboyinga, Y. Mahama, and J. Apaseku. 1987. Assessment of N2-fixation in groundnut (*Arachis hypogaea* L.) and cowpea (*Vigna unguiculata* L. Walp) and their relative contribution to a succeeding maize crop in Northern Ghana. MIRCEN Journal 3: 389-399.

Dendere, S. 1987. Contraints to groundnut production and research priorities for communal areas in Zimbabwe. In: Proceedings of the Second Regional Groundnut Workshop for Southern Africa. ICRISAT, Patancheru, A.P., India, pp. 125-129.

Giller, K.E., J.F. McDonagh, and G. Cadisch. 1994. Can biological nitrogen sustain agriculture in the tropics? In J.K. Syers and D.L. Rimmer (eds.) *Soil Science and Sustainable Land Management in the Tropics*. Wallingford, U.K.: CAB International. pp. 713-191.

Grant, P.M. 1970. Restoration of productivity of depleted sands. Rhodesia Agricultural Journal 67: 131-137.

Henzell, E.F., and I. Vallis. 1979. Transfer of nitrogen between legumes and other crops. In A. Ayanaba and P.J. Dart (eds.) *Biological Nitrogen Fixation in Farming Systems of the Tropics*. Wiley, Brisbane. pp. 73-88.

Jones, M.J. 1974. Effects of previous crop on yield and nitrogen response of maize at Samaru, Nigeria. Experimental Agriculture 10: 278-279.

Kumwenda, J.D.T., S.R. Waddington, S.S. Snapp, R.B. Jones, and M.J. Blackie. 1996. *Soil Fertility Management Research for Maize Cropping Systems of Smallholders in Southern Africa: A review*. NRG Paper 96-02. Mexico, D.F.: CIMMYT.

MacColl, D. 1989. Studies on maize (*Zea mays* L.) at Bunda, Malawi. II. Yield in short rotation with legumes. Experimental Agriculture 25: 367-374.

Matlon, P.J. 1984. Technology evaluation. In P.J. Matlon et al. (eds) Coming Full Cycle: Farmers' Participation in the Development of Technology: 95-118. Ottawa: IDRC.

McDonagh, J.F., B. Toomsan, V. Limpinuntana, and K.E. Giller. 1993. Estimates of the residual nitrogen benefits of groundnut to maize in Northeast Thailand. Plant and Soil 154: 267-277.

Mukurumbira, L.M. 1985. Effects of rate of fertilizer nitrogen and previous grain legume crop on maize yields. Zimbabwe Agricultural Journal 82: 177-179.

Nel, P.C, R.O. Barnard, R.E. Steynberg, J.M. de Beer, and H.T. Groenveld. 1996. Trends in maize grain yields in a long-term fertilizer trial. Field Crops Research 47: 53-64.

SAS Institute, Inc 1997. SAS/STAT Users Guide, Release 6.12 Ed. Cary NC.

Shumba, E.M, S.R. Waddington and M. Rukuni. 1992. Use of tine-tillage, with atrazine weed control, to permit earlier planting of maize by smallholder farmers in Zimbabwe. Experimental Agriculture 28: 443-452.

Shumba, E.M. 1993. Factors contributing to a decline in groundnut production in the Mangwende-Murehwa District, and the need for a technical research input. Zimbabwe Agricultural Journal 80: 251-254.

Swanarit A, C. Suwannarat, and S. Chotechanungmanirat. 1986. Quantities of fixed N and effects of grain legumes on following maize, and N and P status of soil as indicated by isotopes. Plant and Soil 93: 249-258.

Vincent, V. and R.G. Thomas. 1961. An agricultural survey of Southern Rhodesia. Part 1. Agroecological Survey. Harare, pp. 41-102.

Waddington, S.R., J. Karigwindi, and J. Chifamba. 1996. CIMMYT Maize Soil fertility and Agronomy Research in southern Africa. Annual Research Report: CIMMYT-Zimbabwe.

CHAPTER THREE

ECONOMIC ANALYSIS OF SMALLHOLDER MAIZE CROPPING SYSTEMS IN NORTHERN ZIMBABWE

ABSTRACT

Continuous cropping of maize, typical of the smallholder farms of Zimbabwe, at reasonable levels of productivity can not be sustained without substantial additions of nutrients. Thus agronomists have proposed maize-groundnut rotation and maize-legume intercrops as alternatives to improve profit margins and at the same time reduce over-dependence on chemical fertilizers.

This assessment used marginal benefit-cost analysis, a type of partial budgeting analysis, to identify optimum maize cropping systems from a set of alternatives. Field experimental data from a *Gn-Mz-Mz* vs *Mz-Mz-Mz* trial and a *Sole Maize* vs *Maize-legume* intercrop trial were used in this analysis. Sensitivity analysis was also used to assess the stability of results with changing seed prices of sunnhemp and cowpea, and yield increase in a groundnut crop.

Continuous maize at 92 kg N ha^{-1} optimized net benefits over total costs when compared to maize in rotation with groundnut at variable fertilizer N rates. For the maize-groundnut rotation to equal net benefits of continuous maize, current groundnut crop yield needed to be more than doubled, assuming labor costs remained constant. The results suggest that maize-groundnut rotation is less profitable than continuous

maize, especially when the maize crop was grown with fertilizer.

The maize-cowpea intercrop at 60 kg N ha^{-1} was associated with highest net benefits, compared to maize-sunnhemp intercrop and sole maize at variable N rates. Both maize-cowpea and maize-sunnhemp intercrops paid back legume seed costs at the current price in the second season, when a sole maize crop following the intercrops was grown without fertilizer. Sensitivity analysis revealed that a 50% increase in either cowpea or sunnhemp seed price would greatly reduce net benefits of the maize-legume intercrops compared to the control (continuous maize without fertilizer). Results showed that when moderately fertilized (60 kg N ha^{-1}) the maize-cowpea intercrop was more profitable than sole maize or the maize-sunnhemp intercrop.

INTRODUCTION

A primary goal of agricultural production, like other business enterprises, is to provide producers an acceptable level of return to their capital, labor and management inputs. Bernsten (1980) identified five factors that affect the profitability of new technology and thereby influence its acceptability to smallholder farmers. To be appropriate, new technology must be compatible with (i) the production environment, (ii) cultural values, (iii) farmers' goals and, (v) existing institutions.

The "induced innovation" model, as proposed by Hayami and Ruttan in 1977 (Stevens and Jabara, 1988), significantly advances our economic understanding of how agricultural development is achieved. This theory identifies four key elements (*resource endowment, cultural endowment, technology and institutions)* which determine a country's rate of agricultural development. As these four are interactive, changes in the levels of one will induce changes in the level of another element. For example, improvements in marketing institutions will increase the profitability of grain production by reducing input costs and increasing farm gate prices. As a result farmers will adopt improved varieties which are now more profitable.

Enterprise and partial budgets have been used to select optimum production system from a set of alternatives (Hesterman et al., 1986; Shumba et al., 1992). Marginal benefit-cost analysis, a type of partial budgeting analysis, can be used to assess the profitability of alternative cropping patterns. By estimating the ratio between the rates of increase of benefit to cost, this technique estimates the rate of return to capital invested in new technologies (cost of the inputs or test factors which are variable).

Traditionally, benefit-cost analysis assumes that all farmers have equal access to resources (land, labor and capital) and similar access to credit and market for inputs and produce. Based on these assumptions, typically a technology that gives the highest net benefit is recommended to all farmers (Bernsten, 1980). While the concept of recommendation domain is widely used to refer to farmers facing similar circumstances, it is seldomly developed to fully reflect the way in which these differences influence the profitability of technology among farmers facing different circumstances (i.e., production environments, access to resources and institutional support).

There are doubts about the economics of farmers investing more in groundnut production. Work by Shumba, Bernsten and Waddington (1990) showed that for the Mangwende communal area of Zimbabwe it was less profitable to invest in the most promising inputs and practices to raise groundnut productivity (improved seed, early planting and weeding, NPK fertilizer + gypsum) than to invest in maize production.

Sensitivity analysis is a tool which can be used in benefit-cost analysis to accommodate farmer-to-farmer differences in resource endowment, levels of management skills and institutional access that affect profitability.

The objectives of this analysis were to (i) assess the profitability of *Gn-Mz-Mz* versus *Mz-Mz-Mz* cropping systems at variable N fertilizer rates, and (ii) compare the marginal benefits of maize-legume intercrops and a subsequent sole maize crop at variable fertilizer N rates. In addition, sensitivity analysis is used to assess the impact of varying assumption regarding the price of legume seed on the profitability of the alternative cropping patterns.

ECONOMIC ANALYSIS AND ASSUMPTIONS

In Zimbabwe, smallholder maize farmers typically grow continuous maize at zero or low levels of N. Field experimental data from two trials, namely *Gn-Mz-Mz* vs *Mz-Mz-Mz* at two fertilizer N levels (0 vs 92 kg N ha^{-1}) and *maize-legume* intercropping at variable fertilizer N levels, were used in a marginal benefit cost analysis. Costs and benefits of each treatment were compared using partial budgets, which included only the costs and benefits that varied from the control, following methods given in CIMMYT (1988). Discounting procedures for calculating net benefits were adapted from Gittenger (1984). The bank deposit interest rate (in 1996 and 1997) of 23%[1] (Waddington et al., 1997) was used as a proxy for the opportunity cost of capital.

$$Year_n = 1/(1 + \text{interest rate})^{n-1} \qquad [1]$$

The prices of fertilizer and seed (1996) were obtained from local suppliers. Labor was valued at the wage rate paid to hired farm laborers in the area, which was determined through a survey in Chinyika and Mangwende Communal Areas to reflect opportunity cost to family labor. Smallholder farmers have the opportunity to be

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[1]Discount rates of as high as 60% have been reported elsewhere in subsistence agriculture (Bernsten 1998 pers. comm.). The current bank rediscount rate is 37% (Reserve Bank of Zimbabwe, August 1998).

involved in off-farm activities and to name a few; woodcraft, basket weaving, gold panning and quasi-urban employment. All these represent an opportunity cost to on farm labor. Transport cost were calculated, based on charges from the place of purchase to the site where the trials were conducted. Costs and labor data are presented with the budgets.

This analysis in which groundnut forms part of a rotation is when land is relatively short, labor is plentiful and farmers are at least partly subsistence orientated. Under favorable management and when groundnut residues are incorporated on sandy soils versus being fed to livestock, groundnut in rotation can double the following maize grain yield, particularly when that maize is grown with little or no N fertilizer (Mukurumbira, 1985; McDonagh et al., 1993).

Output was valued at the purchase price offered by the Grain Marketing Board (GMB) for grade A white maize and shelled groundnut in 1996 and 1997. Yields were adjusted downwards by 10 percent to account for a higher management level in researcher-managed trials, as compared with fields managed by farmers and to correct for possible yield overestimation in small experimental plots (CIMMYT, 1988). Maize stover and groundnut haulms were assumed to have no value, although in some areas these byproducts are fed to livestock. Net benefits/discounted net benefits where calculated over cash costs and over all costs. Net benefits based on cash costs assumes that there is no opportunity cost to labor and this may not be a true reflection of farmer circumstances. The justification for using net benefits over costs include the high unemployment rate mostly in the urban area or more than 50% of labor force and the relatively few off-farm activities available to smallholder farmers.

In the case of maize-legume intercrops, only the seed cost of either cowpea or sunnhemp was included in the analysis as this was the only variable seed costs. For the three cropping patterns evaluated (maize-maize, maize+cowpea-maize and maize+ sunnhemp-maize), the response of maize to varying levels of fertilizer N (0, 46. 92 and 138 kg N ha^{-1}) was fitted to an exponential curve. Exponential models for maize response to N were used to derive the curves for added maize value. The added value at a particular fertilizer level within a cropping system was calculated as its field benefit less that of continuous maize when no N fertilizer was applied.

$$E[Y] = \alpha + \beta \exp(-\delta N) + e, \qquad [2]$$

where Y= added value (Zim$) for treatment, N = N rate applied (kg ha^{-1}), e = error.

Marginal benefit cost analysis was used to estimate the marginal rate of return to alternative treatments (i.e., the difference in net benefits between this treatment and any other, divided by the difference in costs between those treatments). Dominance analysis (CIMMYT, 1988) was used to identify treatments having similar net benefits but higher costs than other treatments. Sensitivity analysis was conducted to assess the stability of results with changing seed prices of sunnhemp and cowpea, and yield increase in a groundnut crop.

ECONOMIC ASSESSMENT

Continuous maize versus a maize-groundnut rotation

Domboshava. In Domboshava, continuous maize was grown for two years at two levels of N (0 and 92 N ha^{-1}) and in the third year at variable N rates (0, 46, 92 and 138 kg N ha^{-1}). In the maize-groundnut rotation, groundnut was planted in the first year, followed by maize in the second year at two N levels (0 and 92 N ha^{-1}) and maize in the third year at variable N rates (0, 46, 92 and 138 kg N ha^{-1}).

Year One: Gn-Mz-Mz vs Mz-Mz-Mz

For the first year of continuous maize (1994/95 season), maize fertilized at 92 kg N ha^{-1} generated the highest net benefits (Zim$[1] 2,109) among the fertilizer treatments (Table 3.1). The marginal rate of return (MRR) of moving from the farmer's check (maize with no fertilizer) to 92 kg N ha^{-1} was 172%. This suggest that farmers who invested a dollar on fertilizer at Domboshava would recover the money their initial cash outlay, plus an additional Zim$ 1.72 for each Zim$ 1.00 invested in fertilizer. In contrast, farmers who planted groundnut in the same season realized a loss of Zim$ 1,334 (Table 3.1). Since farmers who planted maize without fertilizer would have earned Zim$ 522 ha^{-1}, this represents a total reduction in net benefits of Zim$ 1,856 ha^{-1}. Groundnut net benefits were lower than the other options because of

[1]Zim $ = USD 0.18

low yields and higher labor requirements for planting, weeding and harvesting. For the groundnut crop to equal net benefits of farmers check, yield needed to be raised to 0.7 t ha^{-1} (more than double the current level).

Year Two: Gn-Mz-Mz vs Mz-Mz-Mz

For year two (1995/96), partial budgets for both a first maize crop following groundnut and the second maize crop in the continuous maize pattern are presented in Table 3.2. In continuous maize, moving from zero fertilizer to the recommended rate of 92 kg N ha^{-1} was associated with a marginal rate of return of 134%. When maize was grown following groundnut, the discounted marginal rate of return associated with moving from the farmer's check (continuous maize with no fertilizer) to maize following groundnut was 692%. This increase in discounted net benefits for maize following groundnut was mostly due to higher maize yields realized in this cropping system due to the residual contribution of nitrogen provided by the preceding groundnut crop. Although not recovered in the same year, each dollar invested in growing groundnut in the previous year generated an additional Zim$ 6.92 in the subsequent year. When 92 kg N ha^{-1} was applied to maize following groundnut, discounted net benefits increased by Zim$ 2,124, which represents a marginal rate of return of 173% over maize following maize when no fertilizer was applied.

Year Three: Gn-Mz-Mz vs Mz-Mz-Mz

In contrast, in year three (1996/97), fertilizer treatments were not justified for the third maize crop in continuous maize crop, since the discounted net benefits for all treatments were dominated by the farmer's check (Table 3.3). However, moving from the farmer's check (continuous maize without fertilizer) to maize in rotation with groundnut without fertilizer in the second maize crop had a discounted marginal rate of return of 560%. Fertilizer additions on the second maize crop (0 vs 46 kg N ha^{-1}) following groundnut gave a discounted marginal rate of return of less than 50%.

Combined discounted marginal benefit cost analysis over three seasons

Reflecting on the results of the three seasons under consideration, it is rather sobering to note that combined discounted marginal rate of return of moving from farmer's practice (continuous maize with no fertilizer) to rotating maize with groundnut when no fertilizer was applied to either the maize or the groundnut crop was only 4%, due to the low groundnut yield and high labor costs associated with groundnut resulting in negative net benefits in the first year (Table 3.4). This MRR is clearly not large enough to attract farmers to change from their current practice to a new system that incorporates groundnut in rotation with maize. However, this study showed that applying fertilizer to continuous maize at the recommended level of 92 kg N ha^{-1} generated combined discounted marginal rate of return of 104%, which is sufficiently high to encourage farmers to adopt this recommendation.

Year One: *Gn-Mz vs Mz-Mz*

Chinyika. In Chinyika, trials conducted in 1995/96 and 1996/97 compared two cropping patterns: a groundnut-maize rotation (Gn-Mz) and continuous maize (Mz-Mz). In the first year (1995/96), the groundnut crop generated a negative net benefit of Zim$ 1,917 (Table 3.5). This loss represented a decline of Zim$ 3,212 ha^{-1} in potential net benefits, compared to maize without fertilizer. Highest net benefits were obtained with continuous maize at 92 kg N ha^{-1} (Zim$ 3,587) compared to groundnut and the farmer's control (continuous maize without fertilizer). The marginal rate of return of moving from farmers' control to 92 kg N ha^{-1} was 305%.

Year Two: Gn-<u>Mz</u> vs Mz-<u>Mz</u>

In the second year (1996/97), highest discounted net benefits were obtained with continuous maize at 92 kg N ha^{-1} compared to maize following groundnut at variable N levels (0, 46, 92 and 138 kg N ha^{-1}) and the control (Table 3.6). For maize following groundnut, highest net benefits were obtained when no fertilizer was applied (Table 3.6). At all fertilizer levels in maize following groundnut, discounted net benefits were dominated by the zero fertilizer treatment (Table 3.6). However, when no fertilizer was applied to either the second continuous maize crop or maize following groundnut, the later generated a higher discounted net benefits (Table 3.6). The marginal rate of return for this change was 689%. The increase in discounted net benefits for maize following groundnut was due to a yield increase of 0.2 t ha^{-1} over continuous maize.

Combined marginal benefit cost analysis over two seasons

Summarizing these results over two seasons showed that continuous maize at 92 kg N ha^{-1} produced the highest benefits (Table 3.7). Combined discounted marginal rate of return in continuous maize when moving from zero to 92 kg N ha^{-1} was 133%. In contrast, over two seasons, the groundnut-maize rotation generated negative discounted net benefits at Chinyika. These negative net returns were due to low groundnut yield, little yield improvement in maize following groundnut, and the high labor costs associated with growing groundnut crop. Clearly, the groundnut-maize rotation is far less profitable than continuous maize, especially when the maize crop is grown with fertilizer.

Costing of Labor

The profitability of the groundnut-maize rotation in the economic assessment was highly inflenced by the high labor requirement for producing groundnut. When labor was assigned a zero monetary value (i.e. Net Benefits over cash costs only) made the rotation remotely profitable. Use of on going casual labor rate almost always overestimated the monetary value of labor used to produce groundnut because almost all the labor is normally supplied by female members of the household.

Maize-Legume Intercropping

In Domboshava, a maize-legume intercropping trial was conducted with the following cropping patterns; sole maize, maize-cowpea intercrop and maize-sunnhemp intercrop at three levels of fertilizer N (0, 60 and 120 kg N ha^{-1}) in the first year. In the second year, sole maize was grown following the different cropping patterns (in the previous year) at variable N rates (0, 46, 92 and 138 kg N ha^{-1}).

In the first year, among the cropping patterns, highest net benefits (Zim$ 2 166 per hectare) were obtained in the maize-cowpea intercrop at 60 kg N ha^{-1} (Table 3.8). For the maize monoculture, the marginal rate of return for moving from zero to 60 kg N ha^{-1} was 12 percent, which is not sufficient to induce farmers to change their cropping systems.

In contrast, the marginal rate of return of moving from the control (maize alone without fertilizer) to maize-cowpea intercrop at 60 kg N ha^{-1} was 103%, suggesting that for every dollar invested in cowpea and on fertilizer was recovered plus an additional Zim$ 1.03. Given that a marginal rate of return of between 50 to 100 % is usually regarded as acceptable, the rate of return for this treatment is quite attractive. Maize-sunnhemp intercrop at all the fertilizer levels considered, generated net benefits that were less than the control (hence were dominated) (Table 3.8). The reduced net benefits in maize-sunnhemp intercrop were due to the high cost of sunnhemp seed.

Second year following maize-legume intercrops

In the second year, maize was grown alone following the different cropping patterns from the previous year (season). Fitted exponential regression equations were calculated for added maize value and a linear equation for added cost for fertilizer (Table 3.9).

In the first year (Table 3.8), when no fertilizer was applied the maize-legume intercrops generated lower net benefits (maize-cowpea; Zim$ -254, maize-sunnhemp; Zim$ -409) compared to maize alone. Thus for cropping systems including legumes to be as profitable as maize alone over two years, subsequent maize must generate net benefits in excess by these values. When no fertilizer was applied, maize following the maize-cowpea intercrop and maize following the maize-sunnhemp intercrop produced additional Zim$ 1,089 and Zim$ 645 per hectare, respectively (Fig 3.1), which indicates that legume seed costs invested in the first year were recovered and a profit realized.

Net benefits from N application are maximized when the difference between the added maize value and added cost for fertilizer are greatest. For maize-sunnhemp, maximum benefits were obtained at 109 kg N ha^{-1} (Fig. 3.1). Although maximum net benefits in maize-cowpea were obtained at 138 kg N ha^{-1} (asymptote was not reached at the current maximum N rate but at a higher rate than being considered), the marginal rate of return of moving from 92 kg N ha^{-1} to 138 kg N ha^{-1} was only 15 percent. This MRR indicates that fertilizer rates higher than 92 kg N ha^{-1} did not increase corresponding maize benefits to a level that would be unattractive to farmers.

Sensitivity analysis on maize following the maize-legume intercrops showed that a 50% increase in legume seed cost would greatly reduce net benefits except for maize-cowpea at 60 kg N ha^{-1} (Table 3.10). A 50% increase in legume seed cost requires the maize crop following the maize-cowpea and the maize-sunnhemp intercrops to yield added values of Zim$ 147 and Zim$ 705 per hectare, respectively, to equal the control (continuous maize without fertilizer). In this scenario the maize crop following maize-cowpea intercrop generated added value in excess of Zim$ 1,000, which is 680% higher than returns required to equal the continuous maize when no fertilizer was applied.

Table 3.1 **Partial Budget for the first maize crop in a continuous maize cropping pattern and the groundnut crop in a groundnut-maize rotation in 1994/95 at Domboshava, Zimbabwe.**

	Maize		Groundnut
	0 kg N ha^{-1}	92kg N ha^{-1}	
Adjusted Yield (t ha^{-1})†	1.78	3.87	0.30
Gross Field Benefit (ZD\$ ha^{-1})	2 136	4 644	1 500
Seed cost (ZD\$ ha^{-1})	166	166	350
Planting labor (ZD\$ ha^{-1})‡	1 224	1 224	2 106
Fertilizer Cost (ZD\$ ha^{-1})¶	0	657	0
Harvest cost (ZD\$ ha^{-1})	224	488	378
Total Cost that Vary (ZD\$ ha^{-1})	1 614	2 535	2 834
Net Benefits over cash costs (ZD\$ ha^{-1})	1 746	3 333	772
Net Benefits over all costs (ZD\$ ha^{-1})	522	2 109	-1 334
Marginal rate of return	NA	172%	D

†Yield was adjusted downwards by 10 percent. D=Dominated treatment by the control.
‡Labor data for include land preparation, planting and weeding. ZD\$ = Zimbabwe dollar
‡Cost include labor for fertilizer application.
NA=Not applicable because it is the baseline (control).

Table 3.2 Partial budget for the second crop and in a continuous maize cropping pattern and maize following the groundnut crop in a groundnut-maize rotation in 1995/96 at Domboshava in Zimbabwe.

	Mz-Mz-Mz		Gn-Mz-Mz	
N rate (kg ha^{-1})	0	92	0	92
Adjusted Yield (t ha^{-1})†	2.20	4.72	4.15	7.35
Gross Field Benefit (ZD$ ha^{-1})	2 640	5 664	4 980	8 820
Fertilizer Cost (ZD$ ha^{-1})‡	0	824	0	824
Harvest Cost (ZD$ ha^{-1})	277	595	523	926
Total Cost that Vary (ZD$ ha^{-1})	277	1419	523	1750
Dicounted NB over cash costs (ZD$ ha^{-1})	2 146	3 935	4 049	6 418
Discounted NB over all costs (ZD$ ha^{-1})¶	1 921	3 451	3 624	5 748
Marginal rate of return (MRR)	NA	134%	692%	173%§

†Yield was adjusted downwards by 10 percent
‡Cost includes fertilizer transport and application labor costs
¶Calculation based on discount for year 1 after a groundnut crop= $(1+ \text{interest rate})^{-1}$.
§ MRR is for moving from Gn-Mz-Mz without fertilizer to 92 kg N ha^{-1}, otherwise is from control (Mz-Mz-Mz without fertilizer) to the treatment.
NA=Not applicable because it is baseline (control). NB=Net benefits

Table 3.3 Partial budget for the third maize crop in a continuous maize cropping pattern and the second maize crop following groundnut in a groundnut-maize rotation in 1996/97 at Domboshava, Zimbabwe.

	Mz-Mz-Mz				Mz-Gn-Mz			
N rate (kg ha^{-1})	0	46	92	138	0	46	92	138
Adjusted Yield† (t ha^{-1})	1.46	1.69	2.21	2.55	1.93	2.44	3.30	2.97
Gross Field Benefit (ZD$ ha^{-1})	1752	2028	2652	3060	2196	2928	3960	3564
Fertilizer Cost‡ (ZD$ ha^{-1})	0	466	824	1305	0	466	824	1305
Harvest Cost (ZD$ ha^{-1})	184	213	278	321	231	307	416	374
Total Cost that Vary (ZD$ ha^{-1})	184	679	1102	1626	231	773	1240	1679
Discounnted NB over cash costs (ZD$ ha^{-1})	1159	1032	1208	1160	1452	1627	2073	1493
Discounted Net¶ Benefit over all costs (ZD$ ha^{-1})	1036	892	1024	948	1299	1424	1798	1246
MRR (%)§	NA	D	D	D	560	23	37	D

†Yield was adjusted by downwards by 10 percent.
‡Cost includes fertilizer transport and application labor costs.
¶ Calculation based on discount for year 1 after a groundnut crop= $(1+ \text{interest rate})^{-2}$.
§ MRR = Marginal rate of return. D = Dominated treatment by control or a lesser level treatment.
NA=Not applicable because it is baseline (control). NB=Net benefits

Table 3.4 Summary[¶] of net benefits associated with two fertilizer rates over three seasons (1994-1997) in a continuous maize cropping pattern and maize-groundnut rotation at Domboshava, Zimbabwe.

Cropping system	Mz-Mz-Mz		Gn-Mz-Mz	
N rate (kg ha^{-1})	0	92	0	92
Year	--------------------Zim\$ ha^{-1}	----------------		
1994/95	522	2109	-1334	
1995/96	1921	3451	3624	5748
1996/97	1036	1024	1299	1798
Total	3479	6584	3589	6212
MRR[†] (%)		104	4	D

Mz=maize, Gn=groundnut.
[†]MRR=Marginal rate of return. D = Dominated treatment by control or a lesser level treatment.
[¶] Tables 3.1, 3.2 and 3.3.

Table 3.5 Partial Budget the first maize crop in a continuous maize cropping pattern and the groundnut crop in a maize-groundnut rotation in 1995/96 at Chinyika, Zimbabwe.

	Maize		Groundnut
	0 kg N ha^{-1}	92 kg N ha^{-1}	
Adjusted Yield (t ha^{-1})†	1.78	3.87	0.3
Gross Field Benefit (ZD$ ha^{-1})	3 000	6 296	720
Seed cost (ZD$ ha^{-1})	166	166	350
Planting labor (ZD$ ha^{-1})‡	1 224	1 224	2 106
Fertilizer Cost (ZD$ ha^{-1})¶	0	657	0
Harvest cost (ZD$ ha^{-1})	224	488	378
Total Cost that Vary (ZD$ ha^{-1})	1 705	2 709	2 637
NB over cash costs (ZD$ ha^{-1})	2519	1 485	531
NB over all costs (ZD$ ha^{-1})	522	3 587	-1 917
Marginal rate of return	NA	305%	D

†Yield was adjusted downwards by 10 percent. D=Dominated by control.
‡Labor data for include land preparation, planting and weeding. ZD$ = Zimbabwe dollar. NA= Not applicable because it is baseline (control).
‡Cost include labor for fertilizer application. NB=Net Benefits.

Table 3.6 Partial budget for the second maize crop in a continuous maize cropping pattern and the maize crop following groundnut in a groundnut-maize rotation in 1996/97 at Chinyika, Zimbabwe.

	Mz-Mz				Gn-Mz			
N rate (kg ha^{-1})	0	46	92	138	0	46	92	138
Adjusted Yield† (t ha^{-1})	0.22	0.95	1.37	1.57	0.37	0.58	0.98	1.44
Gross Field Benefit (ZD$ ha^{-1})	264	1140	1644	1879	444	696	1176	1728
Fertilizer Cost‡ (ZD$ ha^{-1})	0	466	824	1305	0	466	824	1305
Harvest Cost (ZD$ ha^{-1})	28	120	173	198	47	73	124	181
Total Cost that Vary (ZD$ ha^{-1})	28	586	997	1503	47	419	948	1486
DNB over cash costs (ZD$ ha^{-1})	215	547	667	467	361	285	286	344
DNB¶ over all costs (ZD$ ha^{-1})	192	450	526	306	323	225	185	197
MRR (%)		46	18	D	689§	D	D	D

†Yield was adjusted by downwards by 10 percent. MRR= Marginal rate of return.
‡Cost includes fertilizer transport and application labor costs. D= Dominated by lower level treatment and or control.
¶Discounted Net Benefits. Calculation based on discount for year 1 after a groundnut crop= $(1+ \text{interest rate})^{-1}$.
§ Based on moving from continuous maize at zero fertilizer.
NA=Not applicable because it is baseline (control).

Table 3.7 Summary[¶] of net benefits associated with two fertilizer rates over two seasons (1995-1997) in a continuous maize cropping pattern and maize-groundnut rotation at Chinyika, Zimbabwe.

Cropping system	Mz-Mz		Gn-Mz	
N rate (kg ha^{-1})	0	92	0	92
Year	----------------------Zim$ ha^{-1} ----------------------			
1995/96	1295	3587	-1917	
1996/97	192	526	323	185
Total	1487	4113	-1594	-1732
MRR[†] (%)		133	D	D

Mz=maize, Gn=groundnut.
[†]Marginal rate of return. D = Dominated by control or lower level treatment.
[¶]Tables 3.5 and 3.6.

Table 3.8 Partial budget for maize + legume intercrops and monoculture maize cropping systems at Domboshava, Zimbabwe.

Cropping system	Maize alone			Maize + cowpea			Maize + sunnhemp		
N rate (kg ha^{-1})	0	60	120	0	60	120	0	60	120
Adjusted Yield† (t ha^{-1})	1.1	1.74	2.3	1.00	2.72	2.11	1.27	2.13	1.82
Gross Field Benefits (\$ ha^{-1})	1320	2088	2760	1200	3264	2532	1524	2556	2184
Seed Cost‡ (\$ ha^{-1})	0	0	0	147	147	147	592	592	592
Fertilizer Costs¶ (\$ ha^{-1})	0	608	1216	0	608	1216	0	608	1216
Harvest Cost (\$ ha^{-1})	139	219	290	126	343	266	160	268	229
Total Costs that Vary (\$ ha^{-1})	139	827	1506	273	1098	1629	752	1468	2037
Net Benefits (\$ ha^{-1})	1181	1261	1254	927	2166	903	772	1088	147
MRR (%)	NA	12	D	D	103	D	D	D	D

†Yields were adjusted downwards by 10 percent. MRR=Marginal rate of return.
‡Seed cost of cowpea or sunnhemp and associated transport charges to farm-gate
¶Include transport and application labor costs.
D=Dominated by control or lower level treatment.
NA=Not applicable beciase it is baseline (control).

Table 3.9. Fitted Regression Equations for added maize value (Zim$) and added cost of fertilizer as a function of N fertilizer applied (x) in the subsequent year (maize + legume - maize).

Cropping system	Equation†	Standard Error		
		α	β	δ
Maize - Maize	Y=4126-4098 exp[-0.018(x)]	679	717	8×10^{-3}
Maize + cowpea - Maize	Y=5479-4390exp[-0.0109(x)]	12.11	11.67	6×10^{-5}
Maize + sunnhemp - Maize	Y=3659-3014exp[-0.0302(x)]	60.32	80.51	2×10^{-3}
		R^2	Significance	
Added Cost	Y = 259 + 12(x)	0.98	$P \leq 10^{-4}$	

† Exponential equations were fitted to model $E[Y] = \alpha + \beta \exp(-\delta x)$.

Table 3.10 Sensitivity analysis on net benefits of a maize-cowpea and maize-sunnhemp intercrops as influenced by cowpea or sunnhemp seed cost changes.

Cropping system†	Maize + cowpea			Maize + sunnhemp		
N rate (kg ha^{-1})	0	60	120	0	60	120
	----------Zim$ ha^{-1}----------					
Current price	927	2166	903	772	1088	147
50% rise	834	2093	830	476	792	-49
100% rise	780	1872	609	180	496	-445
50% decline	1000	2240	977	1068	1384	443

†Control values for continuous maize are Zim$ 1181, 1261 and 1254 for 0, 60 and 120 kg N ha^{-1}, respectively.

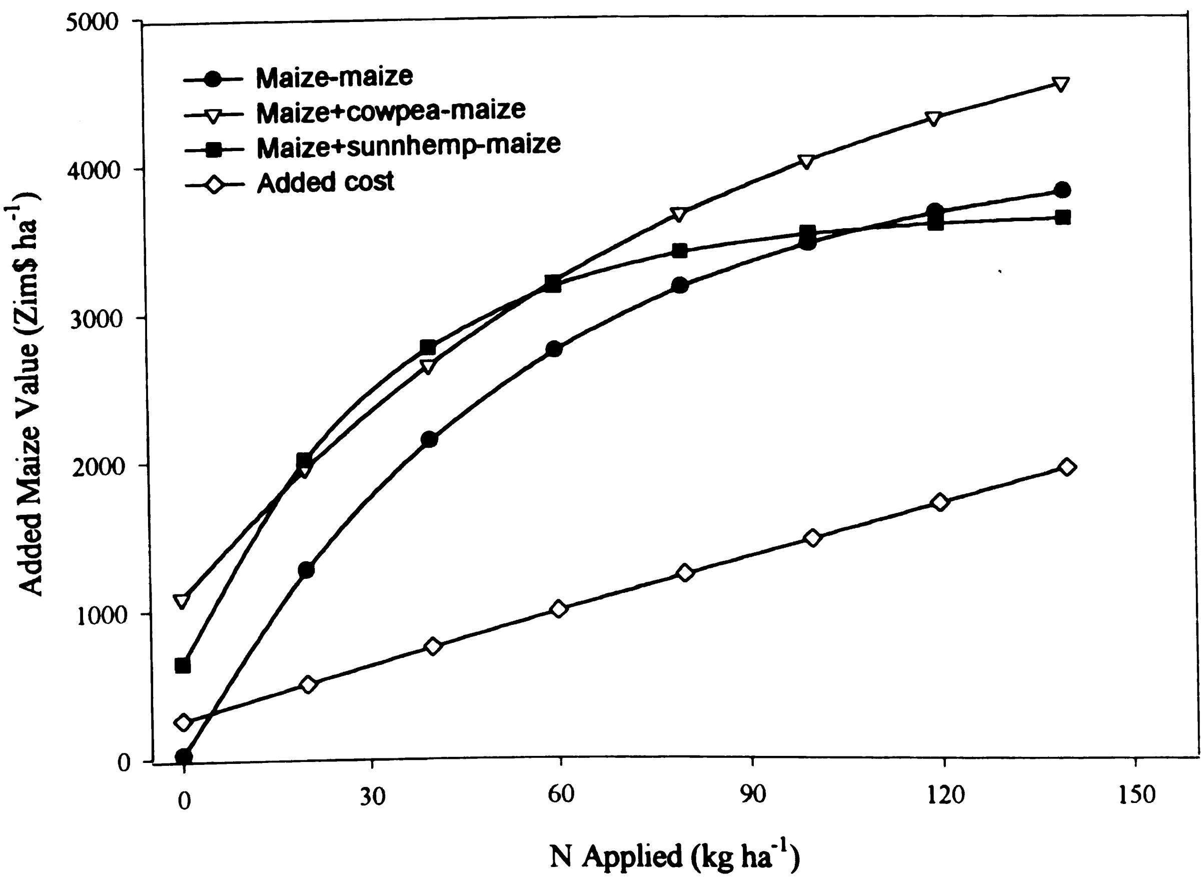

Figure 3.1. Effect of rate of N application on added maize value and added cost for fertilizer at Domboshava following maize-legume intercrops.

CONCLUSIONS

Economic assessment of continuous maize versus a maize-groundnut rotation showed that continuous maize at 92 kg N ha^{-1} optimized net benefits over labor and input costs. However, should a farmer prefer to utilize a maize-groundnut rotation because of rotational benefits such as pests and diseases reduction, the analysis suggests that net benefits would be maximized when no fertilizer was applied to either maize or groundnut, or when the current groundnut crop yields were doubled, assuming labor costs remained constant.

The results for groundnut-maize rotation underline the need for research to (i) increase the yield of groundnut on smallholder farms and (ii) reduce the associated labor costs in producing groundnut without adding much to cash costs. Groundnut yield improvements and reduced labor requirements can be reduced by intermediate technologies for planting, harvesting and processing. Use of intermediate technolgies will initially require institutional support by both public and private sector.

The analysis on maize-legume intercrop has shown that in the first year the maize-cowpea intercrop, at 60 kg N ha^{-1}, generated higher net benefits than sole maize, even when the economic value of cowpea was not included. In the second year, maize yields following the maize-legume intercrops were high enough to pay legume seed outlays in the first year, plus additional cash benefits. Sensitivity analysis revealed that a 50% increase in cowpea and sunnhemp seed costs would greatly reduce net benefits for all maize-legume intercrops, except for the maize-cowpea intercrop at 60 kg N ha^{-1}.

REFERENCES

Bernsten, R.H. 1980. Pre-screening alternative component technologies to identify probable constraints to farmer adoption. A paper presented at the Cropping Systems Economic Training Program, June 2-4 Bogor, Indonesia.

CIMMYT. 1988. From Agronomic Data to Farmer Recommendation: An Economic Training Manual, completely revised Edition, Mexico, D.F.

Gittenger, J.P. 1984. Economic Analysis of Agricultural Projects. Second Edition. The Johns Hopkins University Press. Baltimore, USA, pp. 299-361.

Hesterman, O.B., C.C. Sheaffer, and E.I. Fuller. 1986. Economic comparisons of crop rotation including alfalfa, soybean and corn. Agron. J. 78: 24-28.

McDonagh, J.F., B. Toomsan, V. Limpinuntana and K.E. Giller. 1993. Estimates of the residual nitrogen benefit of groundnut to maize in Northeast Thailand. Plant and Soil 154:267-277.

Mukurumbira, L.M. 1985. Effects of rate of fertilizer nitrogen and previous grain legume crop on maize yields. Zimb. Agric. Journal 82:177-179.

Shumba, E.M., R.H. Bernsten and S.R. Waddington. 1990. Maize and groundnut yield gap analysis for research priority setting in the smallholder sector of Zimbabwe. Zimb. Journal of Agric. Res 28:105-113.

Shumba, E.M., S.R. Waddington, and M. Rukuni. 1992. Use of tine-tillage, with atrazine weed control, to permit earlier planting of maize by smallholder farmers in Zimbabwe. Experimental Agriculture 28: 251-254.

Stevens, R.D., and C.L. Jabara. 1988. *Agricultural Development Principles*. The John Hopkins University Press. Baltimore and London.

Waddington, S.R., J. Karigwindi, and J. Chifamba. 1997. Productivity and profitability of maize + groundnut rotations when compared to continuous maize under smallholder management in Zimbabwe. In Proceedings for the Soil Fert Net Results and Planning Workshop (in press).

Table A3.11. Price and labor data used for the cost-benefit analysis.

Data	Value
GMB buying price for Grade A white maize	Zim$ 1 200 per t.
GMB buying price shelled groundnut	Zim$ 5 000 per t.
Compund D (8-14-7)	Zim$ 2 260 per t.
Ammonium nitrate fertilizer	Zim$ 2 490 per t.
Maize seed price @25 kg ha^{-1}	Zim$ 166 per ha
Groundnut seed @70 kg ha^{-1}	Zim$ 350 per ha
Cowpea seed cost	Zim$ 184 per 25 kg
Sunnhemp seed cost	Zim$ 494 per 25 kg
Local daily casual worker wage rate	Zim$ 18 per day
Labor for Maize	
Land preparation	4 person-days ha^{-1}
Planting	9 person-days ha^{-1}
Fertilizer (basal + top)	8 person-days ha^{-1}
Weeding (2 hand weedings)	24 person-days ha^{-1}
Cutting/stocking	12 person-days ha^{-1}
Removing ears	19 person-days ha^{-1}
Shelling	7 person-days per t grain
Labor for Groundnut	
Land preparation	4 person-days ha^{-1}
Planting	18 person-days ha^{-1}
Weeding (2 hand weedings)	57 person-days ha^{-1}
Pulling	18 person-days ha^{-1}
Plucking	20 person-days ha^{-1}
Shelling	7 pers-days/100 kg grain
Discount rates for 1996 and 1997	23%