EFFECT OF NITROGEN FERTILIZER AND RHIZOBIUM INOCULATION ON GROWTH AND YIELD OF INTERCROPPED MAIZE (*ZEA MAYS*) AND BEANS (*PHASEOLUS VULGARIS*)

BY

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DECLARATION

This thesis is my original work and has not been presented for a degree in any University

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DEDICATION

To my husband Wairegi, and children Nyokabi, Wakina, Mugure and Muchunu.

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ABBREVIATIONS AND SYMBOLS

A.M.S.L.	-	Above Mean Sea Level
CAN	-	Calcium Ammonium Nitrate
CIAT	-	Centro International de Agriculatura Tropical
cm	-	centimeters
DAP	-	Day After Planting
FAO	-	Food and Agriculture Organization
g	-	grammes
kg/ha	-	Kilogrammes per hectare
kg	-	Kilogramme
mg	-	milligramme
MIAC	-	Mid –American International Agricultural Consortium
N	-	Nitrogen
TSP	-	Tri Super phosphate
WAE	-	Weeks After Emergence
%	-	Percent
° C	-	Degrees Centigrade

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ABSTRACT

Most studies on intercrops have not been conclusive. Nitrogen is one of the elements that limit maize and bean production. Since symbiotic N fixation may provide a substantial amount of N in such a system, there is need to study the effect of fertilizer N and rhizobial inoculation on maize and beans in intercrops. Hence, effects of N levels and rhizobial inoculation on bean nodulation and yield of intercropped maize and beans were investigated at Kabete Field Station, University of Nairobi over two seasons in two sites. Treatments were bean inoculation with *Rhizobium leguminosarum biovar phaseoli* (inoculated, non-inoculated) and N levels (0, 50, 100 and 150 kg N/ha) arranged in a factorial structure with three replications.

In season 2, there was significant interaction (P=0.05) between N levels and bean inoculation such that maize grown in association with inoculated beans had significantly higher yield than maize where beans were not inoculated at 0, 100 and 150 kg N/ha. This difference was not observed at 50 kg N/ha. Response to N for maize grown in association with inoculated and non-inoculated beans differed. For maize grown in association with inoculated beans, there was a yield increase with increasing N levels, though 100 and 150 kg N/ha gave yields that were statistically similar (P=0.05). For maize grown in association with non-inoculated beans, application of 50 kg N/ha increased yield significantly. Increasing N beyond this level had no effect on yield. This interaction was not observed in season 1 where increasing N to 100 kg N/ha increased maize yield significantly (P=0.05). Further increase from 100 to 150 kg N/ha reduced yield. Maize grown in association with inoculated beans had significantly higher yield than where beans were not inoculated. For beans, inoculation increased yield significantly (P=0.05).

The results of this study imply that introduced rhizobia may have been superior in N fixation through enhanced nodule activity and not nodule numbers. Both crops probably benefited from this enhanced N fixation though maize also benefited from fertilizer N.

CHAPTER ONE

1.0 INTRODUCTION

1.1 Importance of intercropping

It is expected that by the year 2000, due to demand for food and agricultural products in Kenya, agricultural production should double (Anonymous, 1986). Further increase is expected by the year 2013, as the population is estimated to reach 46.6 m (MIAC, 1993). The national annual growth rate has been estimated at 3.7% (World Bank, 1991). Increase in agricultural production can only be through either intensive or extensive farming methods. Intercropping is a way of achieving agricultural intensification that has been widely practiced, by small-scale farmers in the tropics. It is the growing of two or more crops simultaneously in the same field, where crop competition occurs during all or part of crop growth (Andrews and Kassam, 1976). It, therefore, maximizes use of environmental resources and minimizes risk of total crop failure (Norman, 1975). The Advantages are more likely to occur where growth patterns of the component crops differ in time so that crops make their major demands in resources at different times (Willey, 1979).

1.2 Importance of maize and beans

In Kenya, maize (*Zea mays*) is the most important food crop followed by beans (*Phaseolus vulgaris*) (Njugunah et. al, 1980). Maize is the staple food for over 90% of the people (Laboso *et. Al,* 1994). About 1.2m ha was under maize in 1993 (MIAC, 1993). Production is below optimum and is inadequate. The national average is about 1.5 tonnes/ha but some farmers in high potential areas can produce 7 tonnes/ha (Laboso *et. al*, 1994). The national average was estimated at 2.7 million tonnes per year while consumption was 2.8 million tonnes (MIAC, 1993). By the year 2013, 6.71 million tonnes of maize will be required to meet domestic demand (MIAC, 1993). Bean demand also shows an upward trend due to rising meat prices and growing population (Njugunah *et. al*, 1980). Hence, there is need to increase both maize and bean production.

1.3 Maize and Bean Intercrop

In Africa, 98% and 83% of the production of cowpeas and beans, respectively, are estimated to come from intercropping with other food crops (CIAT, 1986). In Kenya, about 80% of the maize (MIAC, 1993) and 94% of beans (Edge *et al.*, 1980; Njugunah *et. al*, 1980) are grown under intercrop. In maize/bean intercrop, maize is often the maim crop and beans secondary. Intercropping of maize and beans is usually carried out by small - scale farmers.

1.4 Fertilizer Use in Agriculture

Fertilizers have been the main input responsible for increased food production worldwide (Harre and White, 1985). In Kenya, fertilizer use is still below crop requirements (Chege, 1992), mainly due to high fertilizer prices and unavailability of recommended formulations (MIAC, 1993). It has also been suggested by Fertilizer Use Recommendation Project (FURP) that fertilizer recommendations gave lower rates than those appropriate, probably because the only economic information considered is fertilizer and maize prices. Chege (1992) carried out more comprehensive economic analysis on FURP experimental data, from Kisii and Busia Districts, where the economic circumstances of the farmer, alternative demands on the limited capital resource and risks involved in using fertilizers were also considered. The analysis suggested that the current recommendations, for both sites, of 50 kg/ha of both N and P are low. Another study (Mugunieri *et. al,* 1997) carried out in kisii, by suggested that the level of management practices should also be considered when formulating fertilizer recommendations. Farm data collected from a survey conducted on farms when compared to experimental data from FURP, suggested that maize response to recommended fertilizer levels was lower at farm level. This difference was attributed to differences in level of management between researchers on experimental stations and farmers on farms.

1.5 Objectives

The objectives of this study are:

1. Assess the effect of N levels on nodulation, growth, yield and its related parameters in a maize/bean intercrop.
2. Determine the effect of inoculating beans with *Rhizobium* species on bean nodulation, growth, yield and its related parameters in maize/bean intercrop.

1.6 Justification

Although intercropping is the predominant practice in maize and bean production, research has been concentrated more on sole cropping than on intercropping. The major factors limiting production are plant nutrition, population and spatial arrangement, genetic characteristics, insect pests and diseases (Gitari *et. al*, 1997). Most of the studies on intercrops have not been conclusive due to the lack of continuity and follow up. This study has concentrated on plant nutrition because fertilizers, the main supply of plant nutrients constitute the most important purchased input in agriculture. Nitrogen is one of the elements that limit maize and bean production in Kenya. Hence there is need to look for alternative ways of improving N nutrition in a maize/bean intercrop, without necessarily applying the recommended fertilizer levels. Symbiotic N fixation may provide a substantial amount of N in such a system. Since both fertilizer N and biological N fixation are important N sources, there is need to study the effect of fertilizer N and rhizobial inoculation on maize and beans intercrops.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Effect of Intercropping on Growth and Yield of Intercrops

There have been conflicting reports on whether intercropping is beneficial to the legume and non-legume. This depends on the competition and complementarity of the association. Improved yields have been observed in cereals growing in association with beans (Wiley and Osiru, 1972; Chemining'wa and Nyabundi, 1994). Wiley and Osiru (1972) found total yield of maize and bean in the intercrop system to be 38% higher than that of pure stands. In the work of Chemining'wa and Nyabundi (1994), increased proximity of maize and beans caused significant increase in yield of maize under conditions of low soil N. The yield of beans also exhibited corresponding improvements though the increases were not significant. In the following work that also included inoculation of beans with *Rhizobium*, Nuh (1996) reported that increasing proximity between maize and beans in intercrop caused significant increase in yields of both crops.

Other times, competition may outweigh complementarity resulting in a negative relationship between the yields of the two crops (CIAT, 1986). The legume may also compete with the cereal for N. If the intercropped cereal is taller than the legume, shading will occur and photosynthesis and subsequently N fixation will be reduced (Trang and Giddens, 1980). The ability to climb is one of the most important features of the bean plant affecting its ability to compete with maize, presumably through its effect on light interception (CIAT, 1986). Hence, bean germplasm developed for sole crop may not always be good for intercrop. Work on selection of varieties suitable for intercropping is being carried out by Kenya Agricultural Research Institute (KARI, 1994).

The degree of competition and complementarity may be influenced by both crop type and rainfall amount. In a study by Ashiono (1994), the effect of intercropping sorghum with either beans or cowpeas was evaluated by comparing mixed stands to pure stands. Yields of sorghum and beans were lowered by 10% and 32%, respectively, by intercropping. Different findings were observed in cowpea-sorghum intercrop. Sorghum yields increased by 23% while a reduction of 30% was noted in cowpeas. Beans seemed to suppress sorghum growth by smothering it at early stages of growth while cowpea had a compensatory effect on sorghum yield, probably due to N fixation.

2.2 Effect of Intercropping on Nodulation, Fixation and transfer of N, by Intercrops

Intercropping may enhance or reduce legume nodulation. In studies carried out at ICRISAT, pigeon pea intercropped with sorghum nodulated better, than the monocrop (Wiley, 1979). In another study, where monocrops were compared with intercrops, and fertilizer N varied, there was a reduction in soybean nodulation on intercropping with maize, probably due to both increased shading and increased soil N levels (Searle *et al.*, 1981).

In grass-legume intercrop, the grass may benefit from the N fixed by the companion legume (Agboola and Fayemi, 1971). Elmore and Jacobs (1986) reported an increase in total N of sorghum intercropped with nodulating soybeans, but not when intercropped with non-nodulating soybeans. This was probably due to an increase in supply of available N in the root medium. Wiley (1979), quoted Walker *et al.*, (1954), suggested that excretion of N by legumes might be particularly likely where legumes are subjected to shading. This may only be important after good growth has already been made under high light conditions. Hence, N fixed may be utilized by both crops (Finlay, 1975).

The N benefit to the cereal has been difficult to quantify. Studies by Searle *et. al* (1981) and Wahua and Miller (1978b) did not find any benefit. Nitrogen contribution of the intercropped beans to maize has been estimated at 40 Kg N/ha (Willey, 1979). Studies on cowpea suggested that this may be as a result of N excretion, litter, soluble leaf N, and N from decaying nodules (Mulongoy, 1985). Excretion of N by cowpea roots, for the benefit of the companion crop, is more likely in soils low in N (Mulongoy, 1985).

The mechanism of N transfer, from the legume to either non-nodulating legume or cereal has been studied. Martin *et. al* (1991) observed N transfer from nodulating soybenas to non-nodulating soybean in an intercrop. Francis *et. al* (1986) suggested that endomycorrhizal infection can provide channels for direct inter-plant N transfer. This transfer is enhanced by defoliation (Newman, 1988), clipping (Ta and Faris, 1987) or senescence (Hamel *et. al*, 1991) of the donor plant. In studies by Hamel *et. al* (1991) on soybean/maize intercrop, presence of endomycorrhizal fungus reduced N loss from soybean, but improved the efficiency of maize-root system for the recovery of N excreted by the soybean.

The 'sparing effect' has also been studied. When a legume in a cereal-legume intercrop is fixing N, the legume soil N uptake is reduced and the cereal is able to take up more soil N. This is referred to as the `N sparing effect' (Danso *et. al*, 1993). Walker *et. al* (1956) observed that when grown together, N uptake (total N) by the clover was reduced, while it increased in grass, for low soil N levels. There was evidence of the N sparing effect of nodulating soybean for non-nodulating soybean, dwarf maize and tall maize. Agboola and Fayemi (1971) also made similar observations. The N contribution from the sparing effect is greater than that from transfer (Danso and Papastylianou, 1992; Senaratne and Hardson, 1988).

There have also been suggestions that the legume benefits from the association. Phosphorus transfer, from the cereal to legume, in a source-sink relationship, has been suggested (Fujita *et. al*, 1992). Other studies suggest that there may be a tripartite association of the legume, Vesicular-arbuscular mycorrhiza (VAM) fungi and *Rhizobium*. The mycorrhozas improve nodulation and N fixation by the legume rhizobia by improving phosphorus nutrition of the plant (Reid, 1990).

2.3 Effect of Fertilizer N in an intercrop

The response of cereals and legumes to fertilizer N differs. In studies by Searle *et. al* (1981), N applied had no effect on maize grain yield, but it increased maize total dry matter yield. Nitrogen appeared inhibitory to N fixation, both directly from increased soil N and indirectly by stimulation of maize growth and shading of intercropped legumes.

Other studies have made various observations. In a grass-legume mixture, application of increasing levels of N stimulated growth of grass to the detriment of the legume, as light became limiting (Viets, 1965). Succeeding increments of N produced more grass but less legume, and the total dry weight production remained about the same (Viet, 1965). Other studies have shown that intercropped maize responds to low levels of N, compared to non-intercropped maize (Akobundu, 1980; Kang *et. al*, 1981). Hence, there is an N benefit from the legume.

In Kenya, though various studies have been carried out, results have been inconclusive. In maize-bean fertilizer studies, beans responded to fertilizer application but maize response was variable (Muigai and Ndegwa, 1991). Studies on appropriate fertilizer levels, for maize/bean intercrop, in Kiambu, recommended application of 75 kg N/ha and 75 kg P_2O_5, to maize, has been suggested (FURP, 1995). For beans, NPK 20:20:20 at 90 Kg/ha has been recommended (Muigai and Ndegwa, 1991).

Studies have suggested that the response to fertilizer N depends on both fixing ability of the legume and soil N levels. Cowpeas are better N fixers than beans. Eaglesham (1981) postulated that maize grown in association with cowpea did not respond to fertilizer N due to N excretion by the legume. He concluded that N excretion by an intercropped legume gives significant benefit to the associated non-legume crop only in conditions of low mineral N status in the soil. A similar observation was made by Agboola and Fayemi, (1971). Thus, less fertilizer N is required to achieve optimum productivity of the system (Danso, 1994).

2.4 The Effect of Rhizobia Inoculation on Nodulation, N fixation and Plant growth

Frederick (1985) described the process of nodule formation. The rhizobia are stimulated by the root exudates to multiply on the root surface, and the root hair starts to curl. The rhizobia then enter root cells by forming an infection thread in a root hair. Plant cells are stimulated to grow and divide to form a nodule with direct connections to the vascular system. Rhizobia, with envelopes of membrane around them, fill the central cells in the nodule. Nodule specific proteins are elaborated and a massive synthesis of leghaemoglobin takes place (Meijer, 1982). Leghaemoglobin is located outside the bacteriods, where it fulfils its role of supplying oxygen to these aerobic organisms, while the levels of free oxygen are kept low (Meijer, 1982).

Apart from being involved in N metabolism, the association may enhance growth through disease control. Studies have shown that Rhizobia may reduce fusarium root rot and ashy stem blight severity. Data by Buonassisi *et. al*., (1986) suggested that potential exists for controlling fusarium root rot through seed inoculation with nodulating rhizobium strains that are also highly antagonistic to *F. solani f. sp. Phaseoli*. In another study by Perdomo *et al*., (1989), Rhizobium strains reduced the growth of Macrophomina phaseolina.

There have been several studies on legume symbiosis in Kenya. Keya *et. al*., (1982) found bean roots to be nodulated in most bean growing areas but nodule numbers were generally low. Studies by Muigai and Ndegwa (1991) confirm this. Addition of rhizobia inoculaton had little effect on nodulation (Muigai and Ndegwa, 1991). Other legumes may be superior in nodulation. Inoculation of cowpea seeds with rhizobia increased both the amount of N fixed by the cowpea and transferred to maize in an intercropping system (Patra *et. al*., 1986).

There are various factors affecting nodulation. Environmental conditions may affect bean nodulation more than lack of effective inoculum (Dobereiner and Campello, 1977). Studies have suggested soil conditions (Keya *et. al.*, 1982) and in particular Phosphorus (Floor, 1984) as major limiting factors.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Experimental site

Field experiments were conducted at Kabete Field Station, University of Nairobi. The site is located at Latitude 1°15' South and longitude 36°44' East and at an altitude of 1800m. the soil is well drained, very deep friable clay with a humic top soil (humic Nitosol) developed from Limuru Trachyte (Michieka, 1977). The average rainfall is about 1000mm with a mean monthly maximum temperature of 23° C and a minimum of 12° C (Anonymous, 1985).

The field experiment was repeated. It was carried out, in relay, from April 1996 to October 1996 and July 1996 to January 1997. The first experiment was carried out on land that was previously under maize, grown at high density of 109,999 without any fertilizer application. This preceding maize crop was meant to deplete soil N. The second experiment was carried out on land that was previously under sweet potato crop. Total soil N level was 0.34% and 0.23% in site 1 and 2 respectively (Appendix 2).

3.2 Experimental Design and Treatments

The treatment variables were bean inoculation with *Rhizobium* inoculum (inoculated, non-inoculated) and N levels (0, 50, 100, 150 kg N/ha). The treatments were arranged as 2 x 4 factorial, with 3 replications in a Randomised Complete Block Design. Maize cultivar 'Embu 512' and common bean cultivar 'GLP 2' were used. Hill spacing was 75 cm x 25 cm as it was assumed that maize was the main crop and beans secondary. This is the recommended planting arrangement for monocropped Embu 512 hybrid in the Kabete type of ecozone. This arrangement gives a plant population of 53,333 maize plants pre hectare. Two beans were planted in the same hill as maize ensuring a population of 106,666 plants per hectare. The plot size was 6x4.5m.

The crops were sown at the same time. Prior to planting, the bean seeds were inoculated with *Rhizobium leguminosarum biovar phaseoli* strain No. 446 from the University of Nairobi's Mircen Project. Calcium ammonium Nitrate (CAN, 26-0-0) was used as the source of N. It was topdressed along rows at 6 and 4 weeks after emergence in season 1 and 2 respectively. All the plots received a basal application of 20 kg P/ha in the form of Triple Super Phosphate (TSP 0-46-0). This was mixed in the upper 15 cm of the soil, during harrowing.

3.3 Crop Husbandry

In all experiments, 2 seeds of maize and 4 of beans were planted per hill. Two weeks after emergence, the seedlings were thinned to 1 maize and 2 bean seedlings per hill. Control of pest and disease was as follows: immediately after emergence, the bean plants were sprayed with Dimethoate (Dimethyl-S-(N-mthyl carbo-methyl)-phosphothiol othionate) 40% EC for control of beanfly (*Melanogromyza spp*) on the aerial part of the plants. This was continued at weekly intervals into flowering. Benomyl (methyl-N-(1-butylcarbomy (-2-benezimidazole)-carbamate) was applied one day after each application of Dimethoate to control bean rust (*Uromyces phaseoli*) and other fungal diseases. From flowering onwards, Cypermethrin (a synthetic pyrethroid) was sprayed to control flower and pod pests. For maize, Diptrex was applied at about 20 cm plant height to protect against stalk borer. Manual weeding was regularly done for effective control of weeds.

3.4 Sampling, Measurements and Observations

3.4.1 Sampling

The parameters measured were: biomass, nodulation, grain yield and its related parameters. Sampling for biomass and nodulation was repeated every 2 weeks. Sampling for biomass was done in season 2 only, from 6 to 10 WAE. Nodulation was from 6 to 10 WAE in season 1, and 4 to 8 WAE in season 2. At each sampling time, 5 adjacent hills were sampled starting from the outer rows (excluding guard rows) inwards. This stratified and sequential sampling was necessary to prevent creation of gaps that would alter density effects in subsequent samples even in yield.

3.4.2 Nodulation

The bean plants were gently uprooted and N fixing nodules, which are pink/purple in colour, counted.

3.4.3 Biomass Development

Maize and bean plants were cut at the base of the stem and the shoot material chopped or crushed before oven drying at 80° C to constant weight.

3.4.4 Seed Yield and Yield Components

These were determined at harvest. Four center rows (i.e. about 64 maize plants and 128 bean plants) occupying 10.5 m^2 were harvested in each experimental plot for determination of grain yield. The yield components for maize namely, number of rows per cob, number of kernel per cob row, cob length and 100-Kernel weight were obtained from the same plot sample. For determination of 100-kernel weight, 10 samples each of

100 kernels were drawn from the bulk yield sample, air dried to a moisture content of about 14% and weighed.

For beans, number of pods per plant, number of seeds per pod and 100 seed weight were obtained from the same plot sample. Both maize and bean yields were adjusted to a moisture content of 14% using a replicated 0.5 Kg sample of seeds, which were air dried to a constant weight.

3.5 Analysis

The data for each of the growth and yield parameters were subjected to analysis of variance (ANOVA) and means separated using Duncan's Multiple Range Test when the F-test was significant at 5% level, as described by Steel and Torrie (1980).

CHAPTER FOUR

4.0 Results

4.1 Effect of N levels and Inoculation on Nodulation of Beans

In season 1, N application did not affect bean nodule number at 6 WAE (Table 1). However, at 8 WAE (Table 2), inoculation and N levels had significant interaction effect on nodulation at 8 WAE. Mean separation tests performed on bean nodule numbers showed that differences between inoculation and non-inoculation varied with N levels. At 0 kg N/ha, nodulation was significantly lower for beans which had been inoculated compared to non-inoculated. This difference was not observed on fertilizer application. For both inoculated and non-inoculated beans, application of 150 kg N/ha reduced nodule numbers significantly. Later, at 10 WAE, nodulation was not significantly reduced by increase in N levels. Inoculation of beans had no significant effect on nodule numbers at any sampling time.

Season 2 was different. Early in season 2, at 4 WAE (Table 4), no significant observations or trends were noted on N application. At 6 and 8 WAE (Table 5 and 6), there was a significant decline with increase in levels of N. Though N application lowered nodulation significantly at 6 WAE (Table 5), increasing N levels from 100 kg N/ha to 150 kg N/ha did not have a significant effect on nodulation. At 8 WAE in the same season, (Table 6), application of 50 kg N/ha did not lower nodulation significantly, while increase of N to 100 kg N/ha had a significant effect. Beyond this, no significant effect was noted. Inoculation did not affect nodulation significantly in season 2 at different growth stages (Tables 4,5 and 6). Also, inoculation and N levels had no significant interaction effect on nodulation at all growth stages.

TABLE 1 - Effect of Nitrogen Levels and Inoculation on Nodulation (nodules/plant) of Bean Plants 6 Weeks After Emergence (Season 1)

	Nitrogen levels (kg N/ha)				
Inoculation	0	50	100	150	`Means
Inoculated	17	14	21	22	19
Non-inoculated	21	12	19	25	19
Means	19	13	20	23	19

TABLE 2 - Effect of Nitrogen Levels and Inoculation on Nodulation (nodules/plant) of Bean Plants 8 Weeks After Emergence (Season 1)

	Nitrogen levels (kg N/ha)				
Inoculation	0	50	100	150	Means
Inoculated	23[c]	67[a]	58[ab]	17[c]	41
Non-inoculated	70[a]	44[abc]	36[abc]	24[bc]	44
Means	47	55	47	21	43

Means followed by the same letter/s are not significantly different at 5% probability according to Duncan's Multiple Range Test.

TABLE 3 - Effect of Nitrogen Levels and Inoculation on Nodulation (nodules/plant) of Bean Plants 10 Weeks After Emergence (Season 1)

	Nitrogen levels (kg N/ha)				
Inoculation	0	50	100	150	Means
Inoculated	7	3	2	0	3
Non-inoculated	9	8	0	1	5
Means	8	5	1	1	4

TABLE 4 - Effect of Nitrogen Levels and Inoculation on Nodulation (nodules/plant) of Bean Plants 4 Weeks After Emergence (Season 2)

	Nitrogen levels (kg N/ha)				
Inoculation	0	50	100	150	Means
Inoculated	57	49	51	42	49
Non-inoculated	44	44	51	43	46
Means	49	47	51	43	47

TABLE 5 - Effect of Nitrogen Levels and Inoculation on Nodulation (nodules/plant) of Bean Plants 6 Weeks After Emergence (Season 2)

	Nitrogen levels (kg N/ha)				
Inoculation	0	50	100	150	Means
Inoculated	98	70	49	43	65
Non-inoculated	70	64	47	41	50
Means	84[a]	67[b]	48[c]	42[c]	58

Means followed by the same letter/s are not significantly different at 5% probability according to Duncan's Multiple Range Test.

TABLE 6 - Effect of Nitrogen Levels and Inoculation on Nodulation (nodules/plant) of Bean Plants

	Nitrogen levels (kg N/ha)				
Inoculation	0	50	100	150	Means
Inoculated	10	8	4	2	6
Non-inoculated	17	10	3	0	8
Means	14^{a}	9^{a}	4^{b}	1^{b}	7

Means followed by the same letter/s are not significantly different at 5% probability according to Duncan's Multiple Range Test.

4.2 Effect of N levels and inoculation on Biomass Accumulation (g/plant) of Maize and Bean Plants

4.2.1 Maize Biomass

The interaction between N and bean inoculation affected dry matter significantly at 6 WAE. (Table7). Application of 150 kg N/ha, reduced dry matter significantly, for maize grown in association with beans which were not inoculated. Maize grown together with inoculated bean plants showed numerical, though insignificant, differences at 6 and 8 WAE (Tables 7 and 8). At 6 WAE, there was an insignificant increase in dry matter with increasing N levels beyond 50 kg N/h. At 8 WAE, there was increase in dry matter with increase in N for all N levels applied. There were no notable trends at 10 WAE (Table 9).

TABLE 7 - Effect of Nitrogen Levels and Inoculation on Dry Matter (g/plant) of Maize Plants 6 Weeks After Emergence (Season 2)

	Nitrogen levels (kg N/ha)				
Inoculation	0	50	100	150	Means
Inoculated	10.0^{abc}	9.0^{bc}	10.0^{abc}	11.7^{abc}	10.2
Non-inoculated	14.0^{a}	12.3^{ab}	10.3^{abc}	7.7^{c}	11.1
Means	12.0	10.7	10.2	9.7	10.7

Means followed by the same letter/s are not significantly different at 5% probability level according to Duncan's Multiple Range Test.

TABLE 8 - Effect of Nitrogen Levels and Inoculation on Dry Matter (g/plant) of Maize Plants 8 Weeks After Emergence

	Nitrogen levels (kg N/ha)				
Inoculation	0	50	100	150	Means
Inoculated	16.4	16.4	19.7	24.0	19.1
Non-inoculated	25.0	23.2	22.6	17.7	22.1
Means	20.7	19.8	21.1	20.8	20.6

TABLE 9 - Effect of Nitrogen Levels and Inoculation on Dry Matter (g/plant) of Maize Plants 10 Weeks After Emergence (Season 2)

	Nitrogen levels (kg N/ha)				
Inoculation	0	50	100	150	Means
Inoculated	67.7	75.3	77.3	79.7	75.0
Non-inoculated	53.7	76.3	75.3	75.3	70.2
Means	60.7	75.8	76.3	77.5	72.6

4.2.2 Bean Biomass

The interaction between N levels and inoculation affected bean dry matter significantly early in the season. At 6 WAE (Table 10), application of 50 kg N/ha on inoculated plants caused a significant reduction in bean dry matter. Additional N, from 50 to 150 kg N/ha on inoculated plants increased dry matter significantly. In plants that were not inoculated, application of N had no significant effect on dry matter. At 8 and 10 WAE (Tables 11 and 12 respectively), no significant observations were made. Numerically, there was an increase in bean dry matter with increasing levels of N for inoculated plants at 8 WAE. Also, inoculation increased dry matter. Later, at 10 WAE, no significant observations or trends were observed.

TABLE 10 - Effect of Nitrogen Levels and Inoculation on Dry Matter (g/plant) of Bean Plants 6 Weeks After Emergence (Season 2)

	Nitrogen levels (kg N/ha)				
Inoculation	0	50	100	150	Means
Inoculated	5.3[ab]	3.0[c]	5.2[ab]	6.2[a]	4.9
Non-inoculated	5.3[ab]	5.0[ab]	4.5[b]	4.4[b]	4.8
Means	5.3	4.0	4.8	5.3	4.9

Means followed by the same letter/s are not significantly different at 5% level of probability according to Duncan's Multiple Range Test.

TABLE 11 - Effect of Nitrogen Levels and Inoculation on Dry Matter (g/plant) of Bean Plants 8 Weeks After Emergence (Season 2)

	Nitrogen levels (kg N/ha)				
Inoculation	0	50	100	150	Means
Inoculated	8.7	9.8	10.3	11.8	10.2
Non-inoculated	8.7	8.3	8.6	8.7	8.6
Means	8.8	9.0	9.5	10.3	9.4

TABLE 12 - Effect of Nitrogen Levels and Inoculation on Dry Matter (g/plant) of Bean Plants 10 Weeks After Emergence (Season 2)

	Nitrogen levels (kg N/ha)				
Inoculation	0	50	100	150	Means
Inoculated	14.7	14.1	15.7	17.3	15.5
Non-inoculated	15.2	15.1	14.5	18.6	15.9
Means	15.0	14.6	15.1	18.1	15.7

4.3 Effect of N levels and Inoculation on Grain Yield and Yield Components of Maize and Bean Plants

4.3.1 Maize Yield and Yield Components

4.3.1.1 Grain Yield

The interaction of N application and bean inoculation had a significant effect on maize yield in season 2 (Table 13). Maize grown in association with inoculated beans had significantly higher yields than maize where not inoculated at 0, 100 and 150 kg N/ha. For maize grown in association with inoculated beans, there was a yield increase with increasing N levels, though 100 and 150 kg gave yields that were statistically similar. For maize grown with non-inoculated beans, application of 50 kg N/ha increased yield significantly. Increasing N beyond this level had no further effect on yield. Maize grown in association with non-inoculated beans at 0 kg N/ha had the lowest yield among all treatments

In season 1, application of 100 kg N/ha increased yield significantly. Increasing N from 100 to 150 kg N/ha reduced yield significantly. Maize grown in association with inoculated beans had significantly higher yields than where beans were not inoculated.

TABLE 13 - Effect of Nitrogen Levels and Inoculation on Grain Yield (kg/ha) of Maize Plants

	Nitrogen levels (kg/ha)				
Inoculation	0	50	100	150	Means
		a) Season 1			
Inoculated	7324	7536	7723	7264	7462^{a}
Non-inoculated	6483	7441	7532	6300	6939^{b}
Means	6904^{bc}	7488^{ab}	7623^{a}	6782^{c}	7200
		b) Season 2			
Inoculated	7386^{c}	7859^{b}	8339^{a}	8547^{a}	8033
Non-inoculated	6937^{d}	7761^{b}	7917^{b}	7675b^{c}	7572
Means	7167	7810	8128	8111	7802

Means followed by the same letter/s are not significantly different at 5% probability according to Duncan's Multiple Range Test.

4.3.1.2 Yield Components

The interaction between N levels and inoculation has a significant effect on rows/cob of maize in season 1 (Table 16). The highest row numbers were where bean inoculation was combined with 100 kg N/ha. For maize grown in association with inoculated bean plants, application of 50 and 150 kg N/ha had no effect row numbers while 100 kg N/ha caused a significant increase. Where beans were not inoculated, application of 50 and 100 kg N/ha reduced maize row numbers significantly. These trends were absent in season 2. No significant effects were noted on other yield related parameters. Nitrogen levels, inoculation and their interaction had no significant effect on cob length (Tables 14), grain number (Tables 15) and seed weight (Tables 17). Though the smallest seeds were observed on application of 100 and 150 kg N/ha in season 1 and 2 respectively.

TABLE 14 - Effect of Nitrogen Levels and Inoculation on Cob-Length (cm) of Maize Plants

Inoculation	Nitrogen levels (kg N/ha) 0	50	100	150	Means
		a) Season 1			
Inoculated	18.2	17.6	18.4	18.3	18.1
Non-inoculated	16.9	18.1	18.0	16.8	17.5
Means	17.5	17.9	18.2	17.6	17.8
		b) Season 2			
Inoculated	19.4	18.4	17.4	18.5	18.5
Non-inoculated	17.4	19.6	17.0	18.3	18.1
Means	18.4	19.0	17.2	18.4	18.3

TABLE 17 - Effect of Nitrogen Levels and Inoculation on 100-Kernel Weight (g) of Maize Plants

Inoculation	Nitrogen levels (kg N/ha) 0	50	100	150	Means
a) Season 1					
Inoculated	47.3	47.0	44.7	47.0	46.5
Non-inoculated	47.3	45.3	41.0	46.7	44.6
Means	47.3	46.2	42.8	45.8	45.5
b) Season 2					
Inoculated	38.7	41.3	41.0	42.0	40.8
Non-inoculated	36.1	43.0	45.3	38.3	40.7
Means	37.4	4 2.2	43.2	40.2	40.7

TABLE 15 - Effect of Nitrogen Levels and Inoculation on Kernels per Maize Cob

	Nitrogen levels (kg N/ha)				
Inoculation	0	50	100	150	Means
		a) Season 1			
Inoculated	359	340	375	343	354
Non-inoculated	368	358	332	373	358
Means	364	349	354	358	356
		b) Season 2			
Inoculated	368	312	339	362	345
Non-inoculated	335	359	364	375	358
Means	351	335	352	368	352

TABLE 16 - Effect of Nitrogen Levels and Inoculation on Rows per Maize Cob

	Nitrogen levels (kg N/ha)				
Inoculation	0	50	100	150	Means
		a) Season 1			
Inoculated	11.7^{bc}	11.3^{c}	13.3^{a}	11.5^{bc}	12.0
Non-inoculated	12.4^{b}	11.2^{c}	10.9^{c}	12.4^{b}	11.7
Means	12.1	11.3	12.1	11.9	11.3
		b) Season 2			
Inoculated	11.7	11.3	11.5	11.7	11.6
Non-inoculated	11.6	12.0	11.5	8.7	11.0
Means	11.7	11.7	11.6	10.2	11.0

Means followed by the same letter/s are not significantly different at 5% probability level according to Duncan's Multiple Range Test

TABLE 17 - Effect of Nitrogen Levels and Inoculation on 100-Kernel Weight (g) of Maize Plants

	Nitrogen levels (kg N/ha)				
Inoculation	0	50	100	150	Means
		a) Season 1			
Inoculated	47.3	47.0	44.7	47.0	46.5
Non-inoculated	47.3	45.3	41.0	46.7	44.6
Means	47.3	46.2	42.8	45.8	45.5
		b) Season 2			
Inoculated	38.7	41.3	41.0	42.0	40.8
Non-inoculated	36.1	43.0	45.3	38.3	40.7
Means	37.4	4 2.2	43.2	40.2	40.7

4.3.2 Bean Yield and Yield Components

4.3.2.1 Grain Yield (kg/ha)

There was no interaction between N levels and bean inoculation on bean yield (Table 18). Still, similar trends were observed in both seasons. At 0 kg N/ha, inoculated beans exhibited lower yield by 6% and 20% in season 1 and 2 respectively, though these findings were not significant. With inoculation, yield increased with increasing levels of N. The highest yields observed were on application of 100 and 150 kg N/ha in season 1 and 2 respectively. The lowest yield in inoculated plants, in both seasons, was where no N was applied. This was the lowest among all treatments is season 2. Among the non-inoculated plants, yield declined with increasing levels of N in season 1. There was no notable trend in season 2. Nitrogen application had no significant effect on yield in both seasons. Inoculated beans had significantly higher yields in season 2. A similar non-significant observation was made in season 1.

TABLE 18 - Effect of Nitrogen Levels and Inoculation on Grain Yield (kg/ha) of Bean Plants

	Nitrogen levels (kg/ha)				
Inoculation	0	50	100	150	Means
		a) Season 1			
Inoculated	1006	1122	1347	1069	1136
Non-inoculated	1076	1068	1024	1001	1042
Means	1041	1095	1186	1035	1089
		b) Season 2			
Inoculated	369	395	438	441	410^{a}
Non-inoculated	399	345	388	408	384^{b}
Means	384	370	413	422	398

Means followed by the same letter/s are not significantly different at 5% probability according to Duncan's Multiple Range Test.

4.3.2.2 Yield Components

Pod number was not significantly affected by either N levels, inoculation or their interaction (Tables 19). Still, various observations were made. The highest number was on application of 50 kg N/ha in season 1 and 100 and 150 kg N/ha in season 2. Generally, inoculation increased pod number by one in both seasons. The lowest count, in both seasons, was on non-inoculated plants where no N was applied. Season 1 had higher pod number than season 2. The difference was five pods.

Nitrogen levels had no significant effect on seed numbers in both seasons (Tables 20). Though inoculation increased seed number in both seasons, the difference was significant in season 2 only. Interaction of N and inoculation had no significant effect.

Nitrogen and inoculation had no significant effect on seed weight in both seasons (Table 21), although it was noticed that nitrogen application increased seed weight with the one exception at 150 kg N/ha in season 1. Interaction of the two parameters was not significant, although the smallest seeds were observed in inoculated plants where no N was applied. Season 1 had higher seed size than season 2 by 16.1g.

TABLE 19- Effect of Nitrogen Levels and Inoculation on Pod number per Bean Plant

	Nitrogen levels (kg/ha)				
Inoculation	0	50	100	150	Means
		a)	Season 1		
Inoculated	13	17	15	15	15
Non-inoculated	12	17	13	13	14
Means	13	17	14	14	15
		b)	Season 2		
Inoculated	6	6	7	7	7
Non-inoculated	5	6	7	7	6
Means	6	6	7	7	7

TABLE 20 - Effect of Nitrogen Levels and Inoculation on Seeds per Pod of Bean Plants

Inoculation	Nitrogen levels (kg/ha) 0	50	100	150	Means
		a)	Season 1		
Inoculated	3.2	3.3	3.2	3.2	3.2
Non-inoculated	3.6	3.2	3.4	3.3	3.4
Means	3.4	3.3	3.3	3.3	3.3
		b)	Season 2		
Inoculated	3.1	3.5	3.2	3.4	3.3[a]
Non-inoculated	2.7	3.1	3.5	2.9	3.0[b]
Means	2.9	3.3	3.4	3.1	3.2

Means followed by the same letter/s are not significantly different at 5% probability according to Duncan's Multiple Range Test.

TABLE 21- Effect of Nitrogen Levels and Inoculation on 100-Seed Weight (g) of Bean plants

	Nitrogen levels (kg/ha)				
Inoculation	0	50	100	150	Means
		a) Season 1			
Inoculated	63.7	66.0	65.7	65.0	65.1
Non-inoculated	65.7	66.3	65.7	64.0	65.4
Means	64.7	66.2	65.7	64.5	65.3
		b) Season 2			
Inoculated	46.7	48.7	50.7	49.0	48.8
Non-inoculated	48.3	49.0	49.7	51.0	49.5
Means	47.5	48.8	50.2	50.0	49.2

CHAPTER FIVE

5.0 DISCUSSION

The Interaction of N and bean inoculation had a significant effect on maize grain yield in season 2. In the same season, inoculation of beans caused a significant increase on bean yield. This may have been because soil fertility was lower in season 2 (0.23% N) compared to season 1 (0.34% N).

Maize yield increases at 0, 100 and 150 Kg N/ha observed in treatments where beans were inoculated may be attributed to enhanced N fixation by introduced rhizobia. Initial maize growth, at all N levels, may have benefited from bean inoculation since N application was at 4 WAE when nodulation had already started. Later, application of N fertilizer and shading of beans by maize plants may have caused senescence by maize in the association.

Higher yields have been observed in cereals when grown in association with effectively nodulated legumes under conditions of low soil N. Nitrogen contribution from N rich legume root and nodule materials, to the soil in the root zone, may be substantial (Poth *et. al*, 1986). Legumes in mixed stands are generally less competitive for soil N than cereals (Danso, 1994). Sorghum grown with N fixing soybean had higher N yields than sorghum grown with non-fixing soybeans (Elmore and Jacobs, 1986). In studies by Eaglisham *et. al*, (1981), maize intercropped with cowpea had higher N content compared to monocropped maize. Similar results were observed in an experiment testing N transfer from nodulating soybean to maize or to non-nodulating soybean (Martin et. al, 1991).

The positive interaction between legume and cereal has also been attributed to other factors. In studies by Hamel *et. al*, (1991) on the effect of endomycorrhizal fungi in N transfer from soybean to maize, the extent of contact between roots was the most important factor observed. Transfer of carbon and phosphorus has also been demonstrated (Reid, 1990). Therefore, factors influencing root exudation, such as plant age, position on the root and the environment may favour N transfer (Whipps, 1990). It has also been observed that legume root exudates are usually more abundant than grass exudates (Ayo Ounfa, 1979). Hence, transfer may be down the N gradient as legumes are usually rich in N (Hamel *et. al*, 1991).

Experiments have shown that high N levels may reduce N fixation. Floor (1985) observed that high N levels inhibit nodulation. This may be through inhibition of attachment of rhizobia to root hair, abortion of infected thread, slowing of nodule growth, inhibition of fixation within the established nodules, and more rapid senescence of nodules (Noel *et. al*, 1982).

On fertilizer N application, bean nodule numbers did not respond significantly to bean inoculation, though yields of maize and beans improved when beans were inoculated. This implies that introduces rhizobia may be superior in N fixation through enhanced nodule activity (mg N fixed/nodule) and not nodule numbers. Hence, nodule numbers may not always be good indicators of N fixation. Pineda *et. al* (1994) carried out a maize/bean intercrop trial, in several sites, where four Rhizobium inoculant strains were evaluated. It was observed that both Rhizobium inoculated beans and uninoculated control plants had statistically similar nodule numbers. It was also noted that on inoculation, significant yield increases were noted more frequently in maize than beans. Work by Rennie and Dubetz (1986) also note that there may be significant increase in nodulation without corresponding yield increase, or significant yield increase without variation in nodulation.

Presence of effective nodules on roots of uninoculated bean plants suggested presence of indigenous *R. Leguminosarum bv. Phaseoli* rhizobia . Introduced and indigenous rhizobia seem to respond differently to N levels. At 0 Kg N/ha, at 8 WAE, in season1, introduction of rhizobia lowered nodule numbers. This implies that when N is limiting, introduced rhizobia may have caused a negative interaction with native rhizobia on nodulation.

Previous work has suggested that inoculation does not always enhance nodulation. In studies by Chui *et. al* (1984b), inoculation reduced nodulation at 50 DAP (Days After Planting). In other studies, inoculation had no effect on nodulation. Observations on cowpea field experiments showed no stimulation on nodulation by inoculation (Rotimi, 1972). Mulongoy (1985) suggested that this may be due to unnecessary inoculation of cultivars capable of effective nodulation with indigenous rhizobia,; the use, as inocula of strains having poor effectiveness, persistence, competitiveness or nodulating ability; uncontrolled environmental constraints. Rhizobia can persist for several years following applications (Parker et. al, 1977). Persistence is enhanced by repeated growth of the host legume in inoculated fields (Zuberer, 1990). It is possible that the persistence and establishment can be aided by non-host plants, (Robert and Schmidt, 1985).

Bean yield increased on inoculation but did not respond to N application despite low levels of available soil N. This indicates that N was limiting and enhanced N fixation, on inoculation, provided a substantial amount of N to meet plant requirements. Since application of N was later, when light was becoming a limiting factor to bean growth, maize, being taller benefited more. Studies carried out elsewhere in Kenya noted that maize yields were significantly affected by N levels but bean yields were not (Chui *et. al*, 1985; Kanampiu and Micheni, 1991).

In intercrops, if the intercropped non-legume is taller than the legume, shading will occur and photosynthesis and subsequent N fixation will be reduced (Trang and Giddens, 1980; Wahua and Miller, 1978a). The major effect of light on symbiotic N fixation is due to its effect on photosynthesis and thus to the supply of carbohydrates for the growth and functioning of the nodule (Lie, 1974). Nodulation can be accomplished in complete absence of light provided that enough carbohydrates are available (Lie, 1974). Excess shading, may lead to shedding of nodules (Butler and Bathurst, 1956). If the legume senesces well before the maize matures, some of the fixed N is taken up by the maize plant (Henzell and Vallis, 1976).

The effect of inoculation on bean yield was expressed through seed/pod. Due to differences in partitioning, mineral N and symbiotically fixed N may affect yield and its related parameters differently. Westermann *et. al*, (1984) studied N partitioning and mobilization patterns in bean plants. He observed that at early pod development 37% fixed N and 28% of N taken up was found in developing pod walls. At seed filling, 53% and14% of fixed N, and 31% and 2% of N taken up went to seeds and nodules respectively. In studies on soybean by Zapata *et. al* (1987), there was a greater contribution from fixed N (55%) than soil N (43%) in pod at physiological maturity.

Shading affects yield through its related parameters. Mann and Jaworski (1970) observed that pods per branch in soybeans were negatively affected by shading. Wood *et. al* (1979) also noted that seed yields and protein concentrations had an inverse relationship. This complicated further effect of N on yield and its related parameters.

Inoculation did no affect biomass significantly ($P<0.05$) for both crops at 10 WAE. This indicates that the crops may not have exhausted soil N by this time. Also, fixed N may still have been in bean nodules. Inoculation has been observed to either increase or decrease legume dry matter by various studies. Respiration associated with N fixation is considered to reduce the growth of N fixers relative to plants with access to mineral N (Brugge and Thornley, 1984) possibly because N fixation incurs an additional carbon usage (Schuberte and Ryle, 1980). Similar observations were made by Mahon and child, (1979). Plants without nodules, but with adequate nitrate N produced plants with larger tops and smaller roots (Mahon and Child, 1979). Other studies have quantified this cost. From the evidence obtained during the growth of a range of non-nodualting legumes supplied with nitrate as N source, the cost of N fixation was up to twice that when growing on nitrate (Ryle *et. al*, 1979; Pate *et. al*, 1979). In other studies, nodulating cultivars have been observed to have more biomass than non nodulating culativars

(Martin *et. al*, 1991). Pineda *et. al*, (1993) observed that though yields of maize and beans increased significantly when beans in the association were inoculated, biomass was not affected. This implies that dry matter may not indicate the benefits of maize/bean association.

The sites were different in the two seasons. They differed in soil fertility and this may have affected yields of both crops. An inverse relationship between maize and bean yield was observed. Maize yield was higher in season 2 (7568 Kg/ha) compared to season 1 (7101 Kg/ha) while bean yield was higher in season 1 (1089 Kg/ha) compared to season 2 (398 Kg/ha). CIAT (1986) made similar observations on maize/bean intercrop. This was described as compensation by willey (1979). He quoted experiments by Fisher (1976), where hail damage and disease lowered maize yields, but enhanced bean growth and yield.

Significant differences, in nodulation, were noted earlier in season 2 (6 WAE) compared to season 1 (8 WAE) possibly because of the lower soil available N (0.23N) in the season 2 compared to season 1 (0.34%N). Nodulation started earlier in season 2 possibly because of the lower soil N levels. Nodulation in N rich soil may be low possibly due to delay in formation of first nodule (Nutman, 1965). It has also been suggested that in highly fertile soils it is likely that the rhizosphere N fixation is reduced or abolished until nutrient depletion zones are established (Zuberer, 1990).

Yields, especially for maize, were exceptionally high. This may have been because control of diseases and pests was carried out throughout the growing period. The national average is about 1.5 tonnes/ha but some farmers in high potential areas can produce 7 tonnes/ha (Laboso *et. al*, 1994).

Most small-scale farmers, whose soils are poor, can improve production, of maize and bean intercrop, through inoculation of beans and N fertilizer use. Since the enhanced Biological N fixation cannot meet N requirements of both crops, application of some N is necessary. The best combination is bean inoculation combined with application of 100 kg N/ha. Where possible, the negative effects of shading, on bean nodulation, N fixation and growth should be minimized. This may be by planting beans before maize or intercropping maize with climbing beans. Early planting will also give more time for decomposition of nodules and root material to avail this to maize crop.

Recommendation for further Research

Maize yield was increased by inoculation of beans without apparent increase in N fixation. Since nodule numbers was the only indicator of N fixation used, there is need to consider other methods of detecting and measuring biological N fixation. Detailed laboratory studies need to be conducted to investigate any rhizospheral factors which may promote maize yield when grown in close proximity with beans.

The maize yields were exceptionally high. In such studies where intensive disease and insect pest control is carried out, there is need to include a control in which spraying is not carried out.

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APPENDIX 1: ANALYSIS OF VARIANCE TABLES

1. 1 Effect of Nitrogen levels and Inoculation on Bean Nodulation at 6WAE in Season 1

Source	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Prob
Replication	2	410.901	205.450	1.4568	0.2662
Nitrogen (N)	3	344.715	114.905	0.8148	
Inoculation (I)	1	2.667	2.667	0.0189	
N * I	3	32.497	10.832	0.0768	
Error	14	1974.379	141.027		
Total	23	2765.158			

Coefficient of Variation: 63.03%

1.2 Effect of Nitrogen levels and Inoculation on Bean Nodulation at 8WAE in Season 1

Source	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Prob
Replication	2	3070.083	1535.042	4.5506	0.0300
Nitrogen (N)	3	4100.792	1366.931	4.0522	0.0288
Inoculation (I)	1	30.375	30.375	0.0900	
N * I	3	4846.125	1615.375	4.7887	0.0169
Error	14	4722.583	337.327		
Total	23	16769.958			

Coefficient of Variation: 43.26%

APPENDIX 1 CONT.

1.3 Effect of Nitrogen levels and inoculation on Bean Nodulation at 10WAE in Season 1

Source	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Prob
Replication	2	276.083	138.042	5.0691	0.0221
Nitrogen (N)	3	233.458	77.819	2.8576	0.0748
Inoculation (I)	1	15.042	15.042	0.5523	
N * I	3	47.125	15.708	0.5768	
Error	14	381.250	27.232		
Total	23	952.958			

Coefficient of Variation: 140.72%

1.4 Effect of Nitrogen levels and Inoculation on Bean Nodulation at 4WAE in Season 2

Source	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Prob
Replication	2	61.750	30.875	0.1360	
Nitrogen (N)	3	230.792	76.931	0.3388	
Inoculation (I)	1	77.042	77.042	0.3393	
N * I	3	129.125	43.042	0.1896	
Error	14	3178.917	227.065		
Total	23	3677.625			

Coefficient of Variation: 31.81%

APPENDIX 1 CONT.

1.5 Effect of Nitrogen levels and Inoculation on Bean Nodulation at 6WAE in Season 2

Source	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Prob
Replication	2	497.333	248.667	1.4652	0.2644
Nitrogen (N)	3	6462.000	2154.000	12.6919	0.0003
Inoculation (I)	1	541.500	541.500	3.1907	0.0957
N * I	3	700.500	233.500	1.3758	0.2909
Error	14	2376.000	169.714		
Total	23	10577.333			

Coefficient of Variation: 21.65%

1.6 Effect of Nitrogen levels and Inoculation on Bean Nodulation at 8WAE in Season 2

Source	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Prob
Replication	2	12.250	6.125	0.3284	
Nitrogen (N)	3	541.458	180.486	9.6782	0.0010
Inoculation (I)	1	12.042	12.042	0.6457	
N * I	3	53.792	17.931	0.9615	
Error	14	261.083	18.649		
Total	23	880.625			

Coefficient of Variation: 62.81%

APPENDIX 1 CONT.

1.7 Effect of Nitrogen levels and Inoculation on Maize Dry Matter at 6WAE in Season 2

Source	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Prob
Replication	2	80.931	40.465	7.4755	0.0062
Nitrogen (N)	3	18.218	6.073	1.1219	0.3737
Inoculation (I)	1	5.134	5.134	0.9484	
N * I	3	59.735	19.912	3.6840	0.0383
Error	14	75.783	5.413		
Total	23	239.800			

Coefficient of Variation: 21.91%

1.8 Effect of Nitrogen levels and Inoculation on Maize Dry Matter at 8WAE in Season 2

Source	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Prob
Replication	2	578.410	289.205	7.8894	0.0051
Nitrogen (N)	3	5.648	1.883	0.0514	
Inoculation (I)	1	53.700	53.700	1.4649	0.2462
N * I	3	199.565	66.522	1.8147	0.1907
Error	14	513.203	36.657		
Total	3	1350.526			

Coefficient of Variation: 29.37%

1.9 Effect of Nitrogen levels and Inoculation on Maize Dry Matter at 10WAE in Season 2

Source	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Prob
Replication	2	4435.083	2217.542	10.2588	0.0018
Nitrogen (N)	3	1144.833	381.611	1.7654	0.1998
Inoculation (I)	1	140.167	140.167	0.6484	
N * I	3	189.500	63.167	0.2922	
Error	14	3026.250	216.161		
Total	23	8935.833			

Coefficient of Variation: 20.26%

1.10 Effect of Nitrogen levels and Inoculation on Bean Dry Mattet at 6WAE in Season 2

Source	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Prob
Replication	2	7.076	3.538	6.0080	0.0131
Nitrogen (N)	3	6.675	2.225	3.7784	0.0355
Inoculation (I)	1	0.060	0.060	0.1019	
N * I	3	11.183	3.728	6.3304	0.0062
Error	14	8.244	0.589		
Total	23	33.238			

Coefficient of Variation: 15.80%

APPENDIX 1 CONT

1.11 Effect of Nitrogen levels and Inoculation on Bean Dry Matter at 8WAE in Season 2

Source	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Prob
Replication	2	19.826	9.913	2.4829	10.1194
Nitrogen (N)	3	7.381	2.460	0.6163	
Inoculation (I)	1	14.570	14.570	3.6495	0.0768
N * I	3	7.928	2.643	0.6619	
Error	14	55.894	3.992		
Total	23	105.600			

Coefficient of Variation: 21.30%

1.12 Effect of Nitrogen levels and Inoculation on Bean Nodulation at 8WAE in Season 1

Source	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Prob
Replication	2	83.301	41.650	6.0243	0.0130
Nitrogen (N)	3	43.645	14.548	2.1042	0.1456
Inoculation (I)	1	0.920	0.920	0.1331	
N * I	3	5.921	1.974	0.2855	
Error	14	96.792	6.914		
Total	23	230.580			

Coefficient of Variation: 16.80%

APPENDIX 1 CONT.

1.13 Effect of Nitrogen levels and Inoculation on Maize Yield in Season 1

Source	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Prob
Replication	2	5860771.083	2930385.542	10.0951	0.0019
Nitrogen (N)	3	3169738.833	1056579.611	3.6399	0.0395
Inoculation (I)	1	1641174.000	1641174.000	5.6538	0.0322
N * I	3	882332.333	294110.778	1.0132	0.4162
Error	14	406389.583	290277.970		
Total	23	15617917.833			

Coefficient of Variation: 6.87%

1.14 Effect of Nitrogen levels and Inoculation on Maize Yield in Season 2

Source	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Prob
Replication	2	55520.333	27760.167	0.7301	
Nitrogen (N)	3	3672994.458	1224331.486	32.7070	0.0200
Inoculation (I)	1	1270980.375	1270980.375	33.4293	0.0130
N * I	3	453008.792	151002.931	3.9717	0.0306
Error	14	532279.000	38019.929		
Total	23	5984782.958			

Coefficient of Variation: 3%

APPENDIX 1 CONT

1.15 Effect of Nitrogen levels and Inoculation on % Maize Plants with Double Cobs in Season 1

Source	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Prob
Replication	2	2.156	1.078	0.217	
Nitrogen (N)	3	27.954	9.316	1.8643	0.1820
Inoculation (I)	1	7.594	7.594	1.5197	0.2380
N * I	3	104.695	34.898	6.9839	0.0042
Error	14	69.958	4.997		
Total	23	212.350			

Coefficient of Variation: 56.89%
LSD=3.915

1.16 Effect of Nitrogen levels and Inoculation on % Maize Plants with Double Cobs in Season 2

Source	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Prob
Replication	2	41.336	20.668	2.9422	0.0855
Nitrogen (N)	3	25.240	8.414	1.1999	0.3459
Inoculation (I)	1	2.407	2.407	0.3432	
N * I	3	3.610	1.203	0.1716	
Error	14	98.178	7.013		
Total	23	170.773			

Coefficient of Variation: 57.15%

1.17 Effect of Nitrogen levels and Inoculation on Maize Cob Length in Season 1

Source	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Prob
Replication	2	15.458	7.729	10.0661	0.0020
Nitrogen (N)	3	1.721	0.574	0.7473	
Inoculation (I)	1	2.600	2.600	3.3869	0.0870
N * I	3	3.758	1.253	1.6315	0.2271
Error	14	10.749	0.768		
Total	23	34.286			

Coefficient of Variation: 4.93%

1.18 Effect of Nitrogen levels and Inoculation on Maize Cob Length in Season 2

Source	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Prob
Replication	2	0.741	0.370	0.0776	
Nitrogen (N)	3	10.291	3.430	0.7190	
Inoculation (I)	1	0.920	0.920	0.1929	
N * I	3	7.555	2.518	0.5278	
Error	14	66.792	4.771		
Total	23	86.300			

Coefficient of Variation: 11.97%

1.19 Effect of Nitrogen levels and Inoculation on Maize Grains/Cob in Season 1

Source	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Prob
Replication	2	10204.750	5102.375	3.8624	0.0462
Nitrogen (N)	3	702.333	234.111	0.1772	
Inoculation (I)	1	73.500	73.500	0.0556	
N * I	3	596.833	1532.278	1.1599	0.3599
Error	14	18494.583	1321.042		
Total	23	34072.000			

Coefficient of Variation: 10.21%

1.20 Effect of Nitrogen levels and Inoculation on Maize Grains/Cob in Season 2

Source	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Prob
Replication	2	1128.250	564.125	0.1731	
Nitrogen (N)	3	3234.792	1078.264	0.3310	
Inoculation (I)	1	975.375	975.375	0.2994	
N * I	3	5124.125	1708.042	0.5242	
Error	14	45613.083	3258.077		
Total	23	56075.625			

Coefficient of Variation: 16.23%

APPENDIX 1 CONT

1.21 Effect of Nitrogen levels and Inoculation on Maize Rows/Cob in Season 1

Source	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Prob.
Replication	2	3.640	1.820	7.0517	0.0076
Nitrogen (N)	3	2.847	0.949	3.6765	0.0384
Inoculation (I)	1	0.327	0.327	1.2657	0.2795
N * I	3	10.313	3.438	13.3198	0.0002
Error	14	3.613	0.258		
Total	23	20.740			

Coefficient of Variation: 4.29%

1.22 Effect of Nitrogen levels and Inoculation on Maize Rows/Cob in Season 2

Source	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Prob
Replication	2	4.173	2.087	0.4132	
Nitrogen (N)	3	9.407	3.136	0.6208	
Inoculation (I)	1	1.927	1.927	0.3815	
N * I	3	12.980	4.327	0.8567	
Error	14	70.707	5.050		
Total	23	99.193			

Coefficient of Variation: 19.92%

1.23 Effect of Nitrogen levels and Inoculation on Maize 100 Seed Weight in Season 1

Source	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Prob
Replication	2	1.083	0.542	0.0412	
Nitrogen (N)	3	66.125	22.042	1.6748	0.2179
Inoculation (I)	1	22.042	22.042	1.6748	0.2166
N * I	3	10.458	3.486	0.2649	
Error	14	184.250	13.161		
Total	23	283.958			

Coefficient of Variation: 7.9 %

1.24 Effect of Nitrogen levels and Inoculation on Maize 100 Seed Weight in Season 2

Source	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Prob
Replication	2	24.646	12.323	1.0281	0.3832
Nitrogen (N)	3	115.781	38.594	3.2200	0.0553
Inoculation (I)	1	0.020	0.020	0.0017	
N * I	3	62.361	20.787	1.7343	0.2058
Error	14	167.801	11.986		
Total	23	370.610			

Coefficient of Variation: 8.50%

APPENDIX 1 CONT

1.25 Effect of Nitrogen levels and Inoculation on Bean Yield in Season 1

Source	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Prob
Replication	2	139125.583	69562.792	2.4016	0.1268
Nitrogen (N)	3	87397.500	29132.500	1.0058	0.4193
Inoculation (I)	1	52640.667	52640.667	1.8174	0.1990
N * I	3	22707.667	40902.556	1.4121	0.2808
Error	14	405508.417	28964.887		
Total	23	807379.833			

Coefficient of Variation: 15.63%

1.26 Effect of Nitrogen levels and Inoculation on Bean Yield in Season 2

Source	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Prob.
Replication	2	9096.583	4548.292	4.361	0.0337
Nitrogen (N)	3	10776.833	3592.278	3.444	0.0612
Inoculation (I)	1	4320.167	4320.167	4.142	0.0461
N * I	3	2225.389	2225.289	2.134	0.1418
Error	14	14602.084	1043.006		
Total	23	45471.833			

Coefficient of Variation: 27.94%

APPENDIX 1 CONT

1.27 Effect of Nitrogen levels and Inoculation on Beans Pods/Plant in Season 1

Source	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Prob
Replication	2	4.368	2.184	0.2832	
Nitrogen (N)	3	54.375	18.125	2.3507	0.1165
Inoculation (I)	1	8.882	8.882	1.1519	0.3013
N * I	3	3.075	1.025	0.1329	
Error	14	107.946	7.710		
Total	23	178.645			

Coefficient of Variation: 19.59%

1.28 Effect of Nitrogen levels and Inoculation on Bean Pods/Plant in Season 2

Source	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Prob
Replication	2	4.423	2.212	3.6964	0.0514
Nitrogen (N)	3	5.507	1.836	3.0678	0.0627
Inoculation (I)	1	0.007	0.007	0.0111	
N * I	3	2.940	0.980	1.6379	0.2257
Error	14	8.377	0.598		
Total	23	21.253			

Coefficient of Variation: 11.96%

1.29 Effect of Nitrogen levels and Inoculation on Bean Seeds/Pod in Season 1

Source	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Prob
Replication	2	0.206	0.103	1.6868	0.2206
Nitrogen (N)	3	0.041	0.014	0.2254	
Inoculation (I)	1	0.150	0.150	2.4654	0.1387
N * I	3	0.198	0.066	1.0813	0.3890
Error	14	0.854	0.061		
Total	23	1.450			

Coefficient of Variation:7.48%

1.30 Effect of Nitrogen levels and Inoculation on Bean Seeds/Pod in Season 2

Source	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Prob
Replication	2	0.007	0.004	0.0469	
Nitrogen (N)	3	0.768	0.256	3.2038	0.0560
Inoculation (I)	1	0.427	0.427	5.3373	0.0366
N * I	3	0.663	0.221	2.7659	0.0809
Error	14	1.119	0.080		
Total	23	2.985			

Coefficient of Variation: 8.91%

APPENDIX 1 CONT

1.31 Effect of Nitrogen levels and Inoculation on Bean 100 Seed Weight in Season 1

Source	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Prob
Replication	2	185.250	92.625	16.6084	0.000
Nitrogen (N)	3	11.500	3.833	0.6873	
Inoculation (I)	1	0.667	0.667	0.1195	
N * I	3	7.000	2.333	0.4184	
Error	14	78.083	5.577		
Total	23	282.500			

Coefficient of Variation: 3.62%

1.32 Effect of Nitrogen levels and Inoculation on Bean 100 Seed Weight in Season 2

Source	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Prob
Replication	2	32.250	16.125	2.717	0.101
Nitrogen (N)	3	27.458	9.153	1.542	0.248
Inoculation (I)	1	3.375	3.375	0.569	
N * I	3	8.458	2.819	0.475	
Error	14	83.083	5.935		
Total	23	154.625			

Coefficient of Variation: 4.96%

APPENDIX 2

SOIL FERTILITY ANALYSIS RESULTS FOR KABETE FIELD STATION

Nutrient	Site 1	Site 2
pH (H_2O)	5.30	5.40
Na m. e. %	-	0.36
K m. e. %	-	0.55
Ca m. e. %	-	3.20
Mg m. e. %	-	3.07
Mn m. e. %	-	0.74
P. p. p. m	28.50	18.00
Total N (%)	0.34	0.23
Fe p. p. m.	-	49.97
Cu p. p. m.	-	5.50
Zn p. p. m.	-	35.90

APPENDIX 3

WEATHER SUMMARY FOR KABETE FIELD STATION FOR THE PERIOD 1996-1997

Month		Temperature		Rainfall		Evaporation	Mean Radiation
		Max. (°C)	Min.(°C)	Amount (mm)	No. of days	(mm)	(lang-leys/day)
96	Jan	24.3	13.1	12.9	5	164.3	164.3
	Feb	25.9	13.8	36.4	3	168.3	168.3
	Mar	25.3	14.7	110.1	13	174.8	174.8
	Apr	23.7	14.4	91.1	11	119.5	119.5
	May	22.4	14.2	89.3	18	99.5	99.5
	Jun	26.7	12.8	51.2	10	70.2	70.2
	Jul	20.0	11.1	35.6	6	85.2	85.2
	Aug	21.5	10.3	36.6	3	101.4	101.4
	Sep	23.6	11.9	37.0	3	131.0	131.0
	Oct	24.9	13.0	1.3	1	183.0	183.0
	Nov	22.1	13.8	209.7	23	99.6	99.6
	Dec	23.6	13.1	2.6	1	178.1	178.1
97	Jan	25.6	13.3	4.7	2	212.8	212.8
	Feb	28.0	12.8	0.0	0	225.9	225.9