THE EFFECTS OF NITROGEN FERTILIZATION, BEAN RESIDUE, AND MAIZE-BEAN CROPPING SYSTEMS ON NUTRIENT UPTAKE, YIELDS AND SOIL CHEMICAL PROPERTIES IN A SEMI-ARID AREA

BY

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DEDICATED TO:

1) **MY LATE FATHER, JOHN CHUI GITITI**
2) **MY LATE MOTHER, HANNAH WAITHIRA CHUI**
3) **MY LATE DAUGHTER, HANNAH WAITHIRA NJUGUNA**

The above three past away during the time of my study.

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DECLARATION:

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

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July 15th 1994 Date

This thesis has been submitted for examination with my approval as Main University supervisor.

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ABSTRACT

Nitrogen fertilizers have assumed a prominent role in the cultivation of maize especially in pure stands in Kenya. However, knowledge on N utilization in the maize - legume cropping systems which are commonly used in Kenya is lacking.

A field study was therefore conducted between 1987 and 1990 at two sites, Kimutwa and Masii in Machakos District, a semi-arid region in Eastern Province of Kenya to determine the effects of N, bean residue and maize-bean cropping systems on nutrient uptake, yields and soil chemical properties. Soil types used were sandy clay loam (dystric Nitisol) for Kimutwa and sand (Acrisol) for Masii. A split-plot design was used in which N levels (0, 25, 50 and 100 kg N/ha) formed the main-plots and cropping systems formed the sub-plots. Single superphosphate at 40 kg P_2O_5/ha was applied uniformly to all plots.

Fertilizer N significantly increased dry matter yields, yield components, seed yields and uptake of N, P, K, Mg and Ca by maize and beans in sole, intercropping and rotation systems and also improved growth and development of maize in the three cropping systems. Response to N by both crops depended on cropping system, site and season. Bean response to N occurred where soil mineral N prior to planting was 18 and 23 ug N/g or below on the Acrisol and dystric Nitisol, respectively. For maize, response occurred where mineral N was 36 and 60 ug N/g or below on the two soil types, respectively. Generally, the highest response to N by both crops in continuous sole cropping, rotation and those intercropped in the alternate rows was at 50 kg N/ha while that of crops intercropped in the same row was at 100 kg N/ha. Regression analysis indicated that cropping systems with highest response to N at 50 kg N/ha could respond to N rate of 75 kg N/ha while crops intercropped in the same rows could have maximum response at either 75 or 100 kg N/ha depending on the season and site. Effects of nitrogen rates of 50 and 100 kg N/ha were often not significantly different, and therefore, 50 kg N/ha could be used for the production of both crops. But, 25 kg N/ha rate was not adequate although it was better than zero N.

Intercropping was a superior cropping system in both low and high input agriculture with respect to land equivalent ratio (LER) and total grain yields, respectively. Fertilizer N improved soil total N, maintained organic C and increased residual mineral N which consequently improved dry matter, seed yield and nutrient uptake of a test sole maize. Residual mineral N and uptake of nutrients by a test sole maize were higher in plots previously under continuous beans than continuous sole maize at both sites; higher in intercropping and rotation than in continuous sole maize in Masii while the reverse was true in Kimutwa. However, N lowered soil pH, CEC and resulted in greater depletion of soil extractable P and exchangeable K, Mg and Ca relative to zero N treatments. The levels of these chemical properties in the soil were influenced by cropping systems.

Competition between maize and bean intercrops was manifested as early as 20 days after seedling emergence upto maturity, through reduction of total dry matter, growth and development, yield components, seed yield, nutrient uptake and response to N by the intercrops. Intercropping systems, however, resulted in high LERs of 51-176% on average, which depended on bean spatial arrangements and site. Competition was influenced by bean spatial arrangements and generally, the same row intercrops individually or combined out performed those in alternate rows. Rotation benefited both crops, improved maize response to N and had a supplementary effect to N fertilizer on maize of an equivalent of 1-56 kg N/ha fertilizer. Bean residue returned to plots had negative effects on beans but improved LERs, maize yields, response to N by maize in rotation and that in the same row while the effect on nutrient uptake by maize was either positive or negative depending on cropping system, season and site. The returned bean residue also lowered soil pH, extractable P, exchangeable K, Mg, and Ca; it had no effect on total N but had effects on mineral N which were seasonal and dependent on the site. In Masii, soil pH, organic C, mineral N, exchangeable K, Mg and Ca had positive relationships and significant correlations with total N uptake and total grain yield. In Kimutwa, there were negative correlations between soil pH and extractable P, total N uptake and total grain yield. In Kimutwa, positive correlations were found between total grain yield and organic C and N uptake; between mineral N and exchangeable Mg and Ca; and between exchangeable Mg and total grain yield.

CHAPTER I

INTRODUCTION

Nitrogen is an essential nutrient element for plants and is therefore needed in adequate supply for the normal development of crops. However, nitrogen is the most universally deficient nutrient element of the cultivated soils (Jones, 1982), the element that most frequently limits yields in the tropics (Sanchez, 1976) and generally the first element to become deficient in semi-arid and arid regions (Hagin and Tucker, 1982). Nitrogen therefore occupies a unique position among the major nutrients because it occurs in small amounts ranging from 0.02 to 0.4% by weight in the plough layer of the majority of cultivated soils and yet it is required in large quantities by crops (Black, 1968).

In traditional agriculture which was characterized by low population, the restoration of soil fertility was achieved through shifting cultivation and bush fallow systems (Nye and Greenland, 1960; Okigbo, 1975).

In Kenya, the maintenance of soil fertility prior to the 1940s was dependent very largely on the shifting cultivation practices (Graham, 1941). But in later years, the tremendous increase in human population (East African Economic and Statistical Bulletin, 1949; Jaetzold and Schmidt, 1983), caused a very high demand for land. In Machakos District alone, where the present study was conducted, the census of 1979 indicated that a population of 920,270 lived on 1,127,000 ha of arable land giving an area of 1.23 ha per person. Hence, shifting cultivation can no longer support this population pressure and maintain soil fertility in this region because a 13 ha land would be needed for one person under such a system (Nye and Greenland, 1960). The realization of the low level of soil nitrogen in Eastern Kenya (Ikombo, 1984) and in most soils of the agricultural lands in Kenya (Jaetzold and Schmidt, 1983), has led to the use of commercial N fertilizers.

Bellis and Boswinkle (1953-1962) showed marked crop responses to applied N fertilizers in Central Kenya.

In Machakos District, the low level of soil N coupled with the growing of maize as a staple food crop, could result in the impoverishment of the soil thus leading to very low crop production. Growing of maize continuously without the addition of manurial or commercial fertilizers has been found to result in a large depletion of nitrogen and phosphorus (Drysdale, 1965) and reduction of organic matter (Martel and Mackenzie, 1980). In this situation where soil is low in N, the use of commercial N fertilizers becomes very necessary. This is because N has been found to be an important nutrient for maize production where soil N is not adequate (Vine, 1953; Laycock and Allan, 1976). Unfortunately, the small scale farmers who are the majority in Machakos District quite often do not use N fertilizers in maize production (Jaetzold and Schmidt, 1983). This is probably due to the prohibitively high prices of N fertilizers. The high prices of fertilizers calls for a serious search for cheaper sources of N that can be used to supplement commercial N fertilizer in maize production.

One alternate source of N is farmyard manure (Cooke,1967) which unfortunately is not available in quantities sufficient for the farmers in the semi-arid region of Machakos District. Hence, there is need to have well-planned cropping systems which would include legumes which are known to fix N thereby increasing soil fertility and consequently supplementing the required N by succeeding cereal crops (Hesterman et al., 1986 ; MacColl, 1990; Ladd et al., 1983; Blevins et al., 1990; Bruulsema and Christie, 1987). Subsistence farmers in Machakos District, however, do not normally grow forage crops which have the highest N contribution to cereal crops. Also, these farmers do not usually practice sole grain legume-maize rotations probably because of the need to harvest their staple maize crop every season. Hence, data of experiments on rotations between sole grain-legumes and maize grown in this region are scarce and therefore a study to establish the contribution of the grain legumes to N fertilizer in maize production is necessary. The most common cropping system in Machakos District is the intercropping of maize and legumes (Rukandema, 1981). Intercropping, the growing of two or more species simultaneously on the same unit of land, intensifies cropping both in time and space dimensions. Its importance in developing countries is demonstrated by the high percentage of cereals and legumes allocated to mixtures (Santa-Cecilia and Vieira, 1978; Arnon, 1972) and by its social and agronomic advantages over the monoculture cropping (Harwood and Price, 1976; Andrews and Kassam, 1976; Auckland 1970; Ruthenburg, 1971; Swindale, 1981). With the maize-legume system, the usual goal is full production of the maize plus whatever the associated legume may give.

Subsistence farmers in Machakos District intercrop maize with grain legumes such as beans (Phaseolus vulgaris L.), cowpeas (Vigna unguiculata (L.) Walp.), and pigeon peas (Cajanus cajan L.). Legumes intercropped with cereals have been found to benefit the cereal crops (Francis,et al. 1976; Waghmare and Singh, 1984; Mallarino et al, 1990; Henzell and Vallis, 1977; Agboola and Fayemi, 1972). A problem that might arise in the intercropping of maize and a legume is that of competition for soil nitrogen (Hardter, 1989). This is because maize has a high demand for N for its growth (Voss, 1970) and dry matter production (Mackenzie and Kirby, 1969) while legumes are known to rely on inorganic N early in the season in order to obtain early growth and maximum yield (Dart et al., 1977). Also, legumes when intercropped with cereals have resulted in their N fixing capacity reduced (Wahua and Miller, 1978) and this may cause a higher demand for soil N than when planted as a sole crop. However, Searle et al. (1981) found that N uptake by wheat (Triticum aetivum L.) following maize-soybean (Glycine max (L) Merr.) and maize-groundnut (Arachis hypogea L.) intercrops without N fertilizer was substantially improved. The evaluation of the role of legume residue obtained from a maize-legume intercropping system on a succeeding maize intercrop in Kenya is scarce and deserves some study in order to elucidate on this fertility aspect in a region with deficient soil N and intercropping of maize and legumes predominates crop production practices.

There is less work done to compare N uptake of maize in sole, rotation and intercropping systems and the interaction of chemical N fertilizer and bean residue returned in order to establish whether there exists a supplementary effect from bean residue to fertilizer N or whether maize might require more N fertilizer when bean residue is returned. This is because considerable amounts of inorganic N fertilizers are rendered unavailable by biological immobilization when organic plant materials are added to soil (Agarwal, et al. 1972; Allison and Klein, 1962).

Beans in monoculture systems are reported to fix N ranging from 12.2 to 73.7 kg N/ha (CIAT, 1977). But, shading of beans by a maize intercrop might result in the reduction of N fixing potential (Graham and Rosas, 1978). In order to alleviate such a negative interaction of the two crop species, a factor of major importance in the performance of intercrops is their spatial arrangement (Dalal, 1977; Mohta and de, 1980; Chui and Shibles, 1984). This is because it affects edaphic interactions (Cable 1969; Trenbath, 1975) but more so, light penetration into the canopies of both the taller and shorter components (Searle et al, 1981). In order to reduce the competition between component species, selection of crops of widely different growth habits, proper manipulation of spatial arrangements and supplying nutrients to the intercrops have been tried.

The question of intimacy is pertinent where legume contribution to the cereal crop is desired because mingling of legume roots with that of cereals has been found to have beneficial effects (Trenbath, 1976). Also, where legume residue production is desired as in the case of the present study, light penetration into the canopy of the shorter crop is indispensable and so the importance of spatial arrangements. The maize-bean spatial arrangements would help us to understand whether maize would compete differently for N fertilizer with beans planted at different intimacies and whether beans would respond to applied N fertilizer differently.

Application of N to cereal-legume intercrops might present some problems because a maize crop requires heavy N applications for maximum grain yield (Beets, 1978) while such level would decrease symbiotic N fixation of a legume (Bezdicek et al., 1974). Although beans were found to respond to N fertilizer amounting to 80 kg N/ha in Kenya (Keya et al., 1982), the amount that would satisfy maize and beans in an intercropping system is not yet clear. The present study is aimed at elucidating this aspect since information is lacking.

Soil pH is a well known factor that influences plant growth. Soil acidity affects crop yields throughout the world as a result of its influence on nutrient availability (Russell, 1973), toxicity of some elements like aluminium (Sanchez, 1976) and detrimental effects on growth of many beneficial bacteria (Tisdale et al., 1985). On the other hand, high alkalinity reduces the availability of all trace elements except molybdenum (Thomas and Hanway, 1968). Since N fertilizers containing ammonium ion (Pierre, 1928) and decomposition of soil organic matter (Mengel and Kirkby, 1987) contribute to soil acidity, it is not known to what extent the calcium ammonium nitrate fertilizer used would acidify the sandy soil of the study area. Heavy use of N fertilizers has been found to lower pH of soils even those with high exchange capacity, at a rapid rate (Kurtz and Smith, 1967). Also, it is of great interest to understand how different cropping systems and bean residue returned to the soil would interact with N fertilizer in its effect on soil acidification.

Soil organic matter and cation exchange capacity (CEC) are two vital soil factors that contribute to soil fertility. Their effects are influenced by soil texture with clay soils giving higher values of each factor than sandy soils (Brady, 1974; Jenny, 1980). Addition of crop residue may maintain soil organic matter (Kononova, 1961) or might immobilize the available soil N (Kimber, 1973). Also, crop residue addition would improve soil CEC since the amount of CEC is determined partly by humified organic matter (Jones, 1982). Hence, in the present study, the extent to which bean residue returned to the soil would affect these two soil factors will be investigated.

Nitrogen fertilizer application has been shown to increase both soil and phosphate fertilizer availability and uptake by plants (Krantz and Chandler, 1951). The effect of N fertilizer on P uptake of maize is of interest in a maize-bean mixture since P is more limiting than N for tropical legumes (Loneragan, 1972). Also, the influence of N fertilizer on the uptake of K, Ca and Mg by maize in crop mixtures is rarely studied and should be of concern where a complex cropping system of maize and beans may result in competition for soil available nutrients.

Maize and beans are staple food crops in the semi-arid region of Eastern Province of Kenya. Maize is sometimes grown as a monoculture but usually it is grown as an intercrop with grain legumes particularly Phaseolus beans. In this semi-arid region, it is commonly observed that maize seed yields are very low due to low level of soil N, depressive effects of the competitive legume intercrops and insufficient rainfall. In the current study, it is hypothesized that the application of N fertilizer would improve performance of maize and beans in sole and mixtures and bean residue and its rotation with maize would have supplementary effect on N fertilizer in maize production. Furthermore, spatial arrangements of both crop species,that is, planting of maize and beans in the same or alternate row would alter their competition and it is anticipated that planting both crops at reduced intimacy (alternate rows) would result in maize taking up more N and other major nutrients thus resulting in higher seed yields than when both crops were planted at increased intimacy (same row). Also, application of calcium ammonium nitrate fertilizer and return of bean residue are expected to affect some soil chemical properties that would consequently affect the production of maize. These hypotheses were tested in two rainfall regimes, the long and short rainy seasons.

Objectives:

1. To determine the effect of nitrogen fertilizer (calcium ammonium nitrate - CAN) on maize and bean yields in different maize-bean cropping systems.
2. To determine the effect of nitrogen fertilizer on the uptake of N, P, K, Ca and Mg by maize and beans in different maize-bean cropping systems.
3. To assess the effects of bean residue and spatial arrangements of beans on maize and bean performance.
4. To determine the effects of residual N fertilizer and different maize-bean cropping systems on a succeeding sole maize production.
5. To evaluate the effects of CAN applied singly or with bean residue to maize or bean in sole cropping, rotation or maize - bean intercropping systems on the following soil chemical properties:
    - (i) Soil organic carbon
    - (ii) Soil pH
    - (iii) Cation exchange capacity and
    - (iv) Nitrogen, phosphorus, potassium, magnesium and calcium.

CHAPTER II

REVIEW OF LITERATURE

2.1 Source of nitrogen in soil:

The primary source of soil nitrogen is the atmosphere where the strongly bonded gaseous molecule N_2 is the predominant gas making up 79.08 per cent by volume of the gases (Stevenson, 1965). Soil nitrogen originates from several sources. Under natural conditions, two mechanisms considered important in the N cycle are the fixation of elemental N by biological agents (Fogg, 1947; Tchan, 1953; MacConnell and Bond, 1957; Allen and Allen, 1958) and the accession of ammonia and nitrate in rain water (Erikson, 1952). Another important source of soil nitrogen is that of nitrogen fertilizers either in mineral or organic form. Hence, various ways through which the available nitrogen would be supplied to the soil are organic matter, mineralization, symbiotic and nonsymbiotic N fixation, rainfall and fertilizer additions (Scarsbrook, 1965). The total nitrogen content of soil ranges from less than 0.02% in subsoils to more than 2.5% in peats. T he ploughed layer of most cultivated soils contains between 0.08 and 0.5% nitrogen (Bremner, 1965a; Brady 1990). The amount of nitrogen present in a particular soil is determined by several factors, including climate, topography, type of vegetation, parent material and activities of man (Jenny, 1941; Aandahl, 1949; Ensminger and Pearson, 1950; Jenny and Raychaudhuri, 1960).

2.2 **Forms of nitrogen in soil:** Nitrogen in the soil falls into three major categories viz, organic-N, inorganic-N and gaseous-N. Most of the nitrogen in normal soils is in the organic form and only a small percent is in the inorganic form (Harmsen and Kolenbrander, 1965; Bremner, 1965b). The relation between these two forms of N is that inorganic N is continuously formed from the organic N by mineralization processes and some inorganic N is transformed to organically bound form by soil microbes. Gaseous form of elemental nitrogen (N_2) is found in the soil atmosphere, in dissolved form in the soil water and in adsorbed form on the solid surfaces in dry soils. This gaseous form of nitrogen is of direct significance to plants that form symbiotic association with nitrogen-fixing microorganisms (Black, 1968).

2.2.1 **Organic nitrogen in soils:** Nitrogen in soils is mostly in the organic form and is associated with the organic matter of soils (Lyon and Buckman, 1922). Present knowledge indicates that well over 90% of total N in most surface soils is organically combined. Soil organic nitrogen contains amino acids, amino-sugars and traces of other nitrogenous organic compounds (Bremner, 1965a, 1965c) comprising more than 40% of the organic N in most surface soils. Organic nitrogen in soils is not directly available to plants until the organic nitrogenous compounds are decomposed to release the inorganic forms. Interestingly, the organic N in the soil resists microbial attack and is changed to inorganic forms at the rate of less than 2% to as high as 10% per year (Bartholomew and Kirkham, 1960; Black, 1968). However, the organic nitrogenous substances in the soil are the potential reserve of N for nutrition of plants.

Some organic N may be available to plants. The undecomposed urea molecule for example can be absorbed intact by the roots or leaves of plants (Scarsbrook, 1965). Soil organic matter contains 30 to 50% of its nitrogen as amino nitrogen (Stevenson, 1956). However, the quantities present in the soil as free amino acids are small (Sowden and Parker, 1953; Paul and Schmidt, 1961). Although free amino acids are available to plants (Ghosh and Burvis, 1950; Miettinen, 1959) the quantities present are a relatively unimportant source of N because of the rapidity of ammonification and nitrification in most soils.

2.2.2 Inorganic nitrogen in soil: Inorganic form of nitrogen constitutes a small fraction of soil nitrogen (Harmsen and Kolenbrander, 1965) and is usually less than 5 per cent of total soil nitrogen (Barber, 1984). Inorganic N in the soil occurs mainly as ammonium, NH_4^+ and nitrate, NO_3^-, and in some soils with high pH, small amounts of nitrite, NO_2^-, may occur (Black, 1968; Barber, 1984). These three forms are ionic and are found in the soil solution. Nitrite and nitrate occur exclusively or almost exclusively as freely diffusible ions in the soil solution whereas most of the NH_4^+ occurs in exchangeable and nonexchangeable form (Black, 1968). The ratio of NH_4^+ to NO_3^- found in the soil depends on the presence of satisfactory conditions for nitrification; nitrification is inhibited by low soil pH and anaerobic conditions (Barber, 1984). Although these forms account for a small proportion of the total N, they are very important from the standpoint of crop growth because they are the immediately available forms utilized by crops.

Inorganic N contents in the soil vary markedly among soils and between seasons of the year for the same soil. This is attributed to the fact that N mineralization rates depend on temperature, soil pH, clay mineralogy (Soil structure), moisture, C:N ratios, cropping systems, soil texture, recent additions of organic matter, season of the year and fertilizers (Cornfield, 1952; Harmsen and Schreven, 1955; Pritchell et al., 1959). In tropical and subtropical as well as in temperate regions, the fluctuations of the content of inorganic nitrogen follow the sequence of the dry and wet periods (Harmsen and Kolenbrander, 1965). Nitrogen mineralization is faster under alternate wetting and drying than under optimum moisture conditions. Trying to explain this phenomenon, Birch (1960) indicated that drying reduced C:N ratios and the active microbial populations build up rapidly when moisture becomes available and they find abundant decomposable substrate and together with dead microbial populations provide additional substrate which stimulate mineralization further. Also, during dry conditions, nitrification takes place in the subsoil and nitrates move upward with capillary conductivity and accumulate in the topsoil and within a few days after the first heavy rains, dramatic increases in inorganic nitrogen take place (Wetselaar, 1961; Semb and Robinson, 1969).

Nitrogen fertilizers form an important inorganic source of N. Nitrogen from most of the commonly applied inorganic sources such as ammonia, ammonium nitrate, ammonium sulphate, calcium nitrate, sodium nitrate, potassium nitrate and ammonium phosphates quickly becomes a part of the soil solution or the cation exchange complex when applied to most soils (Scarsbrook, 1965). Accordingly, when applied in the plant root zone, N from these sources may be considered as available immediately after application, except when added to extremely dry soil.

2.3 **Nitrogen transformations in the soil:** There are two opposing processes that occur continuously and simultaneously in most systems where organic debris is undergoing microbiological decomposition (Bartholomew, 1965). Mineralization, the microbiological transformation of the organic nitrogen to inorganic ammonium and nitrate ions, renders the nitrogen mobile and available. The reverse process, immobilization, is also a microbiological process in which microorganisms use inorganic nitrogen in the synthesis of cell tissue thus converting inorganic nitrogen to organic form during decomposition, a form which is somewhat resistant to further biological degradation.

2.3.1 **Mineralization:** The microbiological processes that take place in the transformation and the formation of mineral N in aerobic soils follow the order:

Organic - N ---> ammonium - N (NH_4^+) ---> Nitrite - N (NO_2^-)----> nitrate-N (NO_3^-).

The transformation of organic-N to ammonium-N, that is, ammonification, is effected by nonspecialized organisms and this is the rate-controlling step in the over-all process. The oxidation of ammonium to nitrite and nitrite to nitrate, that is, nitrification is carried out by specialized autotrophic organisms, namely, nitrosomonas and nitrobacter respectively. Ammonium and nitrite usually do not accumulate in labile form but are converted to nitrate, which is the principal form of inorganic N absorbed by plants. Mineralization of organic N is possible only when the biological environment is favourable. Thus, release of mineral N from organic-N would be influenced by the relative availability of carbonaceous (energy source) and nitrogenous (microbial tissue) food material for the microorganisms, hence, the importance of C:N ratio in the organic material. Another way of expressing the composition of organic materials in relation to their effects on N mineralization is the use of N percentage. Harmsen and Van Schreven (1955) who reviewed literature on this subject indicated that in most instances the critical ratio of carbon to nitrogen lies between 15 and 33 and the critical N percentage lies between 1.2 and 2.6. Thus, materials with C:N ratio below the critical value and with N percentage above the critical value may be expected to result in net mineralization of N in the soil and hence to supply N to plants grown on the soil. Young plants usually contain a higher percentage of N than older plants and when worked into the soil they decompose more rapidly and release available N much sooner than more mature crop residues (Waksman, 1942). However, the use of N percentage and C:N ratio as guides to the properties of organic materials that affect N mineralization should be taken with caution because there are some differences in their susceptibility to decomposition that are not taken into consideration by these values. There is some evidence that with a given C:N ratio, N mineralization decreases with increasing content of lignin in the material (Peevy and

Norman, 1948) and with decreasing content of water-soluble nitrogen (Iritani and Arnold, 1960).

Another factor of importance in mineralization of organic substances is the soil pH. The soil pH has no effect on ammonification due to the diverse organisms that affect this transformation and a change in nature of the soil population with change in soil pH merely substitutes one group of organisms for a somewhat different group that does the same thing (Black, 1968). But, transformation of NH_4^+ to NO_2^- and of NO_2^- to NO_3^- are influenced by soil pH since specific nitrifying organisms are found to be much more sensitive to soil reaction (Bartholomew and Clark, 1965). The optimum and the limiting pH value for nitrification have not been agreed upon (Norman, 1943, Harmsen and Van Schreven, 1955) although mineralization proceeds to the formation of nitrate only within the range of pH 5.0 and 8.0, whereas at low and high pH the process stops at the formation of ammonium compounds. There is no clear relation between soil pH and rate of nitrification, probably because the effect of acidity is through the toxic effect of active aluminium ions. Thus there are examples of soils with a pH between 4 and 5 which will nitrify slowly (Weber and Gainey, 1962) and others with a pH over 5 which will only nitrify after they have been limed (Millbank, 1959).

The relation of water supply to mineralization of soil organic N was studied by Robinson (1957) who showed that the mineral nitrogen increased steadily as the water content of the soil during incubation increased from that corresponding to the air-dry condition to permanent wilting percentage (21%) and the field capacity (42%).

The effect of the moisture content of the soil on nitrification depends on its effect on aeration at the high moisture content end, but at the dry end the suction depends on the soil. Data from the continental areas of the U.S.A. show that the rate of nitrification is a maximum at suctions below 1 bar, provided aeration is adequate, and fall as the suction rises but still measurable at 15 bar suction or the wilting point of plants (Sabey 1969; Reichman et al., 1966). On the other hand, in some tropical soils, the rate of nitrification may be almost independent of suction up to suctions of 15 bar, and then drops rapidly as the suction rises above this; but soils differ in the effect that high suctions have on the rate (Robinson, 1957).

Nitrification proceeds more rapidly in the soils subjected to alternate wetting and drying than in soils kept permanently moist (Semb and Robinson, 1969; Tisdale et al., 1985) because the alternate wetting and drying causes a more rapid oxidation of soil humus. Thus, in hot regions having pronounced dry and wet seasons, nitrates are produced most rapidly at the commencement of the rains and only slowly during the rainy season itself (Russell, 1973). Semb and Robinson (1969) found flushes between 13 and 180 kg/ha of nitrate-N in 13 soils from different parts of E.Africa shortly after the onset of rains which follow the dry season. Birch (1959) found flushes of 33% of total N by each flush in Kenya soils.

Temperature has distinct effects on ammonification and nitrification during mineralization. Low temperatures do limit both ammonification and nitrification but differently; findings show that nitrification is more retarded than ammonification (Tyler et al., 1959). The optimum temperature for nitrification is usually in the range of 25° to 35°C and at 45°C practically no nitrification takes place. Below optimum, nitrification decreases gradually, following an asymptotic curve and practically ceases near the freezing point. But, ammonification proceeds vigorously in the thermophilic temperature range, 50° to 70°C (Bartholomew and Clark, 1965). From these investigations, retardation of nitrification by high temperatures may be expected to occur frequently only in tropical climates (Tandon and Dhar, 1934).

2.3.2 **Immobilization:** Nitrogen mineralization in the soil is accompanied by the reverse process, immobilization, in which nitrate and other mineral forms of nitrogen are converted back into organic forms. The immobilization process was studied by Doryland (1916) and Waksman (1917) who explained the reason why this phenomenon occurs. Microbes that decompose organic matter synthesize their own protoplasm which has a high N content of between 3 and 12% and in most cases higher than the substrate. Hence, any mineralized N will be utilized for the formation of protoplasm and if the C:N ratio of the substrate is high, there is absorption of inorganic N already available in the soil by the microorganism and no inorganic N will accumulate. Thus the C:N ratio of the decomposing material must be below 20 to 25 corresponding to 1.5 to 2.0% N so that immobilization may not take place (Bartholomew and Clark, 1965). The practical importance of reimmobilization of mineralized N during the decomposition of substances added to the soil with a C:N ratio above the critical value is that a depletion of available N would occur thus inducing the effect of N deficiency.

Factors other than the C:N ratio do influence the immobilization of N. Normik (1962) found that low temperature slowed down biological activity and thus delayed the time when maximum net immobilization was attained. Sub-optimum moisture had a similar effect (Kuo, 1955). Decomposition under anaerobic conditions results in lower quantities of net immobilization than in aerobic conditions.

2.3.3 **Fate of nitrogen in the soil:** When fertilizer nitrogen is added to soil it undergoes changes in chemical composition. Its fate is dependent upon these changes. The resultant chemical compounds and rate of reaction depend upon biological and chemical reactions which are dictated by a whole host of soil properties and processes (Hagin and Tucker, 1982).

In field experiments, the recovery by plants of applied nitrogen is generally 50% or below (Allison, 1966). The rest of applied N is lost through other various ways.

Denitrification is one of the ways through which soil and fertilizer N is lost as gaseous products through reduction of nitrates and nitrites to dinitrogen gas (N_2) and nitrous oxide (N_2O) by bacteria which are predominantly facultative anaerobes (Candy and Bartholomew, 1960; Valera and Alexander, 1961). Soil nitrogen balance sheets have shown that up to 30 per cent of fertilizer N can be lost by denitrification with an average in the range of 9 to 15 per cent (Legg and Meisinger, 1982; Colbourn and Dowdell, 1984). This process of N loss is influenced by temperature and moisture (Nommik and Larsson, 1989), rates of fertilizer N (Ryden, 1983) and is enhanced by alternating aerobic and anaerobic conditions in the soil (Reddy and Patrick, 1976) and periodic drying of soil (Meek et al., 1985). Soil types also influenced denitrification; the highest denitrification rates were found in clay soils followed by well-humified organic soils with sandy soils having an extremely low rate (Nommik and Larsson, 1989). Soil pH was found to be an important factor in denitrification and low pH, 3.6 - 4.8, was found to slow the rate while a rapid rate occurred in high pH, 8.0 - 8.6 (Tisdale et al., 1985).

Loss of nitrogen as ammonia from crop residues, manure and applied fertilizer N (Brady, 1990) is another possible fate of N in the soil. This loss of ammonia by volatilization may occur when N fertilizers are surface-applied especially on calcareous soils (Hagin and Tucker, 1982). Ammonium-containing or forming fertilizers may lose ammonia by dissociation of ammonium to ammonia and hydrogen; an equilibrium found to be pH-dependent (Tisdale et al., 1985). Loss of ammonia through volatilization may be as much as 15 to 25% and often even higher (Harding et al., 1963). However,ammonia volatilization is influenced by several factors. Numerous investigations revealed that ammonia losses usually became greater with increases in pH, calcium, carbonate content, temperature, rate of ammonium applied and could be retarded by increased cation exchange capacity, clay content, moisture content and depth of incorporation of the applied ammonium-containing or forming fertilizer (Fenn and Kiessel, 1973; Avnimetech and Laher, 1977; Terman, 1979; Hagin and Tucker; 1982; Tisdale et al., 1985; Wild, 1988; Clay et al, 1990).

Nitrogen immobilization is another pathway by which the concentration of inorganic nitrogen in the soil is decreased. This is a microbiological process as described above (section 2.3.2) which occurs as a result of adding decomposable low-N organic material to the soil which consequently causes microorganisms to consume the available nitrogen present in soil thus resulting in mineral forms such as nitrates being converted into organic tissue (Hagin and Tucker, 1982). The amount of immobilized N varies with crop species, moisture, aeration, temperature and supply of nutrients (Winsor and Pollard, 1956; Allison,1966).

The nitrogen in the soil may suffer another type of loss by leaching out of the soil (Wetselaar, 1962). Nitrate nitrogen suffers the most loss because it has negatively charged ions that are not adsorbed by the negatively charged colloids that dominate most soils (Brady, 1990). Hence, rainfall or irrigation water in excess of the soil's storage capacity carries with it dissolved nitrates (Wild,1988). Loss is, therefore, less in unirrigated arid and semi-arid regions (Brady, 1990). Factors that influence leaching of nitrogen in the soil include: rate of nitrification, permeability and water-holdingcapacity of soil (soil texture and structure),amount of plant cover and rate of N application (Thompson and Troech, 1973; Jones 1982; Barraclough et al., 1983; Brady, 1990). In a review, Sanchez (1976) reported annual leaching of nitrogen ranging from 2 to 249 kg/ha in different soils of tropical and temperate regions. The importance of plant cover to leaching was shown by Jones

(1982) who reported that 82 kg N/ha/yr were lost in non-cropped soil and only 8 kg N/ha/yr in cropped soil. The influence of soil texture and structure on leaching was reported by Wild (1988) and Snyman et al. (1985) who indicated that nitrite was more readily leached from sandy soils than from loam or sandy loam. Barraclough et al. (1983), using ammonium nitrate fertilizer, found that increasing the rate of N application from 250 to 900 kg N/ha also increased the total amount of nitrate leached from 6.3 to 155.8 kg N/ha. Nevertheless, fertilizer management techniques could be employed to reduce leaching. These include rate of fertilizer application, use of nitrification inhibitors on ammonium fertilizer, applying slow-release N fertilizers and delaying fertilization until planting or applying N as close to use as possible (Hagin and Tucker, 1982).

Other important ways through which soil N may be diminished in the soil is by crop removal whose effect depends on the crop species and yield, soil erosion and ammonium fixation (Neal, 1944; Thompson and Troech, 1973; Jones, 1982; Wild, 1988).

2.4 <u>Nitrogen supply and its role in plant nutrition</u>

Plants require N for their growth and reproduction (Viets, 1965) and therefore must get access for it for absorption. The most important utilizable forms of nitrogen that are readily absorbed by plant roots are ammonium and nitrates. But because the mass of available N in the soil is converted to nitrate by bacterial action, nitrate is the form most commonly absorbed. Barber (1984), however, pointed out that the amount of nitrate and ammonium in the soil that can be transported to the root depends on net release from organic matter mineralization, nitrification of ammonium to nitrate, denitrification of nitrate, loss of nitrate from the soil by leaching, loss of ammonium by volatilization, nitrogen uptake by the crop, N additions in fertilizers, by rainfall and by free-living microorganisms and N fixation into organic forms by microorganisms. On the other hand, the plant nutrient availability in a soil is principally governed by the rate at which nutrients move through the soil to the root surface. Barber et al.(1963) and Barber (1974) suggested three mechanisms by which nutrient ions in the soil can reach the root surface of a growing plant. The mechanisms are: root interception, mass flow and diffusion. Root interception is the process in which the roots grow through the soil and by doing so intercept the nutrient ions. Mass flow is the process whereby the movement of nutrients through the soil to the root is by convective flow of water caused by plant water absorption. The amount of nutrients reaching the root by mass flow is thus dependent on the rate of water flow or the water consumption of the plant and the average nutrient concentration of the water. Diffusion is the mechanism in which nutrient ions move to roots along a concentration gradient, that is, from higher concentration gradient to lower ones. A concentration gradient results from a continued uptake of nutrient ions by plant roots at a rate greater than they can be replaced by mass flow and root interception thus creating a zone of lower nutrient concentration.

The significance of each of the three mechanisms was evaluated by Barber et al. (1963). By measuring the rate of transpiration and nutrient concentration of that water, the amount of ions transported by mass flow was estimated. Root volume was used to calculate the amount of available nutrients intercepted by roots, while the contribution by diffusion was obtained by calculating the difference between the supply by root interception and mass flow. They found that nitrogen, calcium and magnesium could be supplied to the maize plant mainly by mass flow, phosphorus and potassium by diffusion, while root interception supplied only a small amount of N, P and K.

There is evidence, however, that nitrogen can be transported to the root surface by diffusion. Mengel and

Kirkby (1987) reported that nutrients taken up rapidly by plant roots and which are generally present in the soil solution in low concentrations such as ammonium, potassium and phosphate are mainly transported to plant roots by diffusion. Also, investigations of Strebel et al. (1983) showed that the mechanism of transport of nitrate was dependent on its concentration in soil. They found that under field conditions at the beginning of the growth period of sugar beet, mass flow was the major process in transporting nitrate towards plant roots. In the later stages of growth, however, when the nitrate concentration in the soil solution was low, diffusion became the more important process. In maize, nitrogen in nitrate form was reported to move to the root by mass flow (Barber and Olson, 1968).

Nitrogen is an essential macronutrient for crop plants. It is a structural component of amino acids, proteins, enzymes, coenzymes, most plant membranes, many plant hormones and vitamins; also is present in many compounds of great physiological importance in metabolism, such as chlorophyll, the nucleotides, phosphatides, alkaloids as well as being a constituent of the deoxyribonucleic acids making up the genetic code itself (Meyer et al., 1973; Viets, 1965; Jacob and Uexkull, 1958). Nitrogen is quantitatively the most important root-absorbed essential element. The requirement of N in the composition of the crop sets a minimum of the amount of N which must be supplied by the soil and the fertilizer. Young plants may contain 6 per cent N on a dry basis, while in older plants N may range from 0.5 to 2 per cent (Mitchell, 1970). In maize, the percentage of N is found to vary with the supply, genetic characteristics, planting rate, and weather conditions (Kurtz and Smith, 1967). In plants, N is essential for fruit and seed formation and because grain formation depends upon certain threshold level of protein, grain production is significantly related to N supply especially in cereal crops (Pesek et al., 1971). Maize has been shown to use more N than any other fertilizer element and is needed throughout the growing period with the peak occurring during the period of most rapid growth which extends about 2 weeks before to 3 weeks after tasseling (Kratz and Melsted, 1964). The level of supply of N is reflected in its concentration in plant tissue and if it falls below a certain level referred to as critical level, the performance of the crops would be restricted. The critical level of N and P, K, Ca and Mg in maize determined from the ear leaf at tasseling stage were 3.0, 0.25, 1.90, 0.4 and 0.25 per cent (Jones and Eck, 1973).

In the cereal crops, plants are very responsive to N fertilization, when needed, and result in large yield increases (Krantz and Melsted, 1964). Nitrogen fertilization has been shown to increase leaf area of barley and crops such as cocksfoot and perennial ryegrass largely as a result of an increase in the number of leaves and shoots (O'Brien, 1960). Also, working with barley and wheat, Watson (1947) noted that N and P consistently increased tiller numbers whereas K had little effect. The increase in protein content and baking qualities of wheat as a result of N fertilization has been reported (McGuire et al., 1974).

Because of the important role played by N in plants, the effects of N deficiency and excess in plants are readily apparent in colour, rate of growth and habit of the plant. Nitrogen deficient plants remain small and rapidly turn yellow due to lack of N to construct protein and chlorophyll. Thus, the diminished protein synthesis limits cell expansion and division (Hewitt, 1963) and the restricted carbohydrate production due to lack of chlorophyll leads to premature and poor flower formation and fruit development (Jacob and Uexkull, 1958).

Excessive supply of N to plants has a number of consequences. There is tendency for the carbohydrate content to decrease (Hasegawa et al., 1962 - cited by Black, 1968) since it is utilized to form more protoplasm and more cells leading to succulent plants which are more susceptible to diseases (Nightingale, 1936) and other unfavourable qualities (Black, 1968). Lack of sufficient carbohydrates which the plant requires for the construction of the strengthening tissues results in spongy and weak plants and since the abundant N has the action of increasing weight, height and leaf area, the plants are prone to the danger of lodging (Mulder, 1954; Black, 1968). Excessive N supply to plants also increases shoot-to-root ratio of plants, while in some agricultural crops flowering and formation of seeds are retarded (Salisbury and Ross, 1978). Within the range of practical interest, an increase in the supply of N results in unfruitful plants (Kraus and Kraybill, 1918) and delays maturity in some plants (Stakman and Aamodt, 1924). However, plants well supplied with N fertilizer may have silks and tassels appearing earlier in maize than on those deficient in N (Glover,1953; Chui and Shibles, 1984) thus enhancing earlier maturation.

Legumes have the ability to utilize soil and fertilizer N and can fix N_2 from the atmosphere. There have been many reports that legumes depending on their ability to fix N and the status of soil N may respond to applied N fertilizer. The effect of N fertilization on legume nodulation and N fixation varies. Inorganic N sources are reported widely to decrease the nodulation of legumes and to reduce N fixation (Lie 1974). But,other reports also show that nodulation and N fixation could be stimulated by N fertilizer. Hatfield et al. (1964) showed that addition of small quantities of N to cowpea during early growth stimulates nodulation and N fixation.

In Phaseolus beans, N fixation is usually unreliable (Graham, 1981) because of their low and variable levels of nodulation and N fixation (Stephen, 1967; Habbish and Ishag, 1974; Cackett, 1965). Hence, N fertilization of field-grown bean plants is recommended where N response has been observed (Graham 1981; Edje et al., 1975). The amount of N fertilizer to which beans respond varies widely. A low N fertilization rate of less than 50 kg N/ha gave early vigorous bean growth but did not always increase seed yield (Westermann et al., 1981). In Kenya, a trial at Njoro showed that application of 112 kg N/ha increased seed yields of non-inoculated plants but decreased them in inoculated plants (De Souza, 1969). In East Africa, bean response to N has shown some variation. Application of 80 kg N/ha showed a 36% seed yield increase in Embu (Kenya) while in Morogoro (Tanzania) and Makerere (Uganda) no N response was apparent (Keya et al., 1982). Higher N level, however, of 160 and 180 kg N/ha have been shown to significantly give higher bean seed yields than no N (Roberts and Weaver, 1971; Urben et al., 1980). But during the dry season, there was no difference between the N treatments (Urben et al, 1980). Also, application of 160 kg N/ha caused lodging to beans (Urben et al., 1980).

2.5 **Nitrogen fertilizer on maize and bean in different cropping systems:** In the tropics, nitrogen is frequently the limiting nutrient for crop production (Sanchez, 1976). Nitrogen fertilization, therefore, is usually required to supply crop requirements for optimum yields.

The amount of N fertilizer required by a crop depends on the yield level of the crop, the amount of release of N from organic matter, the residual N resulting from N application in previous seasons, and the efficiency of usage of the applied N (Barber and Olson, 1968).

Sole maize crop requires a heavy N application for maximum grain yield (Beets, 1978). It usually responds to N except in newly cleared land when the profile inorganic N is very high or when acidity or serious problems with other nutrients exist. In addition to soil factors the maize response curve is affected by variety, plant population and water regime (Sanchez, 1976). In Mexico, recommended rates of N to maize rose from 40 to 175 kg N/ha as a result of varietal improvement (Sanchez, 1973) while increased population of from 30,000 plants/ha to 50,000 plants/ha required higher N levels (Sanchez, 1976). Rainfall regimes also exerted a marked influence on maize N responses. Lower responses were obtained when either excess moisture or drought occurred in a series of maize experiments in Mexico(Rockfeller Foundation Report, 1963-64). In Nebraska, U.S.A., application of N fertilizer to maize increased yield and water use efficiency by 52 and 43% respectively (Olson et al, 1964). The time of N application to maize affects the effectiveness of N. The postplant sidedress applications of fertilizer N resulted on the average in higher yields of maize and higher plant recovery of fertilizer N than did preplant applications in two different soils, namely, oxisols and ultisols in the humid tropical climate of Puerto Rico (Fox et al.,1974).

Fertilization of multiple cropping systems requires that the residual effects of precious applications be considered. Nitrogen fertilizers generally produce little residual effect, unlike continuous application of even moderate doses of phosphorus (10 to 15 kg P/ha) which builds up significant residual soil phosphorus (Tiwari et al., 1980). Hence, the cereal following another cereal should be fertilized normally with N fertilizer (Bains and Sadaphal, 1971). But, when a cereal crop succeeds a legume crop in rotation, requirement for the cereal might be altered. Several studies have indicated that nitrogen could be economized for cereals that follow legumes in sequential systems. Working with cowpea, Mughogho and Ayonoadu (1975) reported that the contribution of a cowpea residue to a succeeding maize crop was equivalent to 40-80 kg N/ha while Dakora et al. (1987) reported a 60 kg N/ha contribution by the same legume crop. Kumar et al. (1982) also found reduced N requirement of a succeeding maize crop by 40 kg N/ha equivalent from sole pigeon pea crop. Higher fertilizer N value equivalents of alfalfa to a following maize crop have been realized and have been as high as 180 kg N/ha (Voss and Shrader, 1979; Baldock and

Musgrave, 1980).

Even though legumes supposedly receive their N from symbiotic fixation there are instances in which inorganic N fertilization is necessary. One case is where symbiotic N fixation by Rhizobium in a legume crop is negligible and the second instance occurs when soil is severely deficient in nitrogen. A review by Fassbender (1967) cited by Sanchez (1976) indicates that throughout Latin America symbiotic fixation in Phaseolus bean grown as a sole crop is negligible and N application rates of the order of 30 to 100 kg N/ha are needed. Generally, N fixation by common bean is usually unreliable and N fertilization of field-grown plants is recommended (Graham, 1981). A low N fertilization rate of less than 50 kg N/ha was found to give early vigorous bean plant growth but did not always increase seed yields (Westermann et al., 1981). Results of bean response to N fertilization do vary. In Malawi, beans grown under irrigation had their seed yield increased by fertilizer N application of between 40 to 200 kg N/ha (Edje et al., 1975). In Kenya, a trial with beans conducted at Njoro indicated that application of 112 kg N/ha increased seed yields of non-inoculated plants (De Souza, 1969) . In another site at Embu, in Kenya, application of 80 kg N/ha increased seed yield of beans by 36% while in Morogoro, Tanzania, and Makerere in Uganda no N response was apparent when the same rate of fertilizer N was applied (Keya et al., 1982)

Response of beans to fertilizer could also be due to the effect the N fertilizer has on symbiotic fixation. Inorganic N sources have been reported widely to decrease the nodulation of legumes and to reduce N fixation (Lie, 1974). In fact, work of Harper and Cooper (1971), using soybeans, found that the amount of symbiotic N fixed was inversely related to the amount of combined N available. On the other hand, stimulation of nodulation of soybeans by addition of N during the two weeks following seedling emergence was observed (Hatfield et al., 1974) while a starter N increased soybean yields significantly in Nigeria (Kang, 1975). Also, pot experiments have shown that addition of small quantities of N to cowpea during early growth stimulates nodulation and N fixation (Ezedimna, 1964).

Fertilizer requirement of an intercropped cereal may be increased, unaltered or reduced compared to those of the sole crop depending on the crops involved. When the intercrop components respond to a particular nutrient, the intercrop system requirement may be higher than the sole crop needs. The N fertilizer requirement to satisfy a cereal-legume mixture for a maximum grain yield is not yet resolved. The problem is complex because of the differences that occur in response to N fertilizer for the two different crop species. Maize requires a heavy N application for its production (Beets, 1978) and in the case of a maize-legume mixture, the amount required by maize might negatively affect the legume N fixation (Lie, 1974) and promote vegetative growth at the expense of seed yield. Also, increasing N level in an intercropping system was found to favour the growth of maize resulting in shading of the legumes thus decreasing the yield of intercropped groundnuts and soybeans (Searle et al., 1981; IRRI, 1974). Another problem in maize-legume system is how to determine the appropriate amount of N to apply to the cereal crop. This is because legume crops have been found to excrete some of the N they fix during growth (Agboola and Fayemi, 1971, 1972) that benefit nonlegume crops by increasing their yields (CIAT, 1974; Wien and Nangju, 1976). Although reports of Vallis et al. (1967) and Wahua and Miller (1978) indicated lack of evidence for direct transfer of microbially fixed N from the legume to nonlegume in a mixture, investigations show that the benefit accrued depend on the relative growth patterns of the intercrops. That is, when the legume matures earlier than the nonlegume, the N from the mineralized sloughed-off and dead nodules and roots may be transferred to the nonlegume of longer duration (Walker et al., 1954; Agboola and Fayemi, 1971, 1972; Henzell and Vallis, 1977).

Competition for N between cereals and intercropped legumes might, however, be inevitable under some circumstances . This is because some legumes like Phaseolus beans have low N fixing capacity and they respond to N fertilizer (Graham, 1981) while others such as cowpea can only fix about 80% of its N needs (Eaglesham et al., 1977), a fact that is supported by the findings of Ezedimna (1964) and Pate and Dart (1961) who reported that cowpea relies on mineral N early in the growing season before nodules are sufficiently developed. Other studies have shown that the strong growth response of the nonlegume to N application usually causes it to dominate the legume by shading it (Searle et al., 1981) thus resulting in reduction of N_2-fixation by the legume (Graham and Rosas, 1978). Intercropping soybean with a tall sorghum crop showed that N_2-fixation was reduced 99% due to a reduction in the number of nodules per plant, weight per nodule and specific nodule activity (Wahua and Miller, 1978). In the case of maize-beans mixture more nitrogen fertilizer may be required than that applied for sole maize crop partly because the shading effect of maize on beans would consequently lead to reduction of N_2-fixation (Graham and Rosas, 1978) thus making beans rely more on N from other sources. Also, the N fertilizer applied with the aim of enhancing maize production might reduce N_2-fixation of beans as found in other legume crops (Lie, 1974; Harper and Cooper, 1971). This would lead beans to taking up N from the fertilizer source. The work of Ssali and Keya (1980a) elucidated this aspect: thus at lower N fertilizer level (20 kg N/ha) bean plants derived 67.4, 23.8 and 8.8 per cent of their tissue N from non-fertilizer soil N, applied N fertilizer and dinitrogen fixation respectively whereas when a higher dose of N (100 kg N/ha) fertilizer was applied bean plants derived 51.6, 33.1 and 15.0 per cent of their N from non-fertilizer soil N, applied N fertilizer and dinitrogen fixation respectively.

Contradictory results, however, have been reported on the response of intercropped legumes to applied N. Ahmed and Gunasena (1979) showed that the yield of legumes intercropped with maize always decreased with increasing rates of N due to increasing competition from the maize. On the contrary, Kalra and Gangwar (1980) found that both 80 and 120 kg N/ha gave larger cowpea intercrop seed yield than 40 kg N/ha in India. In the former case, the intercrops provided higher economic returns than the sole crops at corresponding N levels. A report by Dalal (1977) also showed that where N fertilizer was applied in an intercropping system, both total grain yield and maize grain yield were always higher, whereas soybean yield was not different compared to plots where no N fertilizer was applied.

Although the above cited literature indicate sustained advantage from intercropping even with fertilization, it is more common to find the land equivalent ratio (LER) reduced, especially at higher levels of applied N (Searle et al., 1981; IRRI, 1974).

2.6 Nitrogen in legume plants and its utilization by cereal crops:

It has long been recognized that nitrogen is the key to soil fertility. The importance of legumes in building and conserving soil fertility has been known since the beginning of agriculture (Nutman, 1965). In the traditional system where N fertilizers are unavailable for being prohibitively expensive, soil N levels are maintained by legumes (Nye and Greenland, 1960) because legumes are able to fix atmospheric N in association with appropriate strains of Rhizobium. In legumes, the amount of N contained is derived from the soil and from symbiotic fixation. The proportion of legume N derived from symbiotic fixation varies. It is often about 50 per cent in fertile soils, but is likely to be higher in N-deficient soils and lower where substantial amounts of N fertilizer are used (Vincent, 1965). In grass-legume mixtures the proportion will probably be 80-90 per cent or more because the grass usually takes up most of the available soil N (Henzell et al., 1968).

The quantity of N_2 fixed by legumes is determined by many factors such as plant species, density of plant stand, weed competition, climatic condition, effectiveness of the bacteria strain, pH and nutrient status (Andrew, 1962) especially the amount of N made available from the soil (Van Schreven, 1958; Burton et al., 1961). Also, shading of a legume by a taller cereal intercrop has been found to result in depressed N fixation in legume crops such as soybeans (Wahua and Miller, 1978) and groundnuts (Searle et al., 1981).

The amount of N_2 fixed by legumes in a unit of land area, however, has often been estimated. Henzell and Norris (1962) reported that the N_2 fixed varies widely from only a few kilograms to 337 kg per ha/yr or occasionally even more. Spector (1956) reported the amount fixed per crop or season in kilograms per ha as follows: alfalfa, 56-393, clovers, 56-225, peas, 34-157, peanuts 99; pastures with legumes 11-618. Beans have been reported to fix N ranging from 9 to 74 kg N/ha by Jansen (1972) cited by Saito (1982) and CIAT (1977). In Kenya, beans have been found to fix from 28 (Ssali and Keya, 1980a) to 55 kg N/ha (Keya, 1977), while cowpea could fix between 51 and 74 kg N/ha (Ssali and Keya, 1980b). Alexander (1961) also reported that cowpea could fix between 64 and 131 kg N/ha per year.

The nitrogen in legume plants is distributed among the plant organs. About 70 per cent or more of the plant N is translocated to the above-ground portions (Whiteman, 1971; Musa and Burhan, 1974) and of this proportion in pulse crops, 60-90 per cent of the N in the tops is found in the fruit (Weber, 1966). The remaining N after above-ground translocation which is between 20 and 30 per cent or more is retained in the root system (Russell, 1973; Oke, 1966).

Several processes by which leguminous crops can add N to the soil are known. One is by sloughing-off of dead nodules and roots (Agboola and Fayemi, 1971; Henzell and Vallis, 1977) and the other is by the excretion by nodules of soluble organic compounds such as the amino acids, aspartic acid and B-alamine (Virtanen et al., 1947). The third way through which legumes add N to the soil is by the mineralization of N in plant residues (Bartholomew, 1965; Smith and Sharpley, 1990). The net amount of symbiotically fixed N in legume residue returned to the cropping system depends on the amount of symbiotic activity, the amount and type of residue left in the soil, and the availability of soil-N to the legume (Heichel, 1985). The proportion of N released during decomposition of the residues is governed by the chemical composition of these residues especially the N content, the manner in which the residues are returned to the soil and the environmental conditions (Henzell and Vallis, 1977). Soil enrichment with N after a legume crop has been grown has been reported. Wild (1972) and Jones (1974) found a higher concentration of mineral N in the top soil after a groundnut crop. In Kenya, Jones (1942) assessed the role of a leguminous cover crop such as Glycine javanica in building up total soil N. The experiments ran for nine years and compared soil samples from a plot planted with the legume to soil from the adjoining cultivated plot. At the end of the study the legume had increased the N content of the Kikuyu friable loam soil (Nitisol) at the rate of 180 kg N/ha per year. Total soil N was increased from 0.206 per cent to 0.292 per cent, a gain of about 40%.

The above literature clearly shows that the inclusion of an N fixing legume in a cropping system restores soil N fertility (Reddy et al., 1966; Hesterman et al., 1986). The N released into the soil by legume plants is found to benefit cereal crops in intercropping systems as well as those in rotations.

Cereal-legume mixtures have formed very important combinations, and, with the high cost of N fertilizers, they are likely to continue to do so. In fact, there are some findings where non-legume yields have been increased when intercropped with a legume compared to when sole cropped, even when high levels of N have been applied (CIAT, 1974; Wien and Nangju, 1976; Francis et al., 1976). This phenomenon has been attributed to N excreted by legumes during growth (Agboola and Fayemi, 1971, 1972) and mineralized N of sloughed-off and dead nodules and roots of the legumes that mature earlier than the non-legume (Walker et al., 1954; Agboola and Fayemi, 1971; Henzell and Vallis, 1977).

Despite the fact that the N_2 fixed by legumes intercropped with taller cereals is depressed, the residual effect of the legume is substantial to a succeeding cereal crop. Searle et al. (1981) found that N uptake by wheat following maize/soybean and maize/groundnut intercrops without N fertilizer was about twice as great as that following maize alone without N and equivalent to that following maize alone with 100 kg N/ha. Nair et al. (1979) had conducted a similar experiment with maize/soybean, maize/groundnut and maize/cowpea intercrops and reported that the grain yield of wheat that succeeded these intercropping systems was increased by 27, 18.2 and 34.3 per cent, respectively.

The contributions of legume crops to soil N in rotations and their improvement in productivity of subsequent cereal crops have been observed and they vary widely depending on the legume species. This is probably due to the difference in N fixation by legumes, their chemical composition and rate of N mineralization. Hence, cereal crops do not benefit from all N in legume residue in the first season (Hoyt, 1990). This is because not all legume residue N is mineralized. At most 60 per cent (Bartholomew, 1965) of the N legume residues is likely to be mineralized in time for a following crop. Evidence from ^{15}N-labelled Medicago residues revealed an uptake of between

20 and 28 per cent of total N in the residue (Ladd et al., 1983) and 5 to 11 per cent (Ladd et al., 1984) with wheat as a test crop.

In another experiment, Ladd (1981) demonstrated that about 60 to 65 per cent of the N in added medicago remained in soil as organic matter after 32 weeks thus leaving about 40 per cent or less of residue N to be available to a succeeding crop. Interestingly, the benefit accrued to cereal crops from the N mineralized from legumes is substantially high in some cases. Research work in Pennsylvania showed that, most if not all, of the fertilizer N requirement of a maize crop following alfalfa (Medicago sativa L.) can be supplied by the alfalfa residue since the residual N fertilizer equivalent for two successive maize crops was at least 90 kg/ha/yr (Fox and Piekielek, 1983). Higher fertilizer N value equivalents of alfalfa to a following maize crop have been shown to be as high as 180 kg N/ha (Voses and Shrader, 1979; Baldfock and Musgrave, 1980).

Although Jones (1974) did not find any beneficial effect of a previous cowpea grain crop to sorghum, Mughogho et al. (1982) reported that the contribution of a cowpea residue to maize was equivalent to 40-80 kg N/ha while that reported by Dakora et al. (1987) was equivalent to 60 kg N/ha giving a maize yield increase of 95 per cent. Also, Lal et al. (1978) found that a fodder legume cowpea benefited a wheat crop to the equivalent of about 40 kg N/ha.

In Ghana, the benefit of groundnut to maize was equivalent to 60 kg N/ha (Dakora et al., 1987) while the same crop in Nigeria benefitted a following grain sorghum to the extent of 60 kg N/ha. Other legume crops such as greengram (Vigna radiata) and blackgram (Vigna mungo) were found to reduce N requirement of a succeeding wheat crop by 30-60 kg N/ha while pigeon pea and soybean reduced the N requirement by 30 kg N/ha. Kumar et al. (1982) found a higher benefit of 40 kg N/ha equivalent from sole pigeon pea crop to maize.

In addition to long-term N released are other associated benefits from legume organic residue such as maintenance of soil structure, improved water holding and cation exchange capacities and resistance to erosion (Herridge, 1982).

2.7 Effect of N fertilizer on the uptake of other macro-nutrients by plants:

Nitrogen fertilizers have been found to influence the uptake of P (Krantz and Chandler, 1951), K, Ca and Mg (Viets et al., 1954) by plants. This effect has been attributed to the fact that plants may absorb nitrate or ammonium N and depending on the regime of the ionic N nutrition, the amount of cations such as K, Ca and Mg absorbed would depend on the need to balance the cation to anion ratio taken up by plants (Dibb and Welch, 1976). Applied N may also cause increases in root growth and foraging capacity for P thus enhancing the growth of plant tops and consequently raising the absorption of P (Mclean et al.,1956; Ohlrogge et al., 1957; Grunes et al., 1958; Cole et al., 1963). Also, the acid-forming N materials do lower soil pH and this has been found to bring more P into solution thus increasing the availability and uptake of P to plants (Rennie and Mitchell, 1954; Miller et al., 1970). The increased P absorption related to the reduction in pH is probably due to two factors: acid-forming N fertilizers which produce ammonium and through nitrification contribute H^+ ions to the soil thus lowering the pH (Pierre, 1928) and to the fact that where NH_4^+ cations are taken up more rapidly than NO_3^- anions by plants, the pH is found to fall because of exchange of H^+ ions within the root for NH_4^+ ions in the soil (Viets, 1965; Riley and Barber, 1969).

The source of N and absorption of N in the cationic (NH_4^+) or anionic (NO_3^-) form may have profound effects on plant chemical composition and growth. Thus, Viets et al. (1954) studied the effect of 5 sources of nitrogen namely

NH_3, $(NH_4)_2SO_4$, NH_4NO_3, $Ca(NO_3)_2$ and urea on maize leaf P, K, Ca and Mg contents, in a field under irrigation. They observed that $(NH_4)_2SO_4$ produced the highest maize leaf P and K contents but the lowest Ca and Mg contents in comparison with $Ca(NO_3)_2$ and NH_4NO_3 as N sources. Another observation was that Mg and Ca contents in the leaf were affected by the rate of application of N sources. In a nutrient culture experiment in which $(NH_4)SO_4$ and $Ca(NO_3)_2$ were the source of N in Mg, K and Ca solutions, Arnon (1939) observed that plants of barley grown in NH_4-N had under all conditions tested higher P and a lower Ca, Mg and K content than plants grown on NO_3-N. But Cole et al. (1963) using maize studied the effect of NH_4^+ and NO_3^- ions in solution plus different levels of P and found that the presence of NH_4^+ or NO_3^- ions in the nutrient culture during the uptake period had negligible effects on rates of P uptake. In a similar experiment, however, Bennett et al. (1964) observed significant differences in dry weight of maize tops and roots, due to the form of N used and higher yields were obtained from plants grown with NO_3-N (plus P) solution than plants grown on NH_4-N(plus P) solution. Working with tobacco, Evans and Weeks (1947) obtained six times as much dry matter produced by plants grown with NO_3-N as with NH_4-N while Holley et al. (1931) had reported similar reports with cotton; use of ammonium-N as a source of N reduced the absorption of bases, the greatest effect being on Ca and Mg.

In a growth chamber experiment, Riley and Barber (1971) the effect of NH_4^+ and NO_3^- ions on the uptake of P by soybean plant using NH_4Cl and $Ca(NO_3)_2$ as sources of N and $Ca(H_2PO_4)_2$ as source of P. They observed that NH_4-N treated plants had a higher P content than the NO_3-N treated plants at the end of 3 weeks of growth.

In Kenya , nitrogen fertilizers have been applied together with those of phosphorus in order to increase the yields of maize in sole cropping systems (Muturi, 1972; Nadar, 1984). But studies on how applied N fertilizers influence the uptake of macronutrients in sole maize crop or maize in different maize-legume cropping systems are few. Using a compound fertilizer as source of N and P, Qureshi (1976) reported that the uptake of N, P, K and Ca by a sole maize crop were increased. On the other hand, a study by Chui (1988), conducted on a humic nitisol at the medium potential region of Kenya, showed that application of different rates of N and uniform level of P did not significantly affect the uptake of N, P, K, Mg and Ca in maize grown in sole and intercropping systems. In the same study by Chui it was reported that N fertilizer application increased the total uptake of N, Ca and Mg in maize-bean intercropping systems and K in one maize-bean intercropping system compared with sole maize crop.

2.8 Plant interaction for environmental resources:

During growth and development, crop plants must intercept and absorb nutrients, light energy and water in order to use them in processes that produce biomass with harvestable yields included. When nutrients, light and water are in relatively short supply, the plants results in competition for them since growth is responsive to the rate of absorption of any one of them. In the agroecosystems the component plant species and the factors of the environment are going to be in constant interaction. The term interference is used to describe the effect that the presence of one plant has on the environment of another. Addition (the production of secondary chemicals by plants, followed by their release into the environment and subsequent effects on associated plant species) (Rice, 1984) and removal (one species of the mixture being able to remove the needed resource better or sooner than the other thus resulting in the depression in performance of the other (Trenbath, 1976; Harper, 1977) reactions on the environment are the basis of interference interactions. The most commonly invoked explanation for yield reduction in crop mixtures is the removal reaction through competition for a limited resource. When the immediate supply of a single necessary factor falls below the combined demands of the plants, competition begins.

2.8.1 <u>Soil resource:</u> The acquisition of soil resources, particularly nutrients, by living plant roots has been visualized as occurring in three phases in which the available ions move into the root sorption zone, are actively taken up and then translocated (Fried and Shapiro, 1961). For root absorption to occur, however, nutrients must first get to the surface of roots. This is accomplished in three ways, namely, root interception, mass flow and diffusion.

The amount of ions by diffusion and by mass flow in water through the soil to the root depletes the soil of these ions in the vicinity of the root. The nitrate ions being more mobile than potassium and phosphate (Bray, 1954; Barley, 1970) are usually taken up at faster rates (Brewster and Tinker, 1970; Hanway and Weber, 1971), and zones of its depletion around active roots do increase in size fastest and overlap the soonest (Bray, 1954; Andrews and Newman, 1970). Since mobile ions like nitrate are carried passively in moving soil water, their depletion zones will be as large as those for water, provided the ions are taken up as fast as they arrive at the root (Barber 1962; Barley 1970). Hence, the competition between plants is much greater for the relatively mobile nutrients (Bray, 1954). But until there is an overlapping of depletion zones of roots of the different components of an intercrop, competition for soil factors between different components cannot begin. Therefore, depending on the planting pattern and rate of planting, plants can grow without competing with each other for any nutrients, can effectively compete for the relatively mobile nutrients or can compete for both relatively mobile and relatively immobile nutrients (Bray, 1954).

The study of the root system of pasture plants

(Clover and grasses) by Evans (1977, 1978) indicated that root morphology may be a very important factor in competition for water and nutrients. Grasses generally were found to have longer, thinner, more finely branched roots than clovers; thus the former could explore a greater volume of soil resulting in grasses having a competitive advantage over clovers in nutrients such as P, K and S when they are in short supply (Evans, 1977). The inability of pasture legumes in general to compete for P, K, and S has also been attributed to their less ramified root systems compared to grasses (Rabotnov, 1977).

However, the degree of overlap between components' root-systems determines the intensity of competition effects (Cable, 1969; Trenbath, 1975) and if the components have similar root properties, the mobile nutrient in the volume of the root-system overlap is shared in proportion to the root lengths of the components present in that volume (Andrews and Newman, 1970; Baldwin et al., 1973). The variation of form of root system between species has been studied (Cannon, 1949) and a good correlation is often found between root abundance and uptake activity (Nye and Foster, 1961; Barley, 1970). One important characteristic that contributes to success in competition for mobile nutrients is earlier uptake whatever the mechanism might be. Barber (1978) found that soybean had a maximum root length density (cm root length per cm^2 soil surface) only one-fifth that of maize measured on the same plot area in an earlier year (Mengel and Barber, 1974). He also noted that, whereas the proportion of maize roots in the 0-15 cm surface layer declined with time, that of soybeans was constant or increased. Maize and soybean were further distinguished by the timing of nutrient uptake, with that of maize being predominantly earlier and that of soybean being later in the season.

In a study reported by Henzell and Vallis (1977), Lotononis bainesii, a legume, was shown to be weakly competitive for mineral nitrogen when grown with pangola grass (Digitaria decumbens stant.). It was concluded that legumes are generally weakly competitive with grasses for soil nitrogen, contributing to the nitrogen-sparing effect. Competition for nutrients will have two main types of effect on less successful component of an intercrop. First, within the soil, the roots of the inferior component may develop less on the side toward plants of the more aggressive component (Baldwin and Tinker, 1972) while within - component competition for soil factors has a similar effect (Hayness and Sayre, 1956). Because roots grow more slowly in soil depleted of nutrients (Duncan and Ohlroge, 1958), root systems of plants at low density or row intercrops may tend to avoid each other (Baldwin and Tinker, 1972). Second, on the whole-scale, plants affected by competition for soil factors are likely to show an increased root/shoot ratio (Weaver and Clements, 1938). Competition for nutrients by plants may lead to visible symptoms of mineral deficiency, reduced content of nutrients in competition (Snaydon,1971) and physiological impairment (Murata,1969).

On low-nitrogen soils, the non-legume is often either suppressed (Stern and Donald, 1962) or has little advantage (Macleod and Bradfield, 1963), but on high nitrogen soils the strong growth response of the non-legume usually causes it to dominate the legume by shading it (Stern and Donald 1962). The vigorously growing non-legume, usually grass, takes up large amounts of nutrients such as P, K, and S (Blaser and Brady, 1950; Walker and Adams, 1958) and legume may suffer deficiency on soils low in these nutrients.

2.8.2 Light resource: Donald (1961) emphasized that photosynthetic energy competition differed from the other resources in that it could not be regarded as a reservoir from which demands could be made as required but is "instantaneously available" and has to be "instantaneously intercepted" if it is to be used for photosynthesis.

Watson (1971) observed that the output of the photosynthetic system depends on how much light falling on the crop is intercepted by leaves. Also, Shibles and Weber (1965) reported that the rate of dry matter production in soybeans was linearly related to percent of light intercepted when soybeans had a leaf area index of approximately 3.2 needed for 95 per cent interception. Depriving plants of light, therefore, may result in physiological impairment. Donald (1963) reported that competition for light may occur whenever one plant casts a shadow on another, or within a plant when one leaf shades another leaf. Hence, leaves rather than plants are the vehicles of light competition. The rate of leaf surface expansion, leaf display, maintenance of leaf area (Black, 1960, Jennings and Aquino, 1968) and plant height (Donald, 1961; Trenbath, 1976) are, therefore, some of the morphological and physiological characteristics that could contribute to competition for light energy. Leaf length (Hamblin and Donald, 1974) petiole length (Black, 1960) leaf inclination (Ledent and Moss, 1977) and phyllotaxy (Williams, 1975) are additional factors affecting leaf positioning in space and thus light competition.

Leaf angle is particularly critical in intercrop light competition when intercrops differ in height. Plant height is a factor in light competition primarily because it affords flexibility in vertical leaf positioning (Donald, 1961). Warren (1960) concluded that optimal canopy structure for interception of direct sunlight would include erect upper leaves and horizontal lower leaves closely paralleling the actual structure of some intercrop canopies including bean with maize. Shading another plant may change its competitive ability. Hall (1974) stated that a plant shaded by its neighbours to an extent that light is limiting its growth may, by virtue of its reduced development, have smaller root system and therefore, possibly be less competitive for minerals and water. When maize and shorter legume crops are intercropped, the shading effect has been found to lower the potential productivity of legumes. Maize intercropped with shorter legumes like soybeans, groundnuts (Searle et al., 1981) and cowpeas (*Vigna sinensis*) (Agboola and Fayemi, 1971; Mongi et al., 1976) was found to reduce photosynthetic photon flux density reaching the legumes and consequently lowering the grain yield of legumes. Also, the shading effect of an intercrop maize has been found to reduce the N_2 fixation of intercropped legumes such as calopo (*calopogonium mucunoides*), greengram (*Phaseolus aureus*) and cowpeas (Agboola and Fayemi, (1971), beans (Graham and Rosas, 1978), groundnuts and soybeans (Searle et al., 1981).

2.9 Spatial arrangements in intercropping systems:

Intercropping, the growing of two or more crop species simultaneously on the same piece of land is a traditional agricultural practice that predominates among farmers in developing tropical and subtropical countries (Andrews and Kassam, 1976; Harwood and Price, 1976; Okigbo and Greenland, 1976; Francis et al.,1976). Both research and actual practice have shown conclusively that intercropping is a system with much potential for labour-intensive, small farms (Francis et al., 1976; Okigbo and Greenland, 1976; Willey, 1979a, b). Intercropping often has shown yield advantages over monocropping and Beets (1978) stated that it is one of the most important ways through which agricultural production in the tropics may be increased. Although many intercropping systems are used, a common one consists of maize with an associated seed legume. With the maize-legume system a common observation is that both the yields of individual crops of the association are reduced. This is attributed to the interspecific competition for the environmental resources, namely, nutrients, water and light. Research, however, has demonstrated that the decrease in yield of the intercrop components due to competition can be minimized and some advantages may be obtained through the selection of crops of widely different growth habits, proper manipulation of spatial arrangement and supplying nutrients to the intercrops.

A factor of major importance in performance of intercrops is their spatial arrangements, which affect light penetration into the canopies of both taller and shorter components, but more so edaphic interaction. The intensity of interactions between component crops depends on the proportion of the interplant contacts between individuals of the different components. A pertinent question is how intimate intercrops should be (Willey, 1979b). Research has revealed that space for the taller cereal can be altered to a certain extent without reducing its yield while providing a more favourable environment for the intercropped legume. Use of double rather than single alternating rows of each species improved intercrop soybean yield without materially changing maize performance relative to monocropping (Singh et al., 1973; Mohta and De, 1980). Intercropping these species in the same row reduced yields of both crops compared with single or double alternating rows, which allowed maize yields similar to those of a monocrop (Dalal, 1977). With sorghum (*sorghum bicolor* (L.) Moench) intercropped with pigeon pea, Freyman and Venkateswarlu (1977) reported improved legume yields by using paired 30-cm sorghum rows, allowing a wider inter-row space for the legume. Dalal(1974) found greater competition for light and nutrients for both maize and pigeon peas when grown in the same hill compared with alternate rows and this particularly affected the yield of maize. On the other hand, Agboola and Fayemi (1971) and Mongi et al., (1976) observed that, while the yield of intercropped legumes were significantly reduced by planting them on either alternate or the same rows with maize, the yield of maize intercrop was not significantly affected. Other contradictory results on how intimate associated crops should be have been reported. Andrews (1972) and IRRI Report (1973) suggest that maximum benefit from any complementary effects can be accrued if crops are as intimately associated as possible. Some investigations show that increasing intimacy has no effect on component crops (Evans, 1960) but in cases where the shorter components are susceptible to shading, it has reduced their yields (Osiru, 1974). Also, Osiru (1974) reported that where intimacy of components was less, the light penetration to the lower component was improved and yield advantages occurred.

Spatial arrangement also affects the root distribution of the intercrops thus influencing the competition for soil factors. The competition for nitrate ions, which are mobile in the soil, begins when there is an overlapping of depletion zones of roots of the different component intercrops (Trenbath, 1976). The degree of overlap between component root-systems determines the intensity of competition effects (Cable, 1969; Trenbath, 1975).

2.10 Role of soil pH, CEC and Organic matter in soil fertility:

These three soil factors play a very important role in determining the fertility of soil and consequently the growth of plants. They are found to be inter-related but here the effect of each factor is dealt with separately.

2.10.1 Soil pH:

Soil pH is a measure of the activity of ionized hydrogen in the soil solution and is defined as the negative logarithm to base 10 of H^+ ion activity. Most soils have pH values between 4 and 8 and by strict definition, any pH below 7.0 is acid and any pH above 7.0 is alkaline. A small zone near 7.0 is considered to be neutral. According to generally held views, the sources of acidity are: Organic matter or humus, aluminosilicate clays, hydrous oxides of iron and aluminium, exchangeable aluminium, commercial fertilizers, leaching and crop removal of basic cations (Tisdale et al., 1985). Nitrogen fertilizers containing or producing ammonium are said to be acid-forming (Pierre, 1928). The acidity from N fertilizer is not present in the fertilizers but is developed in the soil as a result of nitrification of certain N fertilizers and leaching of exchangeable cations by the anions that accompany N fertilizers. The extent of soil acidification is a function of N source (Jones, 1976), placement (Mahler and Harder, 1984) soil type and amount of fertilizer used (Hoyt and Henning, 1982), cropping systems (Abruna et al., 1958; Pierre et al., 1970), N volatilization (Hiltbold and Adams, 1960) and N leaching (Jolley and Pierre, 1977).

The importance of soil pH is that it influences the rate of plant nutrient release by weathering, concentration of different ions in the soil solution and their availability to plants (Thompson and Troeh, 1973; Russell, 1973). Alkalinity reduces the availability of all trace elements except molybdenum (Thomas and Hanway, 1968) while acidity causes soil infertility. It is well known that pH per se has no direct effect on plant growth, except at pH values below 4.2 where the hydrogen ion concentration may stop or even reverse cation uptake by roots (Black, 1968) and might become detrimental to the growth of many beneficial bacteria (Tisdale et al., 1985). However, the indirect effects of pH occur due to one or more of the following factors: Aluminium toxicity, calcium and magnesium deficiency and manganese toxicity (Sanchez, 1976). Crop species are limited in yield and response to fertilizer by unfavourable pH (Thomas and Hanway, 1968) and are found to thrive at different optimum soil pH. Most forage and pulse legumes have their yield reduction when soil pH values fall below 5.6 (Mahler and Mcdole, 1985; Mahler 1986). Optimum pH for Phaseolus bean is about 5.8 - 6.5 in soils of humid regions and pH of 6.0 - 7.5 on semi-arid to arid regions (Boswell and Cooke, 1958). On the other hand, cereals have been found to be more tolerant to low pH and had a minimum acceptance pH value of about 5.2 (Mahler and Mcdole, 1987). The critical pH value for maize has been reported to be around 5.5 (Wild, 1988).

2.10.2 Soil cation exchange capacity (CEC): The cation exchange capacity, usually expressed in milliequivalents per 100 g of soil, is a measure of the capacity of soils to hold exchangeable cations. Thus, it is one of the most important chemical properties of soils related to the soil fertility (Tisdale et al., 1985). It also reflects the property of soil regarding the fine mineral particles and humus component (Hesse, 1971) because they are negatively charged and they hold cations which are positively charged. In the mineral clays, the negative charge generally arises from isomorphous substitution and the ionization of hydroxyl groups attached to the silicon atoms at the broken edges of the tetrahedral planes. In the organic fraction these negative charges arise mainly from carboxylic and phenolic groups and to a lesser extent from enol and imide groups (Tisdale et al., 1985). These are the charges which are neutralized by cations attracted to the surfaces of these colloids. Thus, the amount of CEC of soils is determined by the amount of clays and the amount of humified organic matter (Jones, 1982). Addition of decomposable organic matter to soil results in formation of organic acids which supply most of the CEC of acid and highly weathered soils, but per cent base saturation and pH are lowered (Greenland and Dart, 1972).

Cation exchange capacity is influenced by the soil texture. Finer-textured soils tend to have higher CEC than sandy soils. Also, the kind of clays have shown differences in that, the 1:1 type of clays which include kaolinite have lower CEC than 2:1 type of clays which include montimorillonite (Brady, 1974). Generally, the 1:1 mineral colloids have CEC values of 10 to 20 me/100g; 2:1 mineral colloids about 40 to 80 me/100 g and organic colloids, 100 to 200 or more me/100 g. However, because of highly weathered minerals or sandy textures, many tropical soils commonly have effective CEC values lower that 4 and one way of increasing CEC is by increasing soil organic matter content (Sanchez, 1976). As a rule, however, soils with large amounts of clay and organic matter will have higher exchange capacities than sandy soils which are low in organic matter. The cations which soil colloids adsorb to their exchange sites include calcium, magnesium, potassium, sodium, ammonium, aluminium, iron and hydrogen. These exchangeable cations are partly basic (Ca^{2+}, Mg^{2+}) and partly acidic (H^+, Al^{3+}) when they are in solution and this phenomenon leads CEC to be the principal buffer mechanism in the soil. Soils therefore containing large amounts of mineral clay and organic matter are said to be highly buffered (Tisdale et al., 1985).

The amount of CEC possessed by a soil clay is partly pH-dependent and is found to be lower under acid conditions and rises as the pH rises (Thompson and Troeh, 1973).

It has been realized that apart from providing a source of plant available cations, exchangeable cations affect physical properties of a soil (Hesse, 1971). Thus, exchangeable calcium promotes good tilth whereas exchangeable sodium destroys soil structure causing impermeability and all the consequent effects of poor drainage. Magnesium in the exchangeable form has similar effect on soil to that of sodium. On the other hand, during cropping, the quantities of exchangeable cations will tend to be reduced by leaching and plant removals thus reducing their availability (Nye and Greenland, 1960).

2.10.3 <u>Soil organic matter:</u> The source of soil organic matter is the once-living matter of plants, animals and microorganisms (Adrian, 1927). Organic matter consists of a series of products which range from less completely decomposed plant and animal tissues to the products of decomposition to fairly stable amorphous brown to black material normally defined as the humus (Russell, 1973). Soils vary widely in their organic matter contents. Most soils contain between 1 and 6 per cent organic matter (Thompson and Troeh, 1973). The mean content of organic matter in soils collected in East Africa was 3.36 per cent

(Birch and Friend, 1956). Soil organic matter content partly depends on how much organic matter is turned-over and partly on what per cent of the organic matter decomposes (Thompson and Troeh, 1973); processes that are dependent on factors such as time, climate, vegetation, parent material, topography and effect of cropping (Stevenson, 1982).

Organic matter is a vital constituent of all soils because the productive power of soils is found to be proportionate to the amounts of organic matter present (Adrian, 1927). The significant functions of organic matter in the soil include: serving as a source of N, P, and S for plant growth; providing a substrate for microflora and microfauna organisms; promotion of good soil structure thereby improving tilth, aeration and retention of moisture; formation of complexes with micronutrients preventing their leaching; maintaining of cation exchange and buffering capacities; blocking P fixation sites; absorption of pesticides and other organic chemicals (Greenland and Dart, 1972; Stevenson, 1982; Jeffrey, 1987). Also, the fulvic and humic acids produced during decomposition of humus assist in the release of plant nutrients by decomposing mineral particles (Kononova, 1961).

Carbon is the chief element present in soil organic matter comprising from 48 to 58% of the total weight (Nelson and Sommer, 1982) and by use of appropriate correction factor, it is used to estimate organic matter.

The organic carbon content of a soil in equilibrium with the vegetation is found to be a function of the annual additions and decomposition of organic carbon, but this equilibrium is changed when addition and rate of decomposition of soil organic carbon change as a consequence of cultivation (Sanchez, 1976). The factors that govern microbial activity, that is , temperature, pH, moisture content, oxygen availability, inorganic nutrients, and others all influence the decomposition of both freshly added organic matter and humified organic matter (Jenkinson, 1981). Thus, cultivation which increases aeration and improves physical condition of soil stimulates microorganisms, to greater activity and results in the loss of organic matter (Adrian, 1927). Also, the humus content decreases with the ploughing-up of virgin lands and fallows and with long-term continuous cultivation of annual crops due to the fact that the decomposition of humic substances is not accompanied to a sufficient extent by the new formation of these substances (Kononova, 1961).

In no-fertilizer agricultural soils, the cropping systems where land is continuously cultivated might lead to organic matter decline. Reed (1951) found that carbon contents were maintained at about 75% of the equilibrium levels where traditional shifting cultivation was practiced but had dropped to 50% where crop to fallow period has been reduced by population pressure.

Because organic matter is reduced by cultivation and is known to be essential to successful crop production, rational systems of agriculture have been worked out to provide for its replenishment. Sowing of perennial grasses, application of farmyard manure, greenmanure and crop residues have been established as ways of adding organic matter to the soil (Adrian, 1927; Kononova, 1961; Thompson and Troeh, 1973). The amount of organic matter gained from each practice depends on the rate of decomposition: a process consequently dependent on factors that govern microbial activities (Jenkinson,1981) and also on other factors such as soil structure, size of organic material, soil animals and method of placement of organic material (Wild, 1988). Thus, clay soils have more organic matter than sandy soils because structurally, clay soils have a protective aspect of organic matter through which they adsorb otherwise readily available substrates making them less available to the soil population (Jenny, 1980). Chechire et al., (1974) found that finely ground material of ryegrass lost 61 per cent of its carbon in 448 days and only 52 per cent by the coarse one. Soil animals play a major role in comminuting organic matter (Dickinson and Pugh, 1974) and those large enough like termites and earthworms may assist in transport of plant debris to environment more propitious for biological attack. Also, litter of straw decomposes more slowly on the surface than when incorporated in the soil (Harper and Lynch, 1981).

Although crop residues have been shown to improve soil conditions for crop production, negative effects have also been realized. Straw residues remaining from the preceding crop can result in decreased yields (Elliott et al., 1978) a phenomenon attributed primarily to the production by microorganisms of phytotoxins, notably acetic acid (Cochran et al., 1977). The immobilization ofavailable soil nitrogen in the microbial population which decomposes straw may also contribute to the decrease in yield, but in general this is more of a problem with buried than with surface straw (Kimber, 1973).

CHAPTER III

MATERIALS AND METHODS

3.1 Experimental sites: The objectives of this study were addressed in experiments conducted between March 1987 and August 1990 in Machakos District, a semi-arid region in Eastern Kenya. The sites were situated in low agricultural potential areas which had a ratio of average annual rainfall and the potential evaporation of lower than 40% (Woodhead, 1968; Siderius and Muchena, 1977; Siderius, 1980). They fell under the Agro-climatic zone IV (Jaetzold and Schmidt, 1983). The sites were located at farmers' fields outside the National Dryland Farming Research Centre (NDFRC), Katumani. Kimutwa site (at John Mumo's Farm) is located 2 km East of the NDFRC (37° 17' E and 1° 35' S) at an altitude of 1575 m, above sea level (asl) while Masii site (at Paul Muteti's Farm - Mikuyuni village) is located about 25 km N.E. of NDFRC (37° 28' E and 1° 30' S) and about 6 km south of Masii Agricultural Holding Station situated at an altitude of 1300 m asl.

The rainfall distribution at the two sites is bimodal. The rains normally come in two short seasons: end of March to May, a season referred to as long rains (LR) and end of October to December also referred to as short rains (SR). The monthly rainfall distribution measured during the study period is presented in Appendix Table 1. The soil physical and chemical characteristics of the sites are given in Table 1. The information available about the sites before the experiments were started indicated that Kimutwa site had grass continuously for many years while Masii site was under continuous maize and bean intercrops without animal manure or fertilizer application.

3.2 Soil data collection: Initial sampling at the experimental plots was done during a dry period about a month prior to ploughing of the land. Soil samples were taken from the surface layer depth (0 - 20 cm), using a 10-cm diameter Jarrett auger. A random procedure was

Table 1 - Some characteristics of surface (0-20 cm) initial soils obtained from experimental sites.

Soil Characteristics	Kimutwa near Katumani	Masii at Mikuyuni	Soil classification		Cropping history of the field	
			Kimutwa site	Masii site	Kimutwa site	Masii site
Particle size (Hydrometer method %)			Textural class			
Clay	36	7	sandy clay loam	sand		
Silt	8	3				
Sand	56	90			Grass/cattle grazing for over 5 years	Maize/legumes grown for over 5 years
Soil pH (0.01M $CaCl_2$)	5.60	5.8				
Mineral N (ug/g soil)	0.39	2.99				
Total N (%)	0.11	0.08				
Organic carbon (%)	0.94	0.66				
C/N ratio	8.50	8.3	Soil classification*			
Cation Exchange capacity (CEC) (me/100 g soil)	17.5	6.3	Dystric Nitisol (1)	Acrisol (2)		No fertilizer added
Exchangeable cations:						
Potassium (mg/100 g soil)	41.0	17.6				
Calcium " " "	31.6	12.2				
Magnesium " " "	23.0	3.5				
Extractable P " " "	0.70	0.43				

* (1) Okalebo, 1987.
(2) FURP, 1988.

utilized in taking samples in order to cover the field; 18 samples were taken at Kimutwa and 12 at Masii. The number of soil samples taken were determined by the size of the land donated: Kimutwa field was bigger than that at Masii and so the higher the number of samples taken to cover the field. Soils were air-dried in the laboratory and later ground and sieved through a 2 mm screen and used for physical and chemical analyses. The soil samples for nitrogen and organic carbon determination were ground further to pass through a 60 mesh sieve (0.25 mm).

Other soil samples obtained during the study period were taken from individual treatment plots after the final crop harvest but just one to three days before planting for the following season. Surface soil (0-20 cm layer) samples were taken in all seasons. Four samples per treatment plot were taken. They were first bulked and then sub-sampled to make a single sample per plot for laboratory analysis.

Methods for soil physical and chemical analyses were as follows:

3.2.1 <u>Soil texture:</u> The soil particle-size distribution analysis was carried out using the hydrometer method of Bouyoucos (1962) which utilizes the differences in speed of sedimentation of sand, silt and clay soil particles.

3.2.2 <u>Soil pH:</u> The soil reaction was determined in 0.01 M $CaCl_2$ in a 1:2.5, soil to dilute salt solution suspension (as outlined by Page et al., 1982). The solution was left to equilibrate for 1 hour, and using a direct reading glass electrode of Fisher Accumet pH meter, model 230 the pH readings were taken.

3.2.3 <u>Organic carbon:</u> The Walkley - Black method (1934) was used to estimate organic carbon in the soil. The soil of the study area was thought to have low organic carbon and so the weight of the sample used for analysis was 1 gramme. The procedure uses a mixture of concentrated sulphuric acid, H_2SO_4 and 1N potassium dichromate ($K_2Cr_2O_7$)

to oxidize carbon in the soil. After one hour of reaction, the excess $K_2Cr_2O_7$ not used in the oxidation was titrated with ferrous ammonium sulphate. The $K_2Cr_2O_7$ reduced during the reaction with soil, the difference between added and excess, is taken to be equivalent to the organic C present in the soil sample. The organic C contents in the soil were not corrected for carbon complete recovery.

3.2.4 **Cation exchange capacity (CEC):** The method used in the determination of CEC was that of 1N ammonium acetate (NH_4OAc) solution buffered at pH 7.0, as described by Jackson (1958). The soil was leached with an excess of neutral, 1N NH_4OAC solution to remove the exchangeable cations and to saturate the exchange material with ammonium. After the soil leaching process with NH_4OAC was complete the soil was then leached again with alcohol and finally with potassium chloride (KCl) in order to recover the total ammonium, NH_4, retained by the soil. A volume of 500 ml was collected. A 10-ml leachate was distilled with sodium hydroxide (NaOH) and titrated with hydrochloric acid. The total NH_4, retained by the soils after washing them free of excess NH_4OAC, was regarded as an estimate of C.E.C.

3.2.5 **Exchangeable potassium, calcium, magnesium and ammonium lactate-Acetic acid (AL-solution) phosphorus:** The procedure of Egner et al. (1960) which utilizes lactic acid, anhydrous ammonium acetate and acetic acid to make ammonium lactate-Acetic acid (AL-Solution) was used. This extracting solution was buffered with acetic acid at pH 3.75. The AL-solution was added to the 5 g of air-dry soil (2 mm) sample and the bottle stoppered. The contents were shaken on end-over-end shaker for 1.5 hours and filtered through a Whatman filter paper No. 542. The filtrate was used for the estimation of the above elements. Exchangeable potassium, calcium and magnesium were determined on an atomic absorption spectrophotometer while available phosphorus was estimated colorimetrically using a CE 202 UV spectrophotometer, Model Unican SP 90.

3.2.6 **Total nitrogen:** Total nitrogen was determined by the semi-micro Kjeldahl method. Organic N in the soil sample under analysis was converted to ammonium-nitrogen (NH_4-N) by digestion under heat using concentrated H_2SO_4 and $CuSO_4$-Se-K_2SO_4 mixture as a catalyst. After the completion of digestion the soil digest solutions were diluted with water and then treated with aqueous sodium hydroxide, NaOH, and distilled with steam. The ammonia, NH_3, liberated by distillation of Kjeldahl was collected in dilute boric acid (H_3BO_3) - indicator and determined by titration of the distillate with dilute hydrochloric acid, HCl; the ammonia titrated was used in the estimate of total nitrogen in soil samples.

3.2.7 **Inorganic nitrogen:** The method of extraction and steam distillation described by Keeney and Nelson (1982) was used to determine exchangeable nitrogen (ammonium, NH_4^+, nitrate, NO_3^-). A 10 g air-dry soil (2 mm) was weighed into a 250 ml bottle and 100 ml of 2 M KCl was added to the soil; the contents were stoppered and shaken on a mechanical shaker for 1 hour. The soil-KCl suspension was filtered through a filter paper No. 542. A 20 ml aliquot of the soil extract was distilled with 0.2 g of Magnesium oxide, MgO, as the alkaline reagent and 0.2 g of Devarda's alloy as the reductant. The ammonia, NH_3, liberated was absorbed in dilute boric acid, H_3BO_3, was determined by titration with dilute (0.005 N) sulphuric acid, H_2SO_4, whose 1 ml was equivalent to 70 micro-gram of NH_4-N; the ammonia furnished the estimate of exchangeable N in the soils.

In summary, the sites had contrasting soils: Kimutwa soil was sandy clay loam classified as dystric Nitisol while that of Masii was sand and classified as Acrisol Table 1). Generally, the soil from Kimutwa site was found to be more fertile than that from Masii site with regard to soil nutrients. However, the higher mineral N (NO_3-N + NH_4-N) of soil from Masii than that from Kimutwa could partly be explained by the fact that, soil in Masii was under cultivation, a practice that would enhance decomposition of organic matter (Bauer and Black, 1981) thus leading to increased soil mineral N (Dowdell and Connell, 1975). The higher total N in Kimutwa soil than that in Masii soil may be attributed to higher organic carbon in the former soil than in the latter since N in soils is closely associated with soil organic matter (Lyon and Buckman, 1922). The higher CEC in Kimutwa soil than in Masii soil could be due to higher clay content and organic matter in the former site than the latter. The differences between the soils could partly be due to the different soil types and cropping history of the experimental fields.

3.3 **Experimental design and treatments:** The experimental design, treatments and replication for the trials remained the same during the period of this study. Only the plot size was different because that depended on the area of land allocated by the donor,that is the farmer. Plot size of 3.6 m x 4.0 m was used at Kimutwa site and of 3.0 m x 4.0 m at Masii site.

A split-plot design with three replications of each treatment was used in this study. Four nitrogen fertilization levels with Calcium Ammonium Nitrate (CAN) as the source, formed the main plots and nine cropping systems (cultural treatments) made up the sub-plots.

The cropping system treatments and their codes were as follows:

1. Maize Sole Crop - Continuous (MSC)
2. Bean Sole Crop - Continuous and No bean Residue returned to plots (BSCNR).
3. Bean Sole Crop - Continuous and bean Residue Returned to plots (BSCRR).
4. Maize / Bean sole crop in Rotation and No bean Residue returned to plots (Rot-NR).
5. Maize / Bean sole crop in Rotation and bean

Residue Returned to plots (Rot-RR).

6. Maize / Bean Intercropped in the Same row and No bean Residue returned to plots (MISNR or BISNR)
7. Maize / Bean Intercropped in the Same row and bean Residue Returned (MISRR or BISRR)
8. Maize / Bean Intercropped on Alternate rows (one row of beans between two maize rows) and No bean Residue returned (MIANR or BIANR).
9. Maize / Bean Intercropped on Alternate rows and bean Residue Returned (MIARR or BIARR).

Also, other codes such as M-BISNR, M-BISRR, M-BIANR and M-BIARR were used in some Tables to indicate the effect of maize and beans intercropped in the same row and no bean residue returned, maize and beans in the same row with bean residue returned, maize and beans intercropped in the alternate row and no bean residue returned, and maize and beans intercropped in the alternate row with bean residue returned, respectively. Also, initials like Rot-MNR; Rot-MRR; Rot-BNR; Rot-BRR, were used in Tables 51 and 52 to indicate what kind of crop the rotation has, that is, maize (M) or beans (B).

A maize plant population density of 55,550 plants/ha spaced at a between-row and within-row of 60 cm and 30 cm, respectively, was used in in this study whereas a bean population of 222,220 plants/ha was planted at between-row and within-row spacing of 60 cm and 7.5 cm, respectively.

3.4 **Crops, fertilization, planting and management:** The Katumani composite B maize variety and bean cultivar Mwezi moja, an early maturing bush type suitable for the marginal rainfall were used in the study.

Calcium ammonium nitrate (CAN- 26% N) was the source of nitrogen. Four fertilization levels used were: 0, 25, 50 and 100 kg N/ha, designated as NO, N25, N50 and N100, respectively. Calcium ammonium nitrate is found to contain calcium (7-14%), magnesium (0-6%) and sulfur (10%) (Tisdale et al., 1985; Jones, 1982). Single superphosphate (18% P_2O_5) was the source of phosphorus. Single superphosphate contains 10 -12% sulfur and about 17 - 22% calcium and 0.3% magnesium (Ombwara, 1972; Jones, 1982). Prior to planting, shallow furrows of about 8 cm deep were made using sharp sticks. The CAN was applied in two splits, one at planting and the other one at 20 days after seedling emergence (DAE). At planting, a starter dose of N at the rate of 25 kg N/ha was applied to all treatments receiving N while phosphorus at the rate of 40 kg P_2O_5/ha was applied to all treatments. The starter dose of N was not applied in the SR of 1988/89 at Kimutwa and in both the LR of 1988 and SR of 1988/89 at Masii because it was found to reduce the seedling stand.

The second application of N fertilizer was done the same day plant thinning was carried out at 20 DAE. The CAN was side-dressed to all rows of the treatments that were to receive N.

The first trial was planted during the long rains of 1987 at Kimutwa alone. This was because, there was a long delay in the onset of rains at Masii such that when they came, it was too late to plant. However, both sites were planted during the seasons that followed, that is, from the SR of 1987 to the LR of 1990. The study was carried out for seven seasons in Kimutwa and six in Masii. There were four complete seasons (from LR 1988 through SR 1989/90) in both sites when all treatments were used. In the LR season of 1990, no fertilizer (N or P) was applied. Only sole maize was planted in all plots that were previously under different cropping systems and N fertilizer rates. During this season the objective was to investigate the residual effect of N fertilizer, bean residue and various maize-bean cropping systems on sole maize production.

Maize and beans were planted two seeds per hill in the furrows and three weeks after 75% emergence, seedlings were thinned to one per hill in order to achieve the required population. Beans intercropped with maize were in two spatial arrangements. One pattern had a single row of beans intercropped between two maize rows and was referred to as "alternate row" (-IA--) and the other had maize and beans intercropped on the same row (-IS--). Beans planted in the same row with maize were placed in the same hills and between maize hills so that the needed population was obtained. Seeds in the furrows were then covered with soil.

In all cases plantings were done near or at the onset of rain. During the long rains, plantings were usually done between 12th March and 25th March except one season when it was done between 5th and 8th April. During the short rains, plantings were normally carried out between 25th October and 3rd November except one season when it was done between 3rd and 12th November.

Crops were kept weed free by hand-weeding three times before the final harvest. There were no disease and pest problems. Beans were harvested between 91 and 96 days while maize was harvested later and it was from 114 to 145 days after planting.

3.5 __Plant data collection__: Competition between maize and beans was assessed in the harvests taken during vegetative, reproductive and maturity growth stages. At three sampling dates (20, 40 and 60 days after seedling emergence - which coincided with the growth stages of vegetative; bean flowering /podding and maize initial tasseling; bean seed-fill and maize silking growth stages) six bean plants and four maize plants were sampled at random from each plot. The green harvests were taken to the laboratory where they were weighed for fresh weight then chopped with a knife into small sizes and oven dried at 70°C and dry matter determined. Later, the dry matter was ground in a Wiley mill to pass a 20 mesh screen and the content and uptake of N,P,K,Ca and Mg based on the plant dry weight data were determined.

Data of effects of rotation on maize and bean yields and nutrient uptake in Kimutwa were taken during the SR of 1987/88, SR of 1988/89 and SR of 1989/90 for maize and during the LR of 1988 and LR of 1989 for beans. In Masii, the same data were collected during the LR of 1988 and LR of 1989 for maize and the SR of 1988/89 and SR of 1989/90 for beans. The effect of bean residue on maize and bean performance was evaluated at the above named different growth stages and at maturity of both crops. At maturity, maize stand counts and height measurements were made for the whole plot and plants were harvested by cutting them at the soil surface. Total fresh weight, number of cobs and fresh weight of cobs were recorded in the field. Then a sample of ten cobs and four stovers (tops without cobs) was taken to the laboratory where fresh weight was taken. The samples were then put in the oven at 70°C where they stayed for four days and then removed. Cob and stover dry weight was determined. Grains were removed from cobs by hands. A crop moisture detector model G-6C (Delmhorst Instrument Co.,USA) was used to estimate moisture content of grains and grain yield was expressed on a 15 percent moisture content. Maize grains and stovers were ground and contents and uptake of N, P, K, Ca, Mg determined. At harvest time maize stover was collected and removed from the plots.

The bean stand counts per plot were made at maturity and plants harvested from the whole plot by pulling them out of the soil. Total dry matter of bean plants harvested per plot was determined in the field and bean pods were threshed in order to obtain seeds. The bean seeds obtained were taken to the laboratory where seed fresh weight was determined and then oven dried at 70°C for four days, after which time, the seed dry weight was taken. The moisture content of the dried seeds was estimated by a moisture meter which was used for maize seeds but in the case of beans it was fitted with a bean plate. The bean seed yield was, however, expressed on a 14 percent moisture content. After the bean pods were threshed, a sample of ten plants (haulms) from each experimental plot was collected at random and taken to the laboratory where its fresh weight was determined and oven dried at 70°C. The dry matter yield of the ten plant sample was used to determine the dry matter of haulms per plot which in turn was used in estimating total dry matter yield of haulms per hectare.

The haulms left after the sample of ten bean plants were taken to the laboratory were chopped into small bits using a machete and this residue was evenly spread in the plots where bean residue was to be returned and immediately incorporated into the soil by use of hoe.

The dried haulms and seed samples of both maize and beans were ground separately and stored in sealed polythene bags. A sub-sample of the ground material was put in a test tube, redried in an oven and cooled in a desiccator before subjecting it to chemical analysis in order to determine the nutrient content (percent) and uptake (concentration x dry matter) of N, P, K, Ca and Mg. Total N was determined using the semi-microkjeldahl procedure. The chemical analysis for P, K, Ca, Mg was done by wet-ashing the samples using concentrated sulphuric acid, H_2SO_4, and a 30% W/V of hydrogen peroxide, H_2O_2 as described by Lindner and Harley (1942), Miller and Miller (1948) and Thomas et al. (1967). Phosphorus in the extract was determined calorimetrically on a CE 202 UV spectrophotometer while potassium, magnesium and calcium were measured on an atomic absorption spectrophotometer, model Unican SP 90.

The uptake of nutrients by whole plants was obtained by summing up the individual crop seeds and stovers (haulms) nutrient uptake per season. The uptake by the total systems which was expressed on per hectare basis in a given season (TGY/ha) were calculated as the sum of whole plants nutrient uptake of the two crop species grown as intercrops. Total systems nutrient uptake expressed as per hectare per year (TGY/ha/yr) were calculated differently, however, because they were the summation of nutrients taken up by each cropping system, that is, sole crop, rotation crops or intercrops grown in the same plots in two consecutive seasons, that is, a long rainy season followed by a short rainy season to make a year. The data of nutrient uptake per hectare per year were used to evaluate the uptake by a complete rotation with the other cropping systems, while the data of whole plant and total system expressed on per season basis were meant to evaluate continuous or rotation sole crops and intercrops in a given season.

The evaluation of the productivity of intercropping systems relative to monoculture was done using the Land Equivalent Ratio (LER) (Sanchez, 1976). The LER of each intercropping system was obtained by summing up the relative yields, that is, yields (kg/ha) of maize and beans in the same intercropping system were divided by that of maize and beans in sole cropping in order to give relative yields and then added together to give LER. The formula used for LER was:

$$LER = \frac{Ymi}{YMS} + \frac{Ybi}{YBS}$$

where Ymi is the seed yield of intercropped maize, YMS is seed yield of sole crop maize, Ybi is the yield of intercropped beans and YBS is the yield of sole crop beans, all expressed as kg/ha.

3.6 Data Analysis: Analysis of variance was performed on the data collected both in the field and in the laboratory in order to find the effects of N fertilizer and cropping systems (cultural treatments) on maize and bean performance, contents and uptake of N and other macronutrients and chemical changes that might have occurred in the soil.

Least significant difference (L.S.D.) and to a small extent New Duncan Multiple Range Test (DMRT) were used to compare the differences between N fertilizer treatments and cropping systems while orthogonal contrasts were calculated for group mean comparisons of cropping systems. The relationships between plant parameters measured, fertilizer N applied, soil-test N and other soil chemical properties were obtained by use of correlation and regression analyses.

CHAPTER IV

RESULTS AND DISCUSSION

4.0 Effects of N, bean residue and cropping systems on dry matter yields

4.1 Maize Dry Matter Production:

4.1.1 Maize dry matter at 20 days after seedling emergence (DAE): Nitrogen fertilizer application at planting (i.e. the starter dose) at the rate of 25 kg N/ha as calcium ammonium nitrate (CAN) did not significantly increase maize dry matter yields (DMY) per plant, during the first planting season at any of the sites, Kimutwa (LR 1987) and Masii (SR 1987/88) (Tables 2 and 3). In the other seasons, the N starter dose was found to significantly increase the DMY of maize in Kimutwa during the short rains of 1987/88 ($P < 0.05$), long rains of 1988 ($P < 0.01$) and 1989 ($P < 0.05$) and in Masii during the long rains of 1989 ($P < 0.01$) and short rains of 1989/90 ($P < 0.01$) (Tables 2 through 7). The N starter dose increased the maize DMY at 20 DAE by between 43 to 93% in Kimutwa and from 210 to 249% in Masii. The lower total N in the soil of Masii may explain this higher response to N found in maize DMY.

Nitrogen starter dose was not applied during the planting of long rains of 1988 and short rains of 1988/89 at Masii and during the short rains of 1988/89 at Kimutwa after the CAN application showed some harmful effects on the seedlings at emergence time. During these seasons the full dose, that is, 25, 50 and 100 kg N/ha per treatment was top-dressed at 20 DAE. At 20 DAE during these seasons when no N starter dose was applied, there was a previously N applied residual effect observed on maize DMY at Masii alone. There was a non-significant maize top yields increase of 10, 36 and 95% during the long rains of 1988 and a significant ($P < 0.01$) increase of 142, 113 and 154%

Table 2 – Dry matter yield (g/plant) of maize and beans at different growth stages (days after emergence – DAE) at kimutwa

LR 1987	Cropping Systems	Maize Fertilizer rate (kg/ha)						Beans Fertilizer rate (kg/ha)					
DAE		N0	N25	N50	N100	Mean	LSD 0.05	N0	N25	N50	N100	Mean	LSD 0.05
20	Sole	1.22	2.25	–	–	1.74a		0.92	1.09	–	–	1.01a	
	ISR	0.96	1.30	–	–	1.10b	0.32	0.86	0.99	–	–	0.93ab	0.06
	IAR	1.13	1.38	–	–	1.26b		0.81	0.95	–	–	0.88b	
	Mean	1.08	1.64	–	–	1.36		0.86	1.01	–	–	0.94	
	LSD 0.05												
40	Sole	8.2	7.30	9.95	9.38	8.71a		1.34	1.65	1.45	1.71	1.54a	
	ISR	2.71	3.94	4.66	4.18	3.78b	1.09	1.06	1.25	1.17	1.41	1.22b	0.19
	IAR	3.34	4.09	5.02	4.21	4.17b		0.86	0.99	1.02	1.35	1.06b	
	Mean	4.75	5.11	6.54	5.92	5.58		1.09	1.30	1.21	1.49	1.27	
	LSD 0.05			–									
SR 1987/88													
20	Sole	0.42	0.69	0.79	1.28	0.80a		0.48	0.47	0.42	0.48	0.46	
	ISR	0.46	0.48	0.70	0.69	0.58b	0.19	0.45	0.47	0.47	0.47	0.47	
	IAR	0.43	0.44	0.72	0.91	0.63b		0.49	0.44	0.46	0.44	0.46	–
	Rot.	0.60	0.70	0.59	0.69	0.65b		–	–	–	–	–	
	Mean	0.48b	0.56b	0.69ab	0.83a	0.67		0.47	0.46	0.45	0.46	0.46	
	LSD 0.05			0.15						–			
40	Sole	5.61	7.66	7.16	8.09	7.13a		1.44	1.28	1.11	1.42	1.31a	
	ISR	2.60	4.07	5.45	4.39	4.13b		0.89	1.09	1.14	0.97	1.02b	0.277
	IAR	2.67	3.90	4.44	3.91	3.73b	1.45	0.81	1.03	0.97	1.44	1.06b	
	Rot.	5.00	6.69	6.54	8.77	6.75a		–	–	–	–	–	
	Mean	3.73b	5.28a	5.72a	6.03a	5.44		1.05	1.13	1.07	1.24	1.12	
	LSD 0.05			0.99						–			

Means with the same letter are not significantly different at P = 0.05 level, according to New DMRT.

Table 3 – Dry matter yields (g/plant) of maize and beans at different growth stages (DAE) at Masii.

SR 1987/88

		Maize						Beans					
	Cropping	Fertilizer rate (kg/ha)						fertilizer rate (kg/ha)					
DAE	Systems	N0	N25	N50	N100	Mean	LSD 0.05	N0	N25	N50	N100	Mean	LSD 0.05
20	Sole	0.51	0.51	0.38	0.42	0.46	–	0.59	0.70	0.76	0.81	0.73	–
	ISR	0.41	0.49	0.36	0.56	0.46		0.68	0.67	0.74	0.73	0.71	
	IAR	0.45	0.53	0.46	0.58	0.51		0.61	0.70	0.64	0.65	0.65	
	Mean	0.45	0.51	0.41	0.54	0.48		0.63	0.69	0.71	0.75	0.70	
	LSD 0.05			–						–			
40	Sole	9.49	12.85	9.64	10.32	10.58a	2.18	2.70	4.60	5.06	5.01	4.34a	0.51
	ISR	5.05	6.84	9.27	10.49	7.91b		2.49	3.85	4.75	4.00	3.77b	
	IAR	7.00	8.56	9.01	7.45	8.01b		2.04	3.47	3.24	3.50	3.06c	
	Mean	6.72	8.73	9.24	9.24	8.83		2.41b	3.97a	4.35a	4.17a	3.73	
	LSD 0.05			–						1.47			
60	Sole	9.67	11.83	13.51	11.23	11.56a	1.58	2.66	4.41	4.41	4.68	4.04a	0.59
	ISR	9.14	9.51	8.40	9.8	9.21b		2.57	3.17	3.26	2.56	2.89b	
	IAR	7.82	10.45	8.92	8.61	8.95b		1.66	3.03	2.21	2.54	2.36b	
	Mean	8.72	10.35	9.63	9.61	8.95		2.38	3.76	3.57	3.61	3.10	
	LSD 0.05			–						–			

Means with the same letter are not significantly different at P = 0.05 level, according to New DMRT.

DAE = Days after seedling emergence.

Table 4 – Dry matter yields (g/plant) of maize and beans at different growth stages (days after emergence – DAE), LR 1988.

Site	Kimutw								Masi							
Crop	Maize				Beans				Maize				Beans			
DAE	20	40	60	Mat*.	20	40	60	Mat.	20	40	60	Mat.	20	40	60	Mat.
N0	1.29	19.3	37.3	4467	1.06	4.8	8.7	2115	0.34	4.5	13.3	1246	0.60	1.8	3.0	552
N25	1.81	26.9	51.1	5971	1.19	5.7	11.5	2983	0.37	7.2	25.8	2318	0.56	2.9	5.9	1165
N50	1.87	31.2	59.2	6858	1.25	5.6	13.2	3115	0.46	9.8	27.6	2842	0.60	2.9	7.1	1465
N100	1.87	32.5	60.3	6920	1.27	5.7	12.5	3020	0.66	12.5	38.3	3453	0.68	3.4	7.0	1315
Mean	1.71	27.5	52.0	6054	1.19	5.5	11.5	2808	0.46	8.5	26.2	2465	0.61	2.8	5.8	1124
F test	***	**	***	**	ns	ns	ns	**	ns	ns	*	**	ns	*	ns	ns
LSD 0.05	0.19	0.14	5.51	16.4	–	–	–	500	–	–	11.0	1020	–	0.96	–	–
Cropping Systems																
Sole–NR	2.08	36.6	66.0	6963	1.13	5.6	13.7	3211	0.48	8.9	27.2	2702	0.63	3.5	7.5	1540
Sole–RR	–	–	–	–	1.21	6.9	12.9	3322	–	–	–	–	0.68	2.9	7.1	1354
ISNR	1.64	24.9	44.5	5699	1.23	5.4	8.4	2250	0.41	7.6	25.1	2132	0.60	2.8	5.2	1011
ISRR	1.71	29.2	51.6	6464	1.16	4.9	7.4	2188	0.45	8.0	27.6	2044	0.60	2.5	5.4	982
IANR	1.61	22.7	49.1	5303	1.00	3.9	7.8	1808	0.41	8.1	23.7	2154	0.59	2.7	5.0	910
IARR	1.51	23.9	48.6	5843	1.07	4.1	8.3	1743	0.43	7.6	23.7	2103	0.57	2.0	4.5	949
Rot.NR	–	–	–	–	1.31	5.9	16.8	4193	0.57	10.1	29.5	3215	–	–	–	–
Rot.RR	–	–	–	–	1.34	7.0	14.6	3750	0.48	9.5	26.9	2904	–	–	–	–
Mean	2.14	27.5	52.0	6054	1.19	5.5	11.5	2808	0.46	8.5	26.2	2465	0.61	2.8	5.8	1124
F test	**	*** b	***	**	**	**	**	***	*	ns	ns	*	*	**	*	***
LSD 0.05	0.29	4.24	7.70	15.14	0.18	1.47	3.03	533	0.09	–	–	736	0.05	0.65	1.92	293

*, **, *** = Treatment differences are significant at 0.05, 0.01, 0.001 level, respectively.
ns = Treatment differences are not significant at 0.05 level, respectively.
b, Mat. = Interaction is significant at 0.05, 0.01; maturity, respectively.
Mat*. = dry matter yield in kg/ha

Table 5 – Dry matter yield (g / plant) of maize and beans at different growth stages (days after emergence – DAE), SR 1988

Site	Kimutwa								Masii							
Crop	Maize				Beans				Maize				Beans			
DAE	20	40	60	Mat.	20	40	60	Mat.	20	40	60	Mat.	20	40	60	Mat.
N0	2.46	15.0	56.8	7314	0.97	1.9	3.5	790	0.24	2.1	16.6	1726	0.74	1.9	4.9	986
N25	2.37	15.9	60.1	9022	0.93	2.0	5.6	1039	0.58	2.7	25.4	3666	0.89	2.8	9.0	1586
N50	2.53	16.2	68.0	9031	0.95	1.7	5.8	989	0.51	3.4	25.4	6429	0.96	2.6	9.0	1769
N100	2.54	17.0	69.3	10388	0.84	2.2	5.8	1069	0.61	4.7	27.0	6061	1.05	3.2	6.4	1778
Mean	2.47	16.0	64.1	8939	0.92	1.9	5.2	972	0.49	3.3	23.7	4471	0.91	2.6	7.3	1530
F test	ns	ns	ns	ns	ns	ns	*	ns	**	**	ns	*	ns	ns	ns	*
LSD 0.05	–	–	–	–	–	–	1.5	–	0.15	1.19	–	2793	–	–	–	584
Cropping Systems																
Sole–NR	2.56	17.3	74.0	9412	1.08	2.4	6.8	1329	0.54	4.0	27.5	6082	1.10	2.8	6.6	1539
Sole–RR	–	–	–	–	0.90	1.7	5.9	1157	–	–	–	–	0.93	2.5	7.0	1486
ISNR	2.37	14.4	59.2	7877	0.91	2.1	4.2	829	0.46	3.4	19.5	3244	0.95	3.2	6.8	1542
ISRR	2.37	14.7	60.9	8558	0.90	2.0	5.1	918	0.40	2.8	21.3	3878	0.89	2.1	5.5	1335
IANR	2.20	14.6	60.4	8206	0.92	2.0	4.9	933	0.53	2.7	26.4	4430	0.73	1.7	6.1	1035
IARR	2.55	15.7	55.9	7884	0.83	1.4	4.1	652	0.49	3.1	23.2	4719	0.68	2.5	9.7	1348
Rot.NR	2.79	17.4	70.8	10834	–	–	–	–	–	–	–	–	1.02	3.1	9.4	2137
Rot.RR	2.51	17.9	63.8	9802	–	–	–	–	–	–	–	–	0.97	3.1	7.5	1819
Mean	2.47	16.0	64.1	8939	0.92	1.9	5.2	972	0.49	3.3	23.7	4471	0.91	2.6	7.3	1530
F test	ns	**	*	***	ns	**	**	**	ns	ns	ns	*	*	ns	ns	**
LSD 0.05	–	2.10	11.83	1137	–	0.46	1.57	217	–	–	–	1578	0.26	–	–	496

*, **, ***, = Treatment differences are significant at P = 0.05, 0.01, 0.001 level, respectively.

ns, Mat. = Treatment means are not significantly different at P = 0.05 level; Maturity, respectively.

Mat*. = Dry matter yield in kg/ha

Table 6 – Dry matter yield (g/plant) of maize and beans at different growth stages (days after emergence–DAE), LR 1989.

Site	Kimutwa						Masii					
Crop	Maize			Beans			Maize			Beans		
DAE	20	40	Mat*.	20	40	Mat.	20	40	Mat.	20	40	Mat.
N0	0.62	6.5	2998	0.83	3.7	1575	0.36	2.9	783	0.45	2.0	910
N25	1.18	10.5	3415	1.25	5.4	1992	1.43	8.2	2507	0.77	3.5	1278
N50	1.10	12.0	3438	1.25	5.2	2224	1.30	9.4	3457	0.83	4.5	1580
N100	1.31	10.4	3432	1.15	5.1	1809	1.04	11.2	3104	0.70	3.7	1352
Mean	1.05	9.9	3321	1.12	4.9	1869	1.03	7.9	2463	0.69	3.4	1280
F test	*	**	ns	*	**	** c	**	**	**	*	***	ns
LSD 0.05	0.33	1.94	–	0.27	0.57	257	0.33	0.58	999	0.21	0.57	–
Cropping Systems												
Sole–NR	1.26	13.2	4030	1.13	4.7	1921	1.10	8.9	2640	0.86	4.4	1834
Sole–RR	–	–	–	0.94	4.2	1789	–	–	–	0.64	3.6	1378
ISNR	0.90	8.6	2760	1.15	4.4	1536	1.00	6.8	2147	0.63	3.3	1129
ISRR	0.98	8.6	3113	1.02	4.2	1423	0.97	6.6	1907	0.69	2.9	1173
IANR	0.95	9.0	3423	1.00	3.8	1099	0.95	6.9	2247	0.64	3.4	1089
IARR	1.03	10.0	3287	0.91	3.3	960	0.99	7.4	2245	0.67	2.9	1077
Rot.NR	–	–	–	1.30	7.3	3214	1.25	10.4	3149	–	–	–
Rot.RR	–	–	–	1.50	7.0	3012	0.98	8.5	2903	–	–	–
Mean	1.05	9.9	3321	1.12	4.9	1869	1.03	7.9	2463	0.69	3.4	1280
F test	ns	** c	**	**	** c	**	ns	** c	**	*	***	** b
LSD 0.05	–	1.65	494	0.23	0.59	273	–	0.86	619	0.15	0.49	265

*, **, ***, ns = Treatment differences are significant at P = 0.5, 0.01, 0.001 level, respectively.

ns; b, c; Mat. = Treatment means are not significantly different at P = 0.05 level; Interaction is significant at P = 0.05, 0.01, level; Maturity, respectively.

Mat*. = Dry matter yield in kg/ha

Table 7 – Dry matter yield (g/plant) of maize and beans at different growth stages (days after emergence-DAE), SR 1989/90.

Site	Kimutwa						Masii					
Crop	Maize			Beans			Maize			Beans		
DAE	20	40	Mat*.	20	40	Mat.	20	40	Mat.	20	40	Mat.
N0	1.68	15.2	4764	1.02	3.1	869	0.34	1.5	697	0.97	3.5	1443
N25	2.00	23.6	6832	1.23	5.1	1467	1.17	3.9	2423	1.55	6.0	2555
N50	2.75	27.6	7905	1.66	6.7	1864	0.93	6.9	3706	1.47	8.2	3712
N100	1.96	26.3	7540	1.23	6.6	1661	1.06	7.6	5285	1.52	6.8	2780
Mean	2.10	23.2	6760	1.28	5.5	1417	0.87	4.9	3028	1.38	6.1	2623
F test	ns	*	**	ns	**	**	**	**	**	*	ns	ns
LSD 0.05	–	6.3	1297	–	1.8	302	0.39	2.45	1735	0.36	–	–
Cropping Systems												
Sole-NR	2.11	25.4	6488	1.32	6.6	2248	1.08	4.9	3592	1.34	6.9	3178
Sole-RR	–	–	–	1.18	6.1	1744	–	–	–	1.32	6.3	2410
ISNR	2.01	22.2	6749	1.47	4.7	1285	0.91	5.3	3005	1.42	5.2	2308
ISRR	1.83	22.7	7120	1.16	4.5	1163	0.81	4.6	2994	1.28	4.4	1897
IANR	1.83	22.4	6407	1.28	5.1	1181	0.68	5.2	2636	1.19	4.6	1730
IARR	1.88	19.9	6533	1.32	5.3	1169	0.89	4.7	2912	1.26	4.8	1958
Rot.NR	2.54	26.3	6524	–	–	–	–	–	–	1.75	8.5	3894
Rot.RR	2.47	23.2	7254	–	–	–	–	–	–	1.47	8.2	3606
Mean	2.10	23.2	6760	1.28	5.5	1417	0.87	4.9	3028	1.38	6.1	2623
F test	***	ns	ns	ns	ns	***	ns	ns	ns	ns	***	***
LSD 0.05	0.38	–	–	–	–	443	–	–	–	–	2.2	898

*, **, ***, = Treatment differences are significant at P = 0.05, 0.01, 0.001 level, respectively.
ns; Mat. = Treatment means are not significantly different at P = 0.05 level; Maturity.
Mat*. = Dry matter yield in kg/ha

during the short rains of 1988/89 where 25, 50 and 100 kg N /ha levels had been applied in the previous seasons, respectively (Tables 4 and 5). The N response found in maize DMY in Masii during the long rains of 1988 and short rains of 1988/89 could be explained partly by the increased residual mineral N in the soil which was 3.2 ug N/g soil and 11 ug N/g soil as a result of N application in the previous seasons of short rains of 1987/88 and long rains of 1988, respectively.

The DMY of maize showed variations in response to different cropping systems with regard to seasons and sites. In Kimutwa, the cropping systems had a significant ($P < 0.01$) effect on DMY of maize in four seasons out of six while in Masii, the effect was significant ($P < 0.05$) in only one season out of five (Tables 2 through 7). The depressive effect of intercropped beans on maize DMY was observed as early as 20 DAE at both sites, during all the growing seasons of this experiment (Tables 2 through 7). The DMY of maize were significantly reduced by 25 to 31% during the long rains of 1987, 1988 and short rains of 1987/88 in Kimutwa, while in Masii, the non-significant reduction ranged from 12 to 19%. Physical observation indicated that at 20 DAE, the height of beans was not greater than that of maize. Hence, the depressive effect of beans on maize at this growth stage could not be attributed to shading but probably to underground competition. When N uptake at 20 DAE was considered for the long rains of 1987 and short rains of 1987/88 at Kimutwa, intercropped maize had its N uptake reduced by 39% and 25% respectively, relative to sole maize crop (Table 16). Hence, maize N uptake potential is reduced very early in the growing season and this is reflected in maize DMY. This depressive effect of bean on maize DMY at this early growth stage is important since the DMY at 20 DAE was significantly correlated with total dry matter at 40, 60 DAE, maturity and seed yield (Table 9).

Maize in rotation with beans had higher DMY than continuous sole maize (Tables 2 through 7). In Kimutwa, maize succeeding beans in rotation had significantly higher DMY than continuous sole maize by 19% ($P < 0.01$) during the short rains of 1989/90. In Masii, residual effect of rotation caused a non-significant higher (83%) maize DMY than continuous sole maize during the long rains 1988. The beneficial effects of bean rotation on maize corresponds well with the findings of Jones (1974) for groundnut followed by maize; Giri and De (1979) for groundnut, cowpeas and pigeon pea followed by millet; and Gakale and Clegg (1987) for soybeans followed by sorghum. Soil analyses by Jones (1974) showed that the soil mineral N content was considerably increased after legumes, confirming that yield advantage of cereal/legume rotations were due to a better N supply of the soil. This argument cannot be applied in this study because the differences between the soil mineral N measured in soils taken from continuous sole maize and rotation under bean plots were too small to have caused the significant increase in maize dry matter yields in the rotation system. At 20 DAE , the uptake of N by maize did not reveal the effect of rotation (Table 16). Probably, other soil nutrients may have contributed to the effect of rotation because at the beginning of the season, the rotation under bean plots had higher soil extractable P than that found in continuous sole maize plots by 0.08 to 1.3 mg P/100 g soil (i.e. 13 to 107%) in Kimutwa and by 0.5 to 1.1 mg P/100 g soil (15 to 42%) in Masii. Also, soil exchangeable K was found to be higher in the rotation under beans plots than in continuous sole maize plots by 3.5 to 4.5 mg K/100 g soil (11 to 13%) in Kimutwa and by 1.3 to 2.4 mg K/100 g soil (31 to 36%) in Masii. The effect of returned bean residue on maize DMY was not significant at 20 DAE (Tables 2 through 7).

Maize dry matter yield response to 25 kg N /ha at 20 DAE implied that the soil mineral N measured at the beginning of the season which ranged from 6.6 to 60 ug N/g soil in Kimutwa and from 6.5 to 36 ug N/g soil in Masii

(Tables 51 and 52) was probably not adequate for maize plants during the first 20 DAE or it might have been leached by the rain in the first few days such that maize plants were unable to utilize it. Further research is needed to confirm this theory.

4.1.2 __Maize dry matter at 40 DAE:__ Nitrogen fertilizer rates of 25 to 100 kg N/ha increased DMY of maize in all seasons (Tables 2 through 7). In Kimutwa, DMY of maize were significantly increased by N fertilizer in four out of six seasons and the average increase of the DMY ranged from 52 to 70%. In those four seasons (SR 1987/88, LR 1988, SR 1988/89 and SR 1989/90), the N fertilizer levels increased DMY in the order of N100 > N50 > N25 while in the other two seasons (LR 1987 and 1989), which were characterized by lower rainfall than the other four seasons (Appendix Table 1), the response of DMY to N fertilizer was in the order of N50 > N100 > N25 and N50 > N25 > N100, respectively. In three seasons out of five in Masii, DMY was significantly increased by N fertilizer with maize response to N ranging from 71 to 321%. All seasons in Masii except one (SR 1987/88) which had the lowest rainfall (161 mm), DMY response to N was in the order of N100 > N50 > N25 while the odd one out had the order of N100 = N50 > N25. Hence, DMY response to N was influenced by the amount of rainfall received. However, according to the data on maize DMY, maize in Masii had greater response to N than that in Kimutwa.

The effect of cropping systems on DMY of maize at 40 DAE was significant in five seasons out of six in Kimutwa and two out of five in Masii (Tables 2 through 7). In both sites, intercropping systems reduced DMY of intercropped maize compared with that of continuous sole maize. In Kimutwa, the significant reduction of maize DMY reduction due to intercropping ranged from 14 to 117% while in Masii, the reduction ranged from 23 to 25% . Comparison of DMY of intercropped maize from different spatial arrangements showed some differences. In Kimutwa, maize intercropped in the same row had higher DMY than maize intercropped in alternate row in three seasons (SR 1987/88, LR 1988 and SR 1989/90) by 6 to 16% while the alternate row also had higher DMY than the same row in the other three seasons (LR 1987, SR 1988/89, LR 1989) by 4.4 to 10%. Maize intercropped in the same row spatial arrangement produced significantly ($P < 0.01$) higher DMY than alternate row system in only one season (SR 1987/88). In Masii, DMY of intercropped maize in the two spatial arrangements did not differ significantly. However, one season (SR 1988/89) had maize in the same row system producing non-significantly higher DMY than maize in the alternate row by 7%. Also, two seasons (SR 1987/88 and LR 1989) had maize in alternate row system giving non-significantly higher DMY than that in the same row system by 1.3 and 11%. But two seasons (LR 1988 and SR 1989/90) had maize in the same row and alternate row spatial arrangements giving similar DMY.

The competition between maize and beans at 40 DAE was greater than at 20 DAE when per cent reduction of maize DMY due to the presence of intercropped beans was considered. In Masii, the higher competition which was reflected in higher reduction of maize DMY could partly be attributed to competition for moisture. There were significant reductions of DMY of intercropped maize during short rains of 1987/88 and long rains of 1989 when the amount of rain which fell during the period between 20 DAE and 40 DAE was 32.2 mm and 36.1 mm, respectively. During the long rains of 1988 and short rains of 1988/89 and 1989/90 the amounts of rain which fell in 20 days period, that is, between 20 DAE and 40 DAE were 175 mm, 72 mm and 52 mm, respectively, and DMY of intercropped maize were not significantly reduced. The moisture theory, however, does not explain well the results obtained from Kimutwa site because even when rainfall during the period between 20 DAE and 40 DAE amounted to 209 mm (LR 1988) and 58 mm (SR 1988/89) the competition between maize and beans was still significant. Nevertheless, work by Hardter (1989) showed that during the dry spells, maize suffered from moisture stress and the soil matric potentials confirmed that moisture stress was most severe under mixed cropping which led to low maize production in mixed cropping with cowpeas.

Effect of rotation on maize DMY at 40 DAE was found to vary with the sites (Tables 2 through 7). In Kimutwa, maize following beans in rotation had non-significant and lower dry matter yields than continuous sole maize by 5.3% during the short rain of 1987/88 and 2.4 to 2.6% during the short rains of 1988/89 and 1989/90. However, in Masii although the effect of rotation was not significant, the DMY of maize in rotation was increased above that of continuous sole maize by 10.5% (LR 1988) and 5.8% (LR 1989). The residual effect of bean rotation on maize DMY in Kimutwa at 40 DAE contradicts that observed earlier at 20 DAE whereby maize in rotation had higher dry matter than that from continuous sole cropping. A decrease in maize DMY due to return of bean residue was observed in Masii during the short rains of 1988/89 (3.5%) and 1989/90 (7.3%).

There was a significant ($P < 0.01$) interaction of nitrogen fertilizer levels and cropping systems on maize DMY during the long rains of 1989 at the two sites (Table 6). Data on DMY showed that continuous sole maize, maize in rotation and intercropped maize responded to N fertilizer levels differently (Table 6). In Kimutwa, the highest DMY response to N fertilizer for continuous sole maize and maize in alternate row occurred at N 50, and that in the same row occurred at N 100. At Masii the highest DMY of maize in all cropping systems occurred at N 100, but the DMY increase in each cropping system due to different levels of N fertilizer applied varied disproportionately among the cropping systems.

4.1.3 <u>Maize drv matter at 60 DAE:</u> Data on maize DMY at 60 DAE were not given for the long rain of 1987 and short rains of 1987/88 from both sites because crops did not reach this growth stage due to inadequate rainfall (Appendix Table 1) which caused plants to dry up. Nitrogen fertilizer application increased maize DMY by 16 to 130% at both sites (Tables 3 through 7). In Kimutwa, nitrogen fertilizer significantly increased ($P < 0.01$) the DMY by 52% during the long rains of 1988. Also, during the long rains of 1988 at Masii, maize had its DMY significantly increased ($P < 0.05$) by 130%.

Data on maize DMY of long rains of 1988 showed that continuous sole maize in Kimutwa had a response to N fertilizer of 36% which was less than that of intercropped maize which had a response of 58% and 60% for maize in the same row and alternate row, respectively. In Masii, maize gave greater response to N than that grown in Kimutwa. Thus, in Masii, continuous sole maize gave a response to N fertilizer of 268% while that in a rotation system, intercropped in the same row and in alternate row gave responses of 128, 106, and 113%, respectively relative to zero N treatment.

The cropping systems had a significant effect on maize dry matter yield in Kimutwa site only during the long rains of 1988 and short rains of 1988/89. Intercropping systems reduced maize DMY by 8 to 18% in Masii and by 20 to 36% in Kimutwa, indicating that higher competition between maize and beans occurred in Kimutwa than in Masii. In Kimutwa, rotation compared with continuous sole cropping did not improve DMY at 60 DAE but instead it reduced it by 8.8%. However, maize in the rotation gave significantly ($P < 0.05$) higher DMY than that of intercropped maize by 14%.

4.1.4 <u>Maize dry matter at maturity :</u> Maize in Kimutwa accumulated more dry matter at harvest time than that in Masii by 103% on average (Tables 4 through 7). Nitrogen fertilizer application at both sites was found to increase DMY by between 14 and 302% in all seasons from long rains of 1988 to short rains of 1989/90. In Kimutwa, DMY were significantly increased ($P < 0.01$) during the long rains of 1988 and short rains of 1989/90 by 47% and 51%, respectively. In Masii, the significant increase of DMY due to N fertilizer was by 187% (LR 1988, $P < 0.01$), 212% (SR 1988/89, $P < 0.05$), 288% (LR 1989, $P < 0.01$) and 302% (SR 1989/90, $P < 0.01$). The lack of significant response to N fertilizer by maize in Kimutwa at 40, 60 DAE and at maturity during the short rains of 1988/89 season can be attributed partly to the high rainfall throughout the growing season (Appendix Table 1) which could have caused leaching of N fertilizer applied because prior to planting, the level of mineral N ranged from 32.5 to 46.8 ug N/g (Table 51, 3rd season). The level of end of season mineral N in plots where N fertilizer was applied during the short rains of 1988/89 season seemed to indicate that leaching had taken place since it averaged 20.9 ug N/g soil which was comparable to that for control plots (zero N treatments) which measured 19.7 ug N/g soil. These findings were supported by the observations made by van der Paauw (1963) who showed that seasons that were preceded by greater rainfall provided lower carry-over N compared with seasons whose previous seasons had low rainfall. With reference to rainfall and soil texture, Nelson et al. (1968) reported that 25 mm water on a silt loam penetrates about 15 cm and this would imply that nitrate would be leached deeper in sandy soils as observed by Wild (1988) who reported that nitrate is more readily washed from sandy soil than from a loam soil. Maize is a deep-rooted crop with a high N requirement (Long and Huck, 1980) and can feed upto 150 cm deep or more in some soils (Nelson et al, 1968). The amount of rainfall that was received in three months during the short rains of 1988/89 from the time of N top dressing (20 DAE) to maturity was 267 mm and this was probably enough to leach mineral N to a depth of 160 mm or more in a light - texture soil of Kimutwa, thus reducing the availability of mineral N to the maize plants. In fact, the percentage response to applied N fertilizer in the uptake of N by maize plants during the short rains of 1988/89 season was the second lowest and this was accompanied by the second lowest percentage response to N fertilizer in the uptake of P, K, and Ca and the lowest uptake of Mg compared to other seasons (Tables 16 through 21). This low uptake of other nutrients by maize could be attributed to the resultant effect of rainfall on N uptake; N fertilizers have been found to influence the uptake of P, K, Ca, and Mg by plants (Krantz and Chandler, 1951; Viets, et al., 1954).

The lack of significant response by maize to N in DMY at maturity during the long rains of 1989 in Kimutwa was probably caused by low rainfall which amounted to 191 mm for the whole season and 0 mm from the time of top-dressing (20 DAE) to maturity. This season was characterized by the lowest DMY (Table 6) and the lowest increase in response to N in the uptake of N (18%), P (13%), K (8%), and Ca (37%) and the second lowest percent increase in response to N fertilizer in the uptake of Mg (30%) (Tables 16 through 21). Tisdale et al. (1985) reported that absorption of nitrogen is definitely reduced on dry soils but it is usually not reduced as much as that of phosphorus and potassium.

The cropping systems had significant effects on maize DMY at maturity in all seasons except the short rains of 1989/90 at both sites (Table 7). Intercropping systems were found to reduce maize DMY by between 16 and 27% in three out of four seasons in Kimutwa and by between 19 and 33% in all seasons in Masii. The reduction of maize DMY in intercropping system in Kimutwa was significant during the long rains of 1988 (16%, $P < 0.01$) and 1989 (27%, $P < 0.01$). However, a non-significant increase of 7% in maize DMY in intercropping system was realized in the same row during the short rain of 1989/90. Data on DMY of intercropping systems from Kimutwa indicated that the crop in the same row had higher but non-significant DMY compared with that in the alternate row during the long rains of 1988 (9%), and short rains of 1988/89 (2%) and 1989/90 (7%). However, maize in the alternate row had significantly higher ($P < 0.05$) DMY than that in the same row by 14% during the long rain of 1989. In Masii, the reduction of DMY of intercropped maize was significant (33%; $P < 0.01$) in one season (SR 1988/89) out of four. However, substantial non-significant DMY differences between the two intercropping systems were observed. During the long rains of 1988 and 1989 and short rains of 1988/89 the crop in alternate row had non-significantly higher DMY than that in the same row by 17, 11 and 29%, respectively. However, during the short rains of 1989/90 the DMY of maize in the alternate row was lower than that in the same row by 8%. The data show that maize in the intercropping systems experienced competition from the intercropped beans and that maize in the same and alternate rows did not respond to competition from beans the same way at the two sites. In Kimutwa, maize in the same row experienced less competition from the intercropped beans but in Masii, maize in a similar spatial arrangement received more competition from beans planted in the same row than in alternate row. The results from Kimutwa unlike those from Masii seemed to contradict the findings of Cable (1969) and Trenbath (1975) which indicated that competition could be higher in intercrops at closer proximity because of intermingling of root-systems of the components. The higher competition experienced by maize when planted with beans in the same row in Masii corresponds well with the findings of Chui (1988) using maize and beans in a medium potential region of Kenya; Dalal (1977) on seed yield using maize and soybeans; and Agboola and Fayemi (1971) who found generally higher seed yield reductions of maize intercropped in the same row with cowpea, calopo and greengram legumes compared with that planted in alternate row. The bush type bean variety used in this study was a shorter crop than maize and so any reduction in DMY of maize cannot be attributed to competition for light but rather more so to the soil factors, that is, water and nutrients. In this study, it is anticipated that there were more root interferences between roots of maize and beans planted in the same row than for those planted in rows 30 cm apart (alternate row). In Masii, the percentage reductions of N and P uptake by maize in the same and alternate row (Tables 17 and 18) followed the same trend observed in maize DMY, but the uptake of Mg and Ca indicated that maize in the same row experienced greater reduction than that in alternate row in all seasons (Tables 20 and 21). In half the seasons in Masii (SR 1988/89 and LR 1989), there were more reductions of potassium uptake by maize in the same row than that in the alternate row. In Kimutwa, however, the higher uptake of Ca by maize in all seasons, Mg and K in three (LR 1988, SR 1988/89 and SR 1989/90) out of four seasons and N in two (LR 1989 and SR 1988/89) out of four seasons indicated that maize in the same row had less reductions of nutrient uptake than that in alternate row (Tables 19 to 21). On the other hand, maize in the same row had greater reductions in the uptake of P in all seasons, K and Mg in the long rain of 1989 and short rains of 1989/90 than that in the alternate row (Tables 18, 19, and 20). The bigger reductions of DMY and nutrient uptake by maize planted in the same row than that in the alternate row at both sites seemed to agree with the findings of Cable (1969) and Trenbath (1975) who reported that the degree of overlap between root-systems of the components determined the intensity of competition between the intercrops. The conclusion one can draw from these results is that the nature of interactions of the same intercrops in similar spatial arrangements may differ with sites and can be influenced by seasons. In general, the crop planted in the same row had accumulated more dry matter than that in alternate row in Kimutwa while that in Masii was found to do better in the alternate row than in the same row.

Maize following beans in rotation was generally found to have higher DMY than that in continuous sole cropping at maturity (Table 8). In Kimutwa maize in rotation gave non-significant higher DMY than continuous sole crop during the short rains of 1988/89 (9.5%, 887 kg/ha) and 1989/90 (6.2%, 401 kg/ha). In Masii, maize in the rotation where bean residue was removed (Rot-NR) and that in rotation where the residue was returned (Rot-RR) had significantly ($P < 0.05$) higher DMY than that in continuous sole cropping system by 19 and 11%, that is, 513 and 311 kg/ha during the long rains of 1988, respectively. Also, during the long rains of 1989 in Masii, maize in rotation had a higher but non-significant DMY compared with that in continuous sole cropping by 14.4% (386 kg/ha). The greatest effect of rotation on maize DMY was obtained at zero N fertilizer treatment (Table 8). But where N fertilizer was added, it either decreased positive effect of rotation or rendered it negative. The reduction of positive effect of rotation on the performance of maize by N fertilizer applied was in line with the findings of Mulvaney et al. (1980) and Randall and Lauger (1982) on maize in rotation with soybeans. But, the better performance of maize in continuous sole cropping than that in rotation system when N fertilizer was applied contradicted the observations made by Jones (1973) on maize in rotation with groundnut which showed that the crop in rotation remained superior to that in mono-cropping even at high rates of N fertilizer application.

The benefit obtained from rotation is usually as a result of increased nitrogen available to non-legumes when preceded by a legume crop (Jones, 1974; Gakale and Clegg, 1987). The data in Tables 51 and 52 suggest that factors other than increased availability of nitrogen are responsible for the higher DMY of maize when preceded by beans. Because, even in seasons when soil mineral N in rotation at the beginning of a season was not higher than that in continuous sole maize plots, maize in rotation

Table 8 – Maize dry matter yields at maturity at various rates of added N fertilizer when following maize and beans in rotation at Kimutwa and Masii

Site, Season and Fertilizer	Maize dry matter yield when following		Increase /decrease for following beans	
	Maize	Beans		
Kimutwa	---------kg/ha-----------		kg	%
SR 1988/89				
N0	6836	9568	+ 2732	+ 40.0
N25	10400	9712	– 688	– 6.6
N50	9975	9821	– 154	– 1.5
N100	10439	12101	+ 1662	+ 15.9
Mean	9413	10301	+ 888	+ 9.5
Kimutwa				
SR 1989/90				
N0	4168	4826	+ 658	+ 15.8
N25	5698	7535	+ 1837	+ 32.2
N50	8118	7525	+ 593	– 7.3
N100	7969	7671	– 298	– 3.2
Mean	6488	6889	+ 401	+ 6.2
Masii				
LR 1988				
N0	910	1639	+ 729	+ 80.1
N25	3283	2510	– 773	– 23.6
N50	3029	3821	+ 792	+ 26.2
N100	3585	4268	+ 683	+ 19.1
Mean	2702	3060	+ 358	+ 13.2
Masii				
LR 1989				
N0	561	914	+ 353	+ 62.9
N25	2926	3033	+ 107	+ 3.7
N50	3595	4264	+ 669	+ 18.6
N100	3477	3893	+ 416	+ 12.0
Mean	2640	3026	+ 386	+ 14.6

+, – = Increase and decrease compared with continuous sole maize.

still yielded more and took up higher N than that in continuous sole cropping system. Hence, the better performance of maize in rotations can be attributed partly to the higher levels of extractable P (AL-solution), exchangeable K, Mg, and Ca than in continuous sole maize plots at the beginning of the seasons. Generally, the higher levels of soil nutrients in rotation plots corresponded well with higher uptake of the same nutrients by maize. In Masii, maize in rotation took up more P, K, and Ca than that in continuous sole cropping by 37.5, 22.5, and 17.8% during the long rains of 1988 and 4, 30, and 16.6% during the long rains of 1989, respectively (Tables 18, 19, 21). Also, in Kimutwa the uptake of P by maize in rotation was higher than in continuous sole cropping by 19% and 11% during the short rains of 1988/89 and 1989/90, respectively (Table 17). However, potassium uptake was higher by 2% during the short rains of 1988/89 but lower by 3.7% during the short rains of 1989/90 than in continuous sole maize. Maize in rotation did not take higher Mg than that in the continuous sole cropping even though there was higher exchangeable Mg in the soil from rotation plots at the beginning of the season.

Return of bean residue to plots after harvest at the two sites did not only have a non-significant increase of maize dry matter yields (3.5 to 12%) in two out of three seasons but also a non-significant decrease of DMY of 2.6 to 6.5% in one out of the three seasons (Tables 4 through 7). In Masii, data on DMY showed that all zero N treatments with bean residue returned had lower DMY than where bean residue was removed by 9.2 to 36.6%. However, majority of zero N treatments with bean residue returned to plots in Kimutwa had higher dry matter than where bean residue was removed. At the two sites, the combination of returning bean residue and N fertilizer application was found to have higher DMY than where bean residue was removed by 1 to 18% in five out of six treatments. The commonly accepted explanation for the better performance of maize where legume residues have been returned is that of nitrogen provided by the legumes after mineralization (Ladd et al., 1983). Hence, the added N fertilizer had a priming effect which is reported to result in the stimulation of microbial activity thus resulting in increased decomposition of organic materials with an accompanying mineralization of soil N (Broadbent, 1965; Jenkinson et al., 1985).

Generally, the relationships between maize total dry matter at different growth stages and seed yield were positive and significantly correlated with each other (Tables 9 and 10).

4.1.5 Maize stover weight: Nitrogen fertilizer significantly increased maize stover weight by 117 to 210% in all seasons at Masii and in only one season (65%) at Kimutwa (Table 11). In Kimutwa, the non-significant increase of stover weight due to N fertilizer application was between 17 and 32%. There was a general trend in Masii for maize stover weight to increase with increase in N fertilizer rate. A significant ($P < 0.01$) interaction of N fertilizer and cropping systems was observed in Masii during the short rain of 1989/90, which indicated that continuous sole maize had maximum N response at N25 while that of intercropped maize was at N100. In the other three seasons when interactions were not significant, continuous sole maize had maximum N response at N25 in two seasons and at N50 in only one while intercropped maize had its maximum N response twice at N50 and once at N100. Maize in rotation had maximum N response either at N50 or N100. Unlike maize in Masii, that in Kimutwa did not have a good trend in response to N fertilizer although the highest stover weight occurred in either N50 or N100. The results here, however, seem to confirm the earlier findings that soil in Masii had lower total N than Kimutwa and therefore the higher the maize response to N. Intercropped maize in Masii was found to require higher levels of N

Table 9 – Correlation coefficients (r) between maize dry matter (g/plant for 40 and 60 DAE; kg/ha for maturity) and seed yield of maize (kg/ha for MSYD).

	Long rain 1988				Short rain 1988/89				Long rain 1989			Short rain 1989/90		
DAE a	40	60	Mat.	MSYD	40	60	Mat.	MSYD	40	Mat.	MSYD	40	Mat.	MSYD
Kimutwa														
20	0.720**	0.697**	0.703**	0.679**	0.107 ns	0.461**	0.128 ns	0.255*	0.562**	0.311*	0.342**	0.557**	0.497**	0.474**
40		0.740**	0.740**	0.684**		0.297**	0.447**	0.381**		0.418**	0.424**		0.567**	0.610**
60			0.690**	0.704**			0.270*	0.322**		–	–		–	–
Maturity				0.875**				0.826**			0.864**			0.930**
Masii														
20	0.691**	0.690**	0.661**	0.516**	0.328**	0.414**	0.425**	0.359**	0.589**	0.731**	0.711**	0.514**	0.578**	0.580**
40		0.736**	0.803**	0.780**		0.344**	0.562**	0.569**		0.794**	0.718**		0.710**	0.737**
60			0.801**	0.630**			0.684**	0.581**		–	–		–	–
Maturity				0.770**				0.956**			0.944**			0.966**

a = Days after emergence

*, **, ***, ns = Means are significant at 0.05, 0.01 ,0.001, probability level and non-significant at P = 0.05 level, respectively.

Table 10 : Correlation coefficients (r) between bean dry matter yield (g/plant for 40 and 60 DAE; kg/ha for maturity) and seed yield (kg/ha for BSYD).

Season	Long rain 1988				Short rain 1988/89				Long rain 1989			Short rain 1989/90		
DAE	40	60	Mat.	BSYD	40	60	Mat.	BSYD	40	Mat.	BSYD	40	Mat.	BSYD
Kimutwa														
20	0.597***	0.135	0.581***	0.557***	0.091 ns	0.129 ns	0.274*	0.380***	0.575***	0.553***	0.567***	0.265*	0.297*	0.241*
40		0.030	0.565***	0.562***		0.287*	0.426***	0.503***		0.845***	0.860***		0.754***	0.700**
60			0.212*	0.148			0.659***	0.611***		–	–		–	–
Maturity				0.906***				0.901***			0.978***			0.978***
Masii														
20		0.289*	0.375***	0.258*	0.606	0.206*	0.176	0.682***	0.619***	0.646***	0.639***	0.660***	0.590***	0.631***
40		0.752***	0.821***	0.720***		0.423***	0.051	0.630***		0.660***	0.763***		0.818***	0.856***
60		0.834**	0.737***	–			0.028	0.503***		–	–		–	–
Maturity				0.820***				0.116			0.807***			0.924***

*, **, ***, ns = Means are significant at P = 0.05, 0.01 ,0.001, level and non-significant at P = 0.05, respectively.
Mat.; DAE = Maturity; and days after seedling emergence.

Table 11 – Effect of N rates and cropping systems on maize stover weight (kg/ha).

Fertilizer N kg/ha	Kimutwa				Masii			
	LR 1988	SR 88/89	LR 1989	SR 89/90	LR 1988	SR 88/89	LR 1989	SR 89/90
No	1965	2350	1394	2131	933	562	533	509
25	2958	2905	1746	2577	1720	1446	1336	1019
50	3361	2442	1767	3000	1976	1804	1943	1063
100	3375	3202	1703	2842	2452	1668	1688	1234
Mean	2915	2725	1652	2638	1770	1370	1375	956
F test	**	ns	ns	ns	**	*	**	*
CV (%)	10	17	10	12	19	28	18	22
LSD 0.05	553	–	ns	–	677	762	491	428
Cropping systems								
MSC	3448	3444	1961	2742	1954	1938	1290	969
MISNR	2723	2559	1345	2925	1930	1119	1241	911
MISRR	3139	2910	1598	2743	1678	1010	1139	1094
MIANR	2475	2578	1769	2628	1600	1344	1393	878
MIARR	2791	2133	1590	2549	1436	1439	1310	949
MRNR	–	3395	–	2302	1963	–	1702	–
MRRR	–	2923	–	2575	1890	–	1570	–
Mean	2915	2725	1652	2638	1770	1370	1375	956
F test	*	*	*	ns	ns	*	**	ns
CV (%)	25	34	25	22	36	56	25	23
Interaction	ns	ns	ns	ns	ns	ns	ns	**
LSD 0.05	605	865	341	–	–	636	287	–

*,** = Treatment differences and interactions are significant at P = 0.05, 0.01 level, respectively.

ns = Treatment differences are not significant at P = 0.05 level

fertilizer to attain maximum stover weight than continuous sole maize.

The effect of cropping systems on maize stover weight was significant in three and two seasons out of four in Kimutwa and Masii, respectively (Tables 11). Comparison of intercropping systems and continuous sole maize showed that intercropping systems generally reduced maize stover weight on average by 1.0 - 37% and the effect was significant in three out four seasons in Kimutwa and in one out of four in Masii (Table 11). In Kimutwa, maize in alternate row spatial arrangement had its stover weight reduced significantly reduced ($P < 0.01$) by 24% during the long rains of 1988 while in the long rains of 1989, it was that stover weight of maize planted in the same row which was significantly reduced ($P < 0.01$) by 25%. During the short rains of 1988/89, the intercropping systems had significant ($P < 0.01$) effect on the reduction of stover weight with alternate row having greater reduction effect (46%) than the same row (26%). In Masii, maize in the same row had its stover weight significantly reduced ($P < 0.05$, 45%) during the short rains of 1988/89. On the other hand, during the long rains of 1988, maize in the alternate row had its stover weight reduced more (22.3%) than that in the same row (9.2%). During the long rain of 1989, the stover weight of maize planted in the alternate row was slightly higher than that of continuous sole maize by 4% while that planted in the same row with beans was lower by 8%. A different effect of intercropping on stover weight was observed during the short rains of 1989/90 since stover weight of maize planted in the same row and alternate row was higher than that from continuous sole cropping by 2.5% and 9.7%, respectively. These results indicate that when the crop was planted in the alternate row it tended to experience more competition than that in the same row in Kimutwa while competition received by the crop planted in the same or alternate row was unpredictable in Masii since it was very much dependent on seasons.

Competition between maize and beans planted in alternate row in Kimutwa which was found to reduce the performance of maize was also detrimental to beans for it caused a substantial reduction in bean dry matter yields (Table 3 through 7). This is definitely the opposite of the expected effect since the two crops were not planted close together. Planting maize and beans in the same row which turns out to be better than alternate row in Kimutwa would be advantageous to the community in this region because it would provide weeding animals easier access to rows without damaging the shorter crop beans.

Rotation during the long rains of 1988 at Masii and short rains of 1988/89 at Kimutwa did not affect maize stover weight (Table 11). However, the rotation during the long rains of 1989 at Masii significantly increased ($P < 0.05$) the maize stover weight by 27% while that at Kimutwa during the short rains of 1989/90 had a lower and non-significant maize stover weight compared with continuous sole maize by 11% (Table 11). The residual effect of rotation did not increase stover weight as much as it did in maize DMY (Table 8) and seed yields (Table 35) since the latter two parameters were substantially increased in all seasons at the two sites.

Effect of bean residue returned did not have significant and consistent effect on maize stover weight (Table 11). In Kimutwa, it either lowered maize stover weight (6.6%) or increased it (1.2 - 2.4%) and this phenomenon was also observed in Masii whereby it either lowered (6.9%), increased (12.8%) or had no effect at all. Hence, beneficial effect of bean residue returned on maize stover weight was found to be seasonal, quite unpredictable and did not depend on the amount of bean residue returned.

4.2 Bean Dry Matter Production:

4.2.1 Bean dry matter at 20 DAE:

Application of N fertilizer starter dose at the rate of 25 kg N/ha was found to increase significantly (P< 0.05) bean top dry matter yields by 47% (LR 1989) in Kimutwa, and by 70% (LR 1989) and 56% (SR 1989/90) in Masii (Tables 6 and 7). When the N starter dose did not influence dry matter yield significantly, the increase in DMY ranged from 0 to 18% in Kimutwa and 17.2% in Masii. During the short rains of 1988/89 at Kimutwa there was no N starter dose applied and bean total DMY obtained from zero N treatment did not differ from that obtained from the previous season N treated plots, thus implying that there was no N residual effect. However, where no N starter dose was applied in Masii during the long rains of 1988 and short rains of 1988/89, a non-significant N residual effect was observed. There was an average DMY increase of 6.7% (LR 1988) and 31% (SR 1988/89) and it was observed that the higher the N rate the greater was the N residual effect. There was no significant interactions between N and cropping systems at 20 DAE. But, response to residual N fertilizer topped with 25 kg N/ha as a starter dose varied with cropping systems since continuous sole beans and those planted in alternate rows had their highest responseat the previously applied 25 or 50 kg N/ha level while beans in rotation and those planted with maize in the same rows had 25 and 50 kg N/ha as their best levels, respectively, in Kimutwa. In Masii, the best response for continuous sole beans was found at 25 and 100 kg N/ha, beans planted in the same row was at 100 kg N/ha, those planted in alternate rows could have their best response occurring at 25, 50 or 100 kg N/ha while those in rotation had their best response at 25 and 50 kg N/ha levels.

There was a greater response of bean DMY to N fertilizer in Masii that in Kimutwa (Tables 2 through 7). This was probably due to the fact that soil from Masii had lower levels of mineral N at the beginning of the seasons which ranged from 7 to 36 ug N/g soil compared to that from Kimutwa whose N ranged from 12 to 60 ug N/g soil in plots applied with N fertilizer. The significant bean response to N occurred when mineral N level measured between 20 to 23 ug N/g in Kimutwa (LR 1989) and between 7 and 18 ug N/g soil in Masii. In Kimutwa, there was practically no N fertilizer response by beans during the short rains of 1987/88 and 1988/89 (Tables 2 and 5) when the level of mineral N at the beginning of each season measured 43 to 60 and 33 to 47 ug N/g soil, respectively (Tables 51 and 52). Probably, this level of N fertilizer in the soil was adequate for beans for the first 20 DAE.

The effect of cropping systems on bean DMY varied with seasons. Cropping systems had significant effect on bean dry matter in three out of six seasons in Kimutwa and in three out of five seasons in Masii (Table 2 through 7).

Intercropping maize and beans resulted in the reduction of bean DMY at 20 DAE of between 1.7 and 12.2% in Kimutwa and between 3.3 and 20% in Masii. Apparently, there was greater competition between maize and beans in Masii than in Kimutwa. The spatial arrangements of intercrops did not differ significantly in their reduction of bean DMY except one season in Kimutwa (LR 1988) in which alternate row caused significantly greater ($P < 0.05$, 18%) bean DMY reduction than the same row. The same trend of alternate row having greater though non-significant reduction of bean DMY than the same row was observed in all seasons at both sites. Beans in the same row had higher DMY than those in alternate row by between 2.2 and 14.4% in Kimutwa and between 3.3 and 31% in Masii. The higher DMY accumulation by beans in the same row could be construed as having better competitive ability for N fertilizer because these beans had taken up higher N than those in the alternate row by 4.4% (Table 16).

The DMY of beans in rotation was significantly greater ($P < 0.01$) than that in continuous sole cropping by 18% (LR 1988) and 35% (LR 1989)in Kimutwa. In Masii, the effect of rotation was not significant and it either increased (21%, SR 1989/90) or had no effect (SR 1988/89) on bean DMY compared with continuous sole beans (Tables 5 and 7). Hence, the bean DMY was generally higher when it followed maize. In this study, rotational benefits on beans following maize cannot be due to the effect of maize on the status of soil N. These results suggest that factors other than increased availability of N were responsible for the higher DMY of beans when they were preceded by a maize crop. Other soil nutrients might be playing part in the rotational effect because there were higher levels of extractable P and exchangeable K, Ca and Mg by 9.6, 2.2, 8.5 and 3.4%, respectively in rotation than in continuous sole beans at the beginning of long rains of 1989 season in Kimutwa (Table 51). In Masii, when there was an increase of bean DMY by 21%, only extractable P was higher by 5.6% in rotation than in continuous sole beans while the exchangeable K, Ca and Mg were lower by 11.5%, 11% and 18.6%, respectively (Table 52). Also, in the same site, when rotation had no effect on DMY, it was found that extractable P was lower by 9.9% while the exchangeable K and Ca were higher by 3.4 and 2.6% in rotation than in continuous sole beans (Table 52). Hence, extractable P was probably one of the important factors that contributed to the beneficial effects of rotation since those beans in the rotation significantly took up higher P by 50.2% in Kimutwa and 48% in Masii than continuous sole beans at maturity. Extractable P was highly correlated with bean seed yield (Table 42).

At 20 DAE, effect of bean residue returned had no significant effect on bean DMY (Tables 4 through 7). However, there was a trend in both sites for the returned bean residue to lower DMY by between 5.3 and 10.3%. Only one season (LR 1989) in Kimutwa was there a DMY increase of 19.5% as a result of returned bean residue. The reduction effect on bean dry matter as a result of returning bean residue is a known phenomenon that is observed especially in cereals when a crop follows another or the same crop. There is some evidence that substances released from roots or formed during the decomposition of residuals are responsible for the allelopathic (toxic) effects (Chou and Patrick, 1976; Ruiz-Sifre and Reis, 1983) thus reducing the growth of the succeeding crop.

4.2.2 <u>Bean dry matter at 40 DAE :</u> Nitrogen fertilizer application increased bean DMY in all seasons at both sites by 5 to 96% in Kimutwa and by 51 to 99% in Masii (Tables 2 through 7). In Kimutwa, the effect of N fertilizer was significant in two seasons out of six, that is, during the long rains of 1989 ($P < 0.01$, 44%) and short rains of 1989/90 ($P < 0.05$, 96%). In Masii, there were three seasons out of five when N fertilizer significantly increased bean DMY by 75% ($P < 0.01$, SR 1987/88), 73% ($P < 0.05$, LR 1988) and 97% ($P < 0.01$, LR 1989). During the other two seasons, short rains of 1988/89 and 1989/90 the DMY increase due to N fertilizer was by 51% and 99%, respectively. But, probably the high C.V. of 33 and 43% caused the effect not to be significant. The full dose of N fertilizer was applied at 20 DAE but there was no significant interaction between N and cropping systems at this growth stage. However, beans in different cropping systems showed some differences in their maximum response to N fertilizer. In Kimutwa, the majority of continuous sole beans had their highest N response in terms of DMY at 25 kg N/ha, beans planted in the same row and alternate row had their maximum response at 100 kg N/ha while those in rotation had theirs at either 50 or 100 kg N/ha. In Masii, the bean response to N was slightly different from that in Kimutwa and was dependent on the seasons since continuous sole beans had their maximum N response at 50 and 100 kg N/ha, beans planted in the same row were as for Kimutwa, those in alternate row at 25 and 50 kg N/ha and those in rotation at 25 and 50 kg N/ha. These results indicate that beans in Masii were responding to higher N levels than those found in Kimutwa and irrespective of cropping systems, the majority of beans in various cropping systems had their highest DMY in response to N fertilizer in the order of 100 > 50 > 25 kg N/ha.

The effect of cropping systems on bean DMY was significant in five out six seasons in Kimutwa and in four out of five in Masii (Tables 2 through 7). Intercropping maize and beans caused significant reduction in bean DMY by 12 to 29% in Kimutwa and by 21 to 28% in Masii. Competition between maize and beans was influenced by the spatial arrangements and seasons. In Kimutwa, beans planted in the same row with maize had higher DMY of between 15 and 23% than alternate row beans in four out of six seasons and two (LR 1988 and LR 1989) out of these four seasons had significantly higher DMY. The other two seasons (SR 1987/88 and SR 1989/90) had beans in the alternate rows having non-significantly higher DMY than those in the same rows by 4 and 13%, respectively. In Masii, the long rains of 1989 and short rains of 1989/90, beans planted in the same row and alternate row had similar performance. However, in the other three seasons, those planted in the same row with maize had higher DMY than those planted in the alternate row by between 12 to 27%, with one season (LR 1988) having significant effect ($P < 0.05$). It can be concluded that beans planted in the same row were more competitive than beans in the alternate rows and thus accumulated more dry matter.

Rotation of maize and beans resulted in beans having higher DMY than continuous sole beans by 4 to 62% in Kimutwa and by 18 to 27% in Masii. These results correspond well with the observations made at the 20 DAE (Tables 4 through 7).

Return of bean residue to plots once again lowered bean DMY by 3 to 15% with bean residue returned in continuous sole beans having a significant ($P < 0.01$) reduction of dry matter by 20% during the LR 1989 in Masii (Table 2 through 7).

4.2.3 <u>Bean dry matter at 60 DAE:</u> Nitrogen fertilizer increased bean DMY by between 44 and 64% in Kimutwa and by between 53 and 121% in Masii (Tables 3 through 7). The effect of N fertilizer was significant in only one season in Kimutwa and the lack of significance in the other seasons despite the substantial increase in dry matter yields could have been as result of high coefficient of variation observed (33 to 69%).

Intercropping systems except in one season in Masii (SR 1988/89) were found to significantly reduce bean DMY by between 29 and 37% in Kimutwa and by 31 to 42% in Masii (Tables 4 through 8). At this growth stage, also, the beans planted in the same row had higher DMY than those planted in the alternate row by 2 to 13% in Kimutwa and by 12 to 25% in Masii. These results correspond well with the findings of Cardoso et al. (1987) who found that beans planted in the same row with maize gave higher solar energy conversion and more DMY than beans in the alternate row. These results, however, indicate that beans in Masii were more depressed by maize than those in Kimutwa. Also, bean DMY was more in the rotation system than in the continuous sole cropping by 18% in Kimutwa and by 24% in Masii. Hence, maize preceding beans in rotation probably, did not leave harmful environment that could reduce the growth of beans. Return of bean residue caused a small and a non-significant reduction of bean dry matter by 5% in Kimutwa while in Masii, a small increase of dry matter by 3.4% was obtained.

4.2.4 <u>Bean dry matter at maturity:</u> Beans in Kimutwa had more dry matter (8%) than those in Masii when averaged over four seasons (Tables 4 through 7). Beans in Kimutwa responded to N fertilizer significantly in three out of four seasons (Tables 4 through 7). The increase of DMY of beans where N fertilizer effect was significant was by 28 to 92% (436 to 928 kg/ha) but where N fertilizer effect was not significant the increase was by 31% (242 kg/ha). In Masii, beans did not respond to N fertilizer significantly although there was a substantial DMY increase which ranged from 54 to 139% (492 to 1346 kg/ha). Probably, the high coefficient of variations (50 to 89%) observed in Masii partly caused the lack of significance. Nevertheless, considering all seasons together for both sites, growing of beans without N fertilizer application showed that Kimutwa site had a higher potential for bean production than Masii by 70% (551 kg/ha). But, when N fertilizer was applied the DMY of beans in Masii was raised from 786 to 2059 kg/ha an increase of 162% (1273 kg/ha) while in Kimutwa the increase was by 45% (599 kg/ha), that is, from 1337 to 1936 kg/ha. Averaged over all seasons, the highest bean DMY in Kimutwa was obtained at 50 kg N/ha and that at Masii was from the 100 kg N/ha fertilizer. Hence, beans in Masii responded to higher N more than those in Kimutwa.

These results indicate that N fertilizer is a requirement for the production of higher bean DMY at these two sites and consequently the higher seed yield since the relation between these two parameters was found to be positive and highly correlated with each other in all seasons (Table 10). Beans in Masii were found to respond to higher rates of N fertilizer probably because of lower level of mineral N which averaged 19.6 ug N/g soil over the four seasons compared to 30.0 ug N/g soil in Kimutwa (Tables 51 and 52). The lower level of mineral N in the soil from Masii although both places received similar rate of N fertilizer could be due to soil type differences which could have resulted in the disparity in leaching mineral N. Masii had received a higher seasonal average rainfall (451 mm) than Kimutwa (267 mm) (Appendix Table 1) and had sandy type of soil compared to sandy clay loam from Kimutwa. Wild (1988) reported that sandy soils have higher rate of leaching mineral N than loam soils. Nitrogen fertilizer has been recommended for beans in some regions (Graham, 1981; Edge et al, 1975) because beans have been found not to fix enough N to satisfy their demands due to their low and variable levels of nodulation and N fixation (Stephen, 1967; Habbish and Ishag, 1974; Cackett, 1965).

Different cropping systems at both Kimutwa and Masii had significant ($P < 0.01$) effect on bean DMY in all seasons, that is, from the long rain of 1988 to the short rains of 1989/90 (Tables 4 through 7). Intercropping in Kimutwa significantly reduced DMY of beans during the long rains of 1988 by 39% ($P < 0.05$, 1274 kg/ha), short rain of 1988/89 by 25% ($P < 0.01$, 310 kg/ha), long rains of 1989 by 32.4% ($P < 0.01$, 601 kg/ha) and short rains of 1989/90 by 40% ($P < 0.01$, 489 kg/ha). In Masii, the intercropped beans had their DMY also significantly reduced during the long rains of 1988 by 33.5% ($P < 0.05$, 483 kg/ha), long rains of 1989 by 30.5% ($P < 0.01$, 489 kg/ha) and short rains of 1989/90 by 29.4% ($P < 0.05$, 821 kg/ha). During the short rains of 1988/89 the bean DMY was not significantly reduced (13%) by intercropping systems in Masii. Generally, when the effect of intercropping systems on bean DMY was averaged separately for the long rains and short rains, it was found that irrespective of the site, the intercropped beans experienced greater reduction in DMY during the long rains than those grown during the short rains. This greater competition between maize and beans occurred during the long rain seasons of 1988 and 1989 when rainfall was lower than the short rain seasons of 1988/89 and 1989/90 (Tables 4 through 7). Hence, competition for water between maize and beans intercrops could be one of the contributing factors that caused greater reduction in bean dry matter in these two sites located in the semi-arid region.

The spatial arrangements of maize and beans in the intercropping systems were found to influence competition between the two crops. Beans planted in the same row with maize gave more DMY than those found in the alternate row by between 4.2 and 44%, that is, 49 to 555 kg/ha (Tables 4 through 7). This effect was significant during the short rains of 1988/89 ($P < 0.05$, 247 kg/ha) in Masii and long rains of 1989 ($P < 0.01$, 450 kg/ha) in Kimutwa. Only during the short rains of 1988/89 in Kimutwa was there a better performance of beans in the alternate row than in the same row by 27% (119 kg/ha). Hence, unlike the intercropped maize the effect of spatial arrangements on bean DMY was not very much influenced by sites and seasons.

At maturity, DMY of beans was more in rotation than in the continuous sole crop at both sites (Tables 4 through 7). In Masii, significant increase of bean DMY of 31% ($P< 0.01$, 465 kg/ha) and 34% ($P < 0.01$, 956 kg/ha) due to rotation were obtained during the short rains of 1988/89 and 1989/90, respectively. In Kimutwa, rotation resulted in significant increase in bean DMY of 68% ($P < 0.01$, 125 kg/ha) during the long rain of 1989 but when the effect was not significant, the increase was by 21% (705 kg/ha). This beneficial effect of rotation on beans that succeeded maize was persistent throughout the growing period, that is, from 20 DAE upto maturity.

At maturity, return of bean residue reduced bean DMY. This observation was similar to those of 20, 40 and 60 DAE. However, the reduction of DMY due to return of bean residue which ranged from 4.3 to 13.5% at maturity was not significant in most of the cropping systems. Orthogonal contrasts indicated that the return of bean residue significantly reduced the DMY of beans planted in the alternate row system by 38.3% ($P < 0.05$, 425 kg/ha) during the short rains of 1988/89 in Kimutwa, and those in continuous sole bean system by 25% ($P < 0.01$, 456 kg/ha) compared to similar cropping systems but with bean residue removed. In Masii, a small but significant ($P < 0.01$) increase of bean DMY of 9.3% (203 kg/ha) was observed during the short rains of 1988/89 due to return of bean residue relative to where it was removed. Results here indicate that return of bean residue to plots was not as beneficial to beans as it was to maize crop.

It can be concluded that the residual effect of rotation and bean residue effect on bean DMY were contributed by different factors which provided stimulatory growth effect and inhibitory effect on beans, respectively.

There was a significant interaction ($P < 0.01$) between N fertilizer and cropping systems on bean DMY during the long rains of 1989 in Masii and Kimutwa, thus implying that beans in different cropping systems responded to similar levels of N fertilizer differently. The relationship between bean DMY at different growth stages and its seed yield is shown in Table 10. The relationships between DMY of beans at 20, 40, 60 DAE and maturity were positive and generally highly and significantly correlated with each other. The relationship between DMY of beans at these growth stages and seed yield were positive and significantly correlated. This signified the importance of DMY of beans in seed production.

4.3 Effects of N, bean residue and cropping systems on maize growth and development

4.3.1 Height of maize: Maize in Kimutwa was taller than that in Masii by 20 cm (Tables 12 and 13). In the long rains of 1988 and 1989 the N fertilizer did not significantly increase height of the plants at maturity in either of the experimental sites. However, the height of maize was significantly ($P < 0.01$) increased by 50 cm at 60 DAE in Masii. Intercropping reduced the height of plants by 2 cm in Masii and by 5 to 8 cm in Kimutwa. In the latter site, the height of plants intercropped in the same row was significantly reduced by 6.5 cm while that in the alternate row was reduced by 3.4 cm at maturity compared to continuous sole maize. Intercropping without added N reduced height of plants in the same row by 8 cm but did not affect those in alternate row; however, when N fertilizer was applied, the height of plants was reduced by 6 and 4.7 cm in the two spatial arrangements, respectively. The reduction of height when N was applied indicated that plants in the same row had become more

Table 12 - Effect of N rates and cropping systems on maize and bean growth, development and yield components at Kimutwa.

Fertilizer N kg/ha	Growth and development				Yield components			
	Maize plant height (cm)		Maize tasseled %	Maize silked %	Maize ear weight g/plant		Bean pods per plant	
	LR 1988	LR 1989	LR 1988	LR 1988	LR 1988	SR 1988/89	LR 1989	SR 1989/90
0	138	54	15	16	73	51	6.4	3.0
25	155	59	31	31	81	70	7.9	3.9
50	163	59	36	36	95	74	8.4	3.8
100	161	61	39	40	98	82	8.2	4.3
Mean	**154**	**58**	**30**	**31**	**87**	**69**	**7.7**	**3.8**
F test	**	ns	**	**	*	*	ns	ns
CV (%)	7	4	33	30	18	34	44	33
LSD 0.05	9.8	-	8.9	8.1	11.6	17.5	-	-
Cropping systems								
Sole-NR	161	62	29	39	98	72	10.0	4.8
Sole-RR	-	-	-	-	-	-	8.8	4.2
ISNR	154	55	39	29	80	60	6.2	3.1
ISRR	155	57	27	28	91	58	5.9	3.6
IANR	155	60	30	28	77	62	6.1	3.7
IARR	148	58	32	30	86	67	7.1	3.1
Rot-NR	-	-	-	-	-	85	9.8	-
Rot-RR	-	-	-	-	-	80	10.0	-
Mean	**154**	**58**	**30**	**31**	**87**	**69**	**7.7**	**3.8**
F test	ns	**	ns	*	**	**	**	**
CV (%)	8	8.1	30	29	16	17	34	30
LSD 0.05	-	3.9	-	7.5	11.9	9.6	2.1	0.9

*,** = Treatment differences are significant at P= 0.05, 0.01 level, respectively.

ns = Treatment differences are not significant at P= 0.05 level.

Table 13 - Effect of N rates and cropping systems on maize and bean growth, development and yield components at Masii.

Fertilizer N kg/ha	Growth and development				Yield components			
	Maize plant height (cm)		Maize tasseled %	Maize silked %	Maize ear weight (g/plant)		Bean pods per plant	
	LR 1988	LR 1989	LR 1988	LR 1988	LR 1988	SR 1988/89	LR 1988	SR 1988/89
0	72	51	30	0.8	8.0	12	3.7	3.5
25	109	52	52	2.0	29.0	34	6.7	4.8
50	121	60	54	6.6	34.1	42	6.6	5.8
100	136	79	69	12.3	42.5	47	6.4	4.5
Mean	110	61	51	5.4	28.4	34	5.9	4.7
F test	**	ns	**	*	*	*	ns	ns
CV (%)	34	26	38	189	93	69	49	50
LSD 0.05	28	-	15.0	7.9	20.2	20.7	-	-
Cropping systems								
Sole-NR	108	61	57	5.9	31.4	45	7.2	4.6
Sole-RR	-	-	-	-	-	-	6.7	4.6
ISNR	106	58	47	3.3	21.7	26	5.2	4.6
ISRR	104	59	47	4.0	21.5	23	6.4	4.0
IANR	107	59	48	4.2	22.2	41	4.9	4.1
IARR	108	58	53	3.2	23.8	34	4.7	4.5
Rot-NR	124	67	51	9.0	42.9	-	-	5.8
Rot-RR	114	62	55	8.4	38.9	-	-	5.0
Mean	110	61	51	5.4	28.4	34	5.9	4.7
F test	ns	ns	ns	**	**	ns	*	ns
CV (%)	16	14	23	76	53	66	38	31
LSD 0.05	-	-	-	3.5	12.6	-	1.9	-

*, ** = Treatment differences are significant at P= 0.05, 0.01 level.

ns = treatment differences are not significant at P= 0.05 level.

competitive than those not receiving N while in the alternate row system the N fertilizer seemed to have favoured beans thus providing more competition to maize. This argument was supported by the dry matter yields (Tables 4 through 7) at maturity; the data showed that when N was applied, the DMY of both crops, planted in the same row were increased by 23% for maize and 10% for beans compared to those for the alternate row for which the increases were by 2% for maize and 21% for beans. Height reduction in maize due to intercropping has been observed when maize was intercropped with cowpeas (Enyi, 1973) and soybeans (Chui and Shibles, 1984).

The reduction of height of maize plants due to intercropping with beans in this study suggests that maize experienced some competition from beans particularly in nutrients uptake. Table 16 shows that during the long rains of 1989, the uptake of N by maize was significantly reduced by 24%.

Rotation was found to increase height of maize but not significantly compared to continuous sole cropping. Bean residue did not affect the height of maize.

4.3.2 <u>Maize tasseling:</u> Data on maize tasseling obtained at 60 DAE, that is, 20 days after initial tassel emergence is given in Tables 12 to 13. Nitrogen fertilizer hastened tasseling since it resulted in significantly higher ($P < 0.01$) number of tasseled plants by 138% in Kimutwa and 98% in Masii than treatments receiving no N fertilizer. The higher the N rate the greater the number of tasseled plants. Irrespective of N treatments, however, intercropping delayed tasseling and gave fewer number of tasseled plants than continuous sole cropping by 15% and 16% in Kimutwa and Masii, respectively. Maize in the same row delayed tasseling slightly more than the alternate row.

4.3.3 **Maize silking:** Nitrogen fertilizer hastened silking at 60 DAE and it resulted in significantly greater number of silked plants than those receiving no N fertilizer by 116 and 805% in Kimutwa and Masii, respectively (Tables 12 and 13). The effect of N fertilizer on silking corresponds well with the result obtained by Sharma and Gupta (1968).

Intercropping reduced the number of plants silked by 27% and 37% in Kimutwa and Masii, respectively. The effect was significant ($P < 0.01$) in Kimutwa but not significant in Masii probably because of the high C.V. observed for the latter site. Rotation resulted in significantly more silked plants than intercropping by 135% but non-significantly than sole cropping by 48%.

4.4 Effects of N, bean residue and cropping systems on yield components of maize and beans

4.4.1 **Maize ear weight:** Nitrogen fertilizer significantly increased maize ear weight per plant in all seasons at both sites (Tables 12 and 13). The maize response to N differed with seasons. During the long rains of 1988 and short rains of 1988/89 when ear weight data were taken, the weight increase due to added N were 19 and 24 g/plant in Kimutwa while in Masii the increases were by 27 and 36 g/plant, respectively. Ear weight response to N increased with increase in N rate and was higher during the short rains than the long rainy seasons. One of the reasons why short rains were generally better than long rains was because the former seasons had higher and better distribution of rainfall than the latter ones (Appendix Table 1). Hence, maize in Masii responded to N better than that in Kimutwa because the former site received higher rainfall than the latter one.

Maize ear weight per plant was significantly affected by cropping systems in all seasons at Kimutwa. In Masii, the effect was significant in one out of two seasons probably due to the high coefficient of variation which was 66% (Table 13). Generally, intercropping maize with beans reduced maize ear weight per plant by between 6 and 32% (Table 12 and 13). Maize, however, did not respond uniformly to competition from beans planted at similar spatial arrangements at the two sites. Maize in the same row in Kimutwa gave higher ear weight than that in the alternate row by 5 to 7% while in Masii, it was the latter spatial arrangement which had greater ear weight than the former by between 6.5 and 58%.

The ear weight of maize succeeding beans in rotation was significantly higher than that in continuous sole cropping by 15% ($P < 0.01$, SR 1988/89) and 21% ($P < 0.05$, SR 1989/90) in Kimutwa (Table 12) while in Masii, the increase was by 30% (LR 1988) but was not significant (Table 13).

4.4.2 Bean pods per plant: Number of pods per plant was evaluated during the long rains of 1988 and the short rains of 1988/89 (Tables 12 and 13). Nitrogen fertilizer increased pod number per plant but non-significantly.

Cropping systems had significant effect on pod number per plant during the long rains of 1988 and short rains of 1988/89 in Kimutwa and in only one out of the two seasons in Masii (Tables 12 and 13). In Kimutwa, intercropping significantly reduced pod number/plant by 33% ($P < 0.01$, LR 1988) and 25% ($P < 0.01$, SR 1988/89) while in Masii the reduction of 30.4% was significant $P < 0.01$, LR 1988) through the alternate row spatial arrangement.

Beans succeeding maize in rotation had slightly higher pod number per plant than continuous sole beans by 5% in Kimutwa and by 17.4% in Masii (Tables 12 and 13). But, return of bean residue to plots tended to reduce bean pod number per plant by 5%.

4.5 Effects of N, bean residue and cropping systems on mineral nutrient uptake by maize and beans

4.5.1 Concentration and uptake of nutrients in seeds and stovers:

Tissue concentrations (%) and uptake (kg/ha) of N, P, K, Mg and Ca were assessed in maize and beans after harvest (Appendix Tables 2 through 20). Beans generally gave higher concentrations of the nutrients in both seeds and haulms than the corresponding maize tissues. Also, higher concentrations of N and P were found in seeds than in stovers while K, Mg and Ca were higher in the latter than in the former tissues of both crops.

Generally, nitrogen fertilizer increased the concentration of N in seeds of maize and beans and maize stovers but in the case of bean haulms, it either increased or decreased the concentration depending on the season. With regard to the other nutrients, N fertilizer resulted in lowering the concentration of P in seeds and stovers of both crops at both sites while the effect on the concentration of K, Mg,and Ca in the crop tissues was inconsistent and was influenced by seasons and sites. The uptake of these nutrients was generally more enhanced by N fertilizer in Masii than in Kimutwa. Effects of intercropping, rotation and bean residue on the concentration of N, P, K, Mg, and Ca in both maize and bean tissues were inconsistent and the concentrations were either increased or decreased depending on seasons and sites. The uptake of these nutrients by maize and bean tissues were lower in crops in intercropping than in the sole cropping. Also, the uptake by bean tissues was higher in beans planted in the same row than those in the alternate row while in maize, the higher uptake of nutrients was obtained from maize in the same row in Kimutwa and that in alternate row in Masii. Although rotation increased the uptake of nutrients by bean tissues and by maize seeds and P uptake by maize stovers, it was also found to either increase or decrease the uptake of N, K, Mg and Ca by maize stovers depending on sites and seasons. On the other hand, the effect of bean residue returned on the uptake of nutrients by maize tissues was unpredictable since it could lower or raise the uptake depending on sites and seasons. However, there was a trend in bean tissues to have decreased uptake when bean residue was returned at both sites.

4.5.2 <u>Nutrient uptake by whole plants and total systems:</u>

The data on the uptake of nutrients by the whole plants and total systems are presented in Tables 14 through 32. In Kimutwa, the uptake of N by maize at 20 days after seedling emergence was 34 and 30% that of beans during the long rains of 1987 and short rains of 1987/88, respectively (Table 14). Also, at maturity the uptake of Mg and Ca by beans was higher than that of maize by 33 and 30%, respectively (Tables 18, 18, 23, and 24). However, the uptake of N, P, and K by maize at maturity was greater than by beans by 71, 113 and 64%.

Nitrogen fertilizer increased the uptake of N, P, K, Mg and Ca by maize and bean plants and by total systems. The uptake of these nutrients by the total systems was significantly increased by N fertilizer in all seasons except one (SR 1988/89) which was characterized by the highest rainfall (404 mm) and one of the best distributions in Kimutwa. Probably, the heavy rainfall which occurred during this season resulted in leaching of the N added. The significant effect of N fertilizer on the uptake of the nutrients by maize and bean plants was influenced by seasons and sites. Crops in Masii showed greater response to N fertilizer although they had greater variations in response to N among the seasons than those in Kimutwa. A similar observation was found with regard to dry matter yield (DMY) of crops in Masii. Probably, the influence of N fertilizer and seasons on DMY in Masii invariably affected the uptake pattern since the nutrient uptake was calculated as the product of nutrient

Table 14 - Effect of N rates (kg / ha) and cropping systems on maize and bean N uptake at 20 DAE at Kimutwa.

Cropping systems	Maize					Beans				
	N0	N25	N50	N100	Mean	N0	N25	N50	N100	Mean
LR 1987		kg/ha					kg/ha			
Sole	2.09	4.15	4.25	4.12	3.65	6.59	9.31	9.62	9.05	8.64
ISR	1.63	2.23	2.54	2.12	2.13	5.99	8.31	8.56	8.09	7.74
IAR	1.73	2.58	2.57	2.56	2.36	6.24	7.21	7.72	8.84	7.51
Mean	1.81 b	2.99 a	3.12 a	2.94 a	2.72	6.28 b	8.28 a	8.63 a	8.66a	7.96
SR 1987/88										
Sole-NR	0.90	1.5	2.14	2.81	1.84 a	4.43	5.84	4.65	3.92	4.71
Sole-RR	-	-	-	-	-	4.55	5.06	3.95	4.60	4.54
ISNR	1.06	1.23	1.41	1.28	1.25 b	3.87	4.37	5.16	5.57	4.74
ISRR	0.82	0.90	1.66	2.59	1.49 b	3.55	5.38	5.11	5.33	4.84
IANR	1.56	1.56	1.49	1.62	1.56 a	5.44	5.05	4.34	4.91	4.93
IARR	0.87	1.46	1.26	1.41	1.25 b	3.39	4.34	4.36	4.54	4.16
Rot-NR	0.75	0.96	1.50	1.51	1.18 b	-	-	-	-	-
Rot-RR	1.05	1.06	1.55	1.40	1.27 b	-	-	-	-	-
Mean	1.00 b	1.24ab	1.57 a	1.80 a	1.40	4.20	5.01	4.59	4.81	4.65

Means followed by the same letter are not significantly different at P= 0.05 level according to New DMRT.

DAE = Days after seedling emergence

Table 15 – Effect of N rates and cropping systems on N uptake (kg/ha) by maize.

Fertilizer (kg N/ha)	Kimutwa				Masii			
	LR 1988	SR 1988/89	LR 1989	SR 1989/90	LR 1988	SR 1988/89	LR 1989	SR 1989/90
0	50.4	75.9	42.7	52.3	9.9	19.0	6.8	6.8
25	70.5	97.4	48.0	90.7	21.0	41.5	27.5	27.9
50	77.9	101.3	50.1	105.2	26.9	70.4	34.5	44.9
100	85.3	116.3	52.1	92.7	34.8	76.1	38.8	68.0
Mean	71.0	97.9	48.2	85.2	23.1	51.8	25.6	36.9
F test	***	*	ns	**	**	**	**	*
CV (%)	16	11	12	14	21	27	20	32
LSD 0.05	10.0	21.1	–	22.9	9.8	23.7	10.2	35.3
Cropping systems								
MSC	82.7	98.6	59.8	81.9	27.3	60.1	29.9	46.7
MISNR	67.9	93.2	40.2	83.3	18.9	37.0	21.5	37.5
MISRR	74.3	87.1	44.9	98.5	18.4	49.5	19.5	36.2
MIANR	63.3	91.8	48.0	79.3	22.1	53.8	21.5	32.1
MIARR	66.9	87.4	48.3	77.8	19.1	58.9	23.7	32.2
MRNR	–	116.1	–	79.6	29.6	–	32.3	–
MRRR	–	110.0	–	96.2	26.8	–	30.9	–
Mean	71.0	97.9	48.2	85.2	23.1	51.8	25.6	36.9
F test	**	***	***	*	**	*	**	ns
CV (%)	15	19	17	21	36	36	36.5	64
Interaction	ns	ns	ns	ns	ns	ns	ns	ns
LSD 0.05	6.4	15.4	6.8	14.4	6.9	14.1	7.7	–

*, **, *** = Treatment differences are significant at P= 0.05, 0.01, 0.001, level, respectively.
ns = Treatment differences or N x cropping systems interaction are not significant at P= 0.05 level.

Table.16 – Effect of N rates and cropping systems on phosphorus uptake (kg/ha) by maize.

	Kimutwa				Masii			
Fertilizer (kg N/ha)	LR 1988	SR 1988/89	SR 1989	SR 1989/90	LR 1988	SR 1988/89	LR 1989	SR 1989/90
0	4.3	8.4	3.2	4.7	1.3	3.3	0.8	1.2
25	5.8	9.9	3.9	7.7	2.4	5.7	2.4	4.1
50	6.0	9.3	3.6	7.7	2.6	11.3	3.1	6.3
100	6.8	9.9	3.3	7.7	3.2	10.7	2.7	8.4
Mean	5.8	9.4	3.5	7.0	2.4	7.7	2.3	5.0
F test	*	ns	ns	*	ns	*	*	*
CV (%)	12.9	17	26	12	31	33	31	29
LSD 0.05	1.5	–	–	1.7	–	5.2	1.4	2.9
Cropping systems								
MSC	6.4	9.1	4.3	6.4	2.3	10.0	2.6	5.8
MISNR	5.6	8.1	3.1	6.6	2.1	5.5	1.9	5.5
MISRR	6.2	9.0	3.2	8.1	1.8	7.6	1.6	4.7
MIANR	5.3	8.9	3.7	7.3	2.1	7.8	1.7	4.3
MIARR	5.3	8.8	3.3	6.2	2.1	7.8	2.2	4.7
Rot–NR	–	11.4	–	6.4	3.2	–	2.8	–
Rot–RR	–	10.3	–	7.7	3.1	–	2.6	–
Mean	5.8	9.4	3.5	7.0	2.4	7.7	2.3	5.0
F test	*	**	*	**	**	*	ns	ns
CV (%)	18	20	26	20	40	43	49	70
Interaction	ns	ns	ns	**	ns	ns	ns	ns
LSD 0.05	0.9	1.6	0.8	1.1	0.8	2.8	–	–

*, **, ***, = Treatment differences and interactions are significant at P = 0.05, 0.01, 0.001, level.

ns = Treatment differences and interactions are not significant at P = 0.05 level.

Table 17 – Effect of N rates and cropping systems on potassium uptake (kg/ha) by maize.

Fertilizer (kg N/ha)	Kimutwa				Masll			
	LR 1988	SR 1988/89	LR 1989	SR 1989/90	LR 1988	SR 1988/89	LR 1989	SR 1989/90
0	32.0	59.3	16.5	29.5	13.0	12.9	8.1	3.9
25	44.8	68.6	18.0	38.1	24.4	44.2	25.6	13.1
50	54.1	66.9	19.8	44.6	24.7	50.5	35.6	16.6
100	51.4	88.5	17.7	45.1	42.0	50.5	24.7	23.1
Mean	45.6	70.8	17.8	39.3	25.5	39.5	23.5	14.2
F test	ns	ns	ns	*	*	ns	**	**
CV (%)	21	15	16	32	30	41.7	21	22
LSD 0.05	–	–	–	8.3	15.4	–	9.9	6.3
Cropping systems								
MSC	57.8	81.6	23.4	40.9	25.5	60.5	22.6	15.9
MISNR	38.1	63.0	15.0	42.5	25.7	28.7	20.4	13.9
MISRR	49.3	70.0	15.9	40.9	21.2	31.7	16.9	14.4
MIANR	37.0	59.3	18.8	36	22.6	41.6	23.0	12.6
MIARR	45.5	55.5	16.9	36.4	21.4	34.9	22.7	14.0
Rot -NR	–	88.2	–	37.7	33.9	–	32.2	–
Rot-RR	–	78.3	–	41	28.5	–	26.5	–
Mean	45.6	70.8	17.8	39.3	25.5	39.5	23.5	14.2
F test	**	**	**	ns	ns	**	**	ns
CV (%)	28.8	33	29	23	52.3	54	38.4	43
Interaction	ns	ns	ns	ns	ns	ns	ns	ns
LSD 0.05	10.9	19.3	4.3	–	–	17.8	7.4	–

*, **, ***, = Treatment differences are significant at P = 0.05, 0.01, 0.001 level, respectively.

ns = Treatment differences and interactions are not significant at P = 0.05 level.

Table 18 - Effect of N rates and cropping systems on magnesium uptake (kg/ha) by maize.

Fertilizer (kg N/ha)	Kimutwa				Masii			
	LR 1988	SR 1988/89	LR 1989	SR 1989/90	LR 1988	SR 1988/89	LR 1989	SR 1989/90
0	3.4	5.9	3.7	8.4	6.0	3.5	1.6	1.0
25	5.7	6.6	5.0	11.0	12.7	7.3	4.8	3.1
50	5.4	6.5	5.0	12.3	15.1	10.8	6.1	3.9
100	6.5	8.0	5.2	13.4	17.2	8.5	5.3	5.9
Mean	5.3	6.8	4.7	11.3	12.7	7.5	4.5	3.5
F test	ns	ns	ns	**	**	*	**	**
CV (%)	21	19	13.4	10	16	32	15	25
LSD 0.05	-	-	-	2.1	4.2	4.8	1.0	1.7
Cropping systems								
MSC	5.8	6.9	5.4	11.2	14.6	9.9	4.8	3.5
MISNR	4.8	6.1	4.1	11.3	11.2	5.7	5.4	3.6
MISRR	6.1	6.6	4.5	12.1	10.5	5.7	5.3	3.8
MIANR	4.5	6.0	4.9	13.3	11.7	8.2	4.0	3.1
MIANR	5.1	5.5	4.8	10.9	11.8	8.0	3.5	3.4
Rot-NR	-	8.2	-	10.5	15.9	-	4.0	-
Rot-RR	-	8.2	-	11.4	13.4	-	4.3	-
Mean	5.3	6.8	4.7	11.3	12.7	7.5	4.5	3.5
F test	ns	**	ns	ns	ns	ns	**	ns
CV (%)	36	26	23	23	39	58	30	43
Interaction	ns	ns	ns	ns	ns	ns	ns	ns
LSD 0.05	-	1.5	-	-	-	-	1.1	-

*, **, = Treatment differences are significant at P = 0.05, 0.01 level.
ns = Treatment differences and interactions are not significant at P = 0.05 level.

Table 19 – Effect of N rates and cropping systems on calcium uptake (kg/ha) by maize.

Fertilizer (kg N/ha)	Kimutwa				Masii			
	LR 1988	SR 1988/89	LR 1989	SR 1989/90	LR 1988	SR 1988/89	LR 1989	SR 1989/90
0	7.3	3.1	3.6	5.9	3.1	1.7	4.3	0.4
25	14.3	4.4	5.0	8.5	6.5	4.3	10.7	3.6
50	13.0	3.3	4.9	9.6	7.1	5.1	14.0	6.6
100	15.2	5.2	4.9	8.7	8.1	4.3	11.8	10.3
Mean	12.5	4.0	4.6	8.2	6.2	3.9	10.2	5.2
F test	*	ns	ns	ns	*	**	**	**
CV (%)	22	27	14	17	21	20	16	35
LSD 0.05	5.4	–	–	–	2.6	1.5	2.7	3.6
Cropping systems								
MSC	14.9	4.7	5.6	8.0	6.3	4.8	10.4	6.7
MISNR	11.3	3.9	3.5	8.6	5.2	3.5	9.0	5.6
MISRR	14.5	3.7	4.9	8.5	5.6	3.0	7.7	3.8
MIANR	9.5	4.2	4.7	7.8	5.8	3.9	9.7	5.0
MIARR	12.1	2.8	4.5	7.6	5.7	4.0	10.4	5.0
Rot-NR	–	4.3	–	6.8	8.5	–	12.6	–
Rot-RR	–	4.2	–	9.9	6.4	–	11.6	–
Mean	12.5	4.0	4.6	8.2	6.2	3.9	10.2	5.2
F test	ns	ns	*	ns	ns	ns	*	ns
CV (%)	44	47	33	29	43	62	34	78
Interaction	ns	ns	ns	ns	ns	ns	ns	ns
LSD 0.05	–	–	1.3	–	–	–	2.9	–

*, **, = Treatment differences are significant at P = 0.05, 0.01 level.

ns = Treatment differences and interactions are not significant at P = 0.05 level.

Table 20 – Effect of N rates and cropping systems on nitrogen uptake (kg / ha) by beans.

	Kimutwa				Masii			
Fertilizer (kg N/ha)	LR 1988	SR 1988/89	LR 1989	SR 1989/90	LR 1988	SR 1988/89	LR 1989	SR 1989/90
0	49.6	16.3	34.8	21.9	11.6	22.1	19.6	33.7
25	68.5	21.5	54.4	38.9	30.7	34.1	34.1	54.1
50	78.0	21.7	55.4	48.7	35.3	40.1	38.6	81.4
100	80.8	23.1	46.2	47.5	34.7	37.8	35.9	63.4
Mean	69.2	20.7	47.7	39.3	28.1	33.5	32	58.1
F test	*	ns	*	**	*	*	ns	ns
CV (%)	12	16	12	15	30	18	26	34
LSD 0.05	16.6	–	11.1	11.4	17	12.3	–	–
Cropping systems								
BSCNR	75.6	28.9	51.0	62.9	38.6	36.4	42.4	66.4
BSCRR	85.7	24.9	48.6	47.7	33.8	30.2	35.9	54.8
BISNR	57.0	17.3	36.5	36.2	26.5	34.8	26.2	51.6
BISRR	54.8	19.9	35.1	28.7	24.4	29.0	32.4	45.7
BIANR	42.1	20.1	30.9	30.3	21.4	24.5	28.0	42.4
BIARR	44.0	12.8	26.4	29.8	23.8	27.7	27.3	42.5
Rot-NR	103.8	–	77.7	–	–	47.4	–	83.5
Rot-RR	91.1	–	74.7	–	–	38.2	–	78.3
Mean	69.2	20.7	47.7	29.3	28.1	33.5	32.0	58.1
F test	***	***	***	***	**	***	***	***
CV (%)	23	28	17	28	40	37.0	22	41
Interaction	ns	ns	***	ns	ns	ns	**	ns
LSD 0.05	12.9	4.8	6.5	9.2	9.2	10.1	5.8	19.3

*, **, ***, = Treatment differences and interactions are significant at P = 0.05, 0.01, 0.001, level, respectively.

ns = Treatment differences and interactions are not significant at P = 0.05 level.

Table 21 – Effect of N rates and cropping systems on phosphorus uptake (kg / ha) by beans

Fertilizer (kg N/ha)	Kimutwa				Masii			
	LR 1988	SR 1988/89	LR 1989	SR 1989/90	LR 1988	SR 1988/89	LR 1989	SR 1989/90
0	4.1	1.4	2.3	1.8	1.1	2.0	1.8	2.4
25	4.8	1.7	2.9	2.6	2.0	2.9	2.9	3.7
50	5.6	1.6	3.3	3.4	2.2	3.4	3.0	6.5
100	5.4	1.5	2.6	2.9	2.1	2.9	2.5	3.8
Mean	5.0	1.5	2.8	2.7	1.8	2.8	2.6	4.1
F test	ns	ns	***	**	ns	ns	**	*
CV (%)	12	22	7	13	35	21	11	11
LSD 0.05	–	–	0.4	0.7	–	–	0.6	2.6
Cropping systems								
BSCNR	5.6	2.3	3.0	4.5	2.5	3.1	3.4	4.6
BSCRR	6.3	1.9	2.9	3.4	2.5	2.6	3.0	3.6
BISNR	4.0	1.3	2.4	2.1	1.6	2.8	2.1	3.8
BISRR	3.6	1.5	2.4	2.2	1.5	2.8	2.6	3.0
BIANR	2.7	1.5	1.9	2.0	1.4	2.1	2.1	2.3
BIARR	3.4	0.9	1.6	1.9	1.5	2.1	2.2	3.4
Rot-NR	7.2	–	4.3	–	–	3.7	–	6.4
Rot-RR	7.0	–	3.8	–	–	3.3	–	5.7
Mean	5.0	1.5	2.8	2.7	1.8	2.8	2.6	4.1
F test	***	***	***	***	***	*	***	***
CV (%)	23	28	27	30	39	42	17	37
Interaction	ns	ns	ns	ns	ns	ns	***	*
LSD 0.05	0.9	0.4	0.6	0.7	0.6	1.0	0.4	1.3

*, **, ***, = Treatment differences and interactions are significant at P = 0.05, 0.01, 0.001, level, respectively.

ns = Treatment differences and interactions are not significant at P = 0.05 level.

Table 22 – Effect of N rates and cropping systems on potassium uptake (kg / ha) by beans.

Fertilizer (kg N/ha)	Kimutwa				Masii			
	LR 1988	SR 1988/89	LR 1989	SR 1989/90	LR 1988	SR 1988/89	LR 1989	SR 1989/90
0	32.0	11.6	19.9	12.3	7.5	15.4	14.7	22.2
25	43.7	16.4	28.4	20.7	17.2	25.0	23.2	36.9
50	44.7	14.2	37.3	28.2	21.1	29.0	25.8	56.4
100	44.7	16.1	28.0	24.3	19.9	28.1	20.8	46.8
Mean	41.3	14.6	28.4	21.4	16.4	24.4	21.1	40.6
F test	**	ns	*	**	ns	ns	*	ns
CV (%)	8	20	14	12	33	23	15	33.5
LSD 0.05	6.9	–	8.0	5.2	–	–	6.3	–
Cropping systems								
BSCNR	46.0	21.1	28.3	33.8	22.4	24.4	27.9	47.0
BSCRR	50.6	17.6	28.8	26.1	20.4	22.0	22.8	40.8
BISNR	30.2	12.0	20.9	18.0	15.7	24.8	19.3	34.5
BISRR	31.0	13.5	21.6	16.7	14.8	20.8	20.8	29.8
BIANR	23.3	13.6	16.0	16.8	11.8	17.2	17.8	23.9
BIARR	26.9	9.8	15.0	16.9	13.2	22.3	17.9	32.2
Rot-NR	64.4	–	49.3	–	–	35.1	–	62.5
Rot-RR	57.7	–	47.3	–	–	28.4	–	54.0
Mean	41.3	14.6	28.4	21.4	16.4	24.4	21.1	40.6
F test	***	***	***	***	***	*	***	***
CV (%)	25	31	27	30	36	45	19	15
Interaction	ns	ns	ns	ns	ns	ns	**	ns
LSD 0.05	8.3	3.7	6.3	5.2	4.8	10.9	3.3	15.8

*, **, ***, = Treatment differences and interactions are significant at P = 0.05, 0.01, 0.001, level, respectively.

ns = Treatment differences and interactions are not significant at P = 0.05 level.

Table 23 – Effect of N rates and cropping systems on magnesium uptake (kg / ha) by beans.

	Kimutwa				Masii			
Fertilizer (kg N/ha)	LR 1988	SR 1988/89	LR 1989	SR 1989/90	LR 1988	SR 1988/89	LR 1989	SR 1989/90
0	14.5	5.6	4.6	3.0	1.9	8.6	2.6	2.9
25	20.8	7.5	7.1	4.9	4.5	15.0	3.9	4.9
50	20.0	7.1	7.7	6.3	6.0	16.9	4.4	8.2
100	20.0	7.3	6.3	5.7	6.2	16.9	4.0	6.1
Mean	18.8	6.9	6.4	5.0	4.6	14.3	3.7	5.5
F test	ns	ns	**	**	ns	*	*	ns
CV (%)	13	24.1	11	15.4	44.1	18.7	15.0	33.9
LSD 0.05	–	–	1.3	1.5	–	4.4	1.1	–
Cropping systems								
BSCNR	20.9	10.3	6.9	7.1	6.6	14.5	4.8	6.4
BSCRR	20.0	4.5	6.6	5.7	5.5	12.8	3.8	5.1
BISNR	17.1	6.1	5.0	4.5	5.2	14.9	3.5	5.0
BISRR	16.8	6.9	5.0	4.1	4.3	12.0	3.7	3.9
BIANR	13.9	6.4	4.0	4.4	3.0	10.1	3.2	3.8
BIARR	12.8	4.0	3.6	3.9	3.3	14.4	3.0	4.1
Rot-NR	25.8	–	10.4	–	–	18.9	–	8.5
Rot-RR	23.3	–	9.8	–	–	17.1	–	7.2
Mean	18.8	6.9	6.4	5.0	4.6	14.3	3.7	5.5
F test	***	***	***	***	***	*	***	***
CV (%)	38	36	22	30	40.6	42.6	19.9	39.6
Interaction	ns	ns	*	ns	ns	NS	**	ns
LSD 0.05	5.8	2.1	1.1	1.2	1.6	5.0	0.6	1.8

*, **, ***, = Treatment differences and interactions are significant at P = 0.05, 0.01, 0.001, level, respectively.

ns = Treatment differences and interactions are not significant at P = 0.05 level.

Table 24 – Effect of N rates and cropping systems on calcium uptake (kg / ha) by beans.

	Kimutwa				Masii			
Fertilizer (kg N/ha)	LR 1988	SR 1988/89	LR 1989	SR 1989/90	LR 1988	SR 1988/89	LR 1989	SR 1989/90
0	7.2	4.2	13.2	3.2	1.5	4.7	6.4	6.2
25	12.4	5.5	16.9	6.4	4.3	7.4	9.1	9.8
50	9.4	6.0	20.5	7.5	6.2	7.9	10.8	17.2
100	10.2	5.8	16.9	7.0	5.8	8.0	8.6	13.2
Mean	9.8	5.4	16.8	6.0	4.4	7.0	8.7	11.6
F test	*	ns	*	*	ns	*	ns	ns
CV (%)	16	16	13	20	53	13	18.9	37
LSD 0.05	3.2	–	4.2	2.4	–	1.8	–	–
Cropping systems								
BSCNR	10.0	6.6	17.6	8.8	6.8	7.2	11.4	14.3
BSCRR	11.6	6.3	17.0	7.0	5.9	6.8	8.2	11.7
BISNR	8.0	4.5	13.0	5.5	3.9	6.8	9.2	10.3
BISRR	8.3	5.4	13.1	5.0	4.6	5.9	8.9	8.4
BIANR	6.8	5.2	10.9	5.0	2.5	5.0	7.5	7.4
BIARR	6.2	4.2	9.5	4.8	3.0	6.6	7.2	8.7
Rot–NR	14.1	–	26.2	–	–	9.4	–	16.5
Rot–RR	13.3	–	27.1	–	–	8.1	–	15.7
Mean	9.8	5.4	16.8	6.0	4.4	7.0	8.7	11.6
F test	***	**	***	***	***	*	**	***
CV (%)	29	29	24	32	42	43	30	42
Interaction	*	ns	ns	ns	ns	ns	*	*
LSD 0.05	2.3	1.3	3.3	1.6	1.5	2.5	2.2	3.9

*, **, ***, = Treatment differences and interactions are significant at P = 0.05, 0.01, 0.001, level, respectively.

ns = Treatment differences and interactions are not significant at P = 0.05 level.

Table 25 - Effect of rotation of maize and beans on bean nutrient uptake

Site/ Nutrient/ Season	Continuous sole beans	Beans after maize	Increase due to rotation	Uptake increase in beans
Kimutwa	--------	kg/ha	---------	%
Nitrogen				
LR 1988	80.6	97.6	17	18
LR 1989	49.8	76.3	27	53
Mean	65.2	87.0	22	33
Phosphorus				
LR 1988	5.9	7.1	1.2	21
LR 1989	3.0	4.4	1.4	50
Mean	4.5	5.8	1.3	30
Potassium				
LR 1988	48.3	61.1	12.8	26
LR 1989	28.5	48.3	19.8	69
Mean	38.4	54.7	16.3	42
Magnesium				
LR 1988	20.5	26.8	6.3	31
LR 1989	6.7	10.2	3.5	52
Mean	13.6	18.5	4.9	36
Calcium				
LR 1988	10.7	13.7	3.0	28
LR 1989	28.5	48.3	19.8	70
Mean	19.6	31.0	11.4	58
Masii				
Nitrogen				
SR 1988/89	33.3	42.8	9.5	29
SR 1989/90	60.6	80.9	20.3	33
Mean	47.0	62.0	15	32
Phosphorus				
SR 1988/89	2.9	3.5	0.6	22
SR 1989/90	4.1	6.1	2.0	48
Mean	3.5	4.8	1.3	37
Potassium				
SR 1988/89	23.2	31.9	8.7	38
SR 1989/90	43.9	58.3	14.4	33
Mean	33.5	45.1	11.6	34
Magnesium				
SR1988/89	13.6	18.0	4.4	32
SR 1989/90	5.8	7.9	2.1	36
Mean	9.7	13.0	3.3	34
Calcium				
SR 1988/89	7.0	9.0	2.0	29
SR 1989/90	13.0	16.1	3.0	24
Mean	10.0	12.5	2.5	26

Table 26 – Effect of N rates and cropping systems on maize and beans nitrogen uptake (kg/ha).

	Kimutwa				Masii			
Fertilizer (kg N/ha)	LR 1988	SR 1988/89	LR 1989	SR 1989/90	LR 1988	SR 1988/89	LR 1989	SR 1989/90
0	71.4	69.9	54.7	55.3	15.5	30.2	18.4	30.8
25	100.2	90.0	75.0	95.3	36.8	53.5	44.1	60.9
50	112.7	93.2	77.4	114.3	44.5	74.9	52.5	97.3
100	119.2	106.3	70.0	103.7	50.2	75.9	50.2	93.2
Mean	100.9	89.9	69.3	92.2	36.7	58.6	41.3	71.3
F test	**	*	*	**	**	**	*	*
CV %	8.4	10.3	8.6	11.3	20.7	19.5	22.3	27.1
LSD 0.05	17.0	18.5	12.0	20.9	15.2	22.8	18.4	38.6
Cropping systems								
MSC	82.7	98.5	59.8	81.9	27.3	60.1	29.9	46.7
M-BISNR	123.3	107.0	76.7	119.5	45.4	71.8	47.7	89.1
M-ISRR	129.0	110.8	80.4	124.5	42.8	78.5	51.9	79.8
M-BIANR	105.3	110.6	78.9	109.7	43.6	78.4	49.5	74.5
M-BIARR	110.9	96.2	75.5	107.6	42.9	86.5	51.0	74.6
Rot-NR	104.1b	121.1m	77.7b	79.6m	29.6m	47.4b	32.3m	83.5b
Rot-RR	91.1b	111.0m	74.8b	96.1m	26.8m	38.2b	31.0m	78.3b
BSCNR	75.6	28.9	51.0	62.9	38.6	36.4	42.4	60.5
BSCRR	85.7	24.9	48.6	47.7	33.8	30.2	35.9	54.8
Mean	100.9	89.9	69.3	92.2	36.7	58.6	41.3	71.3
F test	***	***	***	***	**	***	***	*
CV %	17.2	17.3	13.5	19.9	36.3	33.2	25.6	45.6
Interaction	ns	ns	**	ns	ns	**	ns	ns
LSD 0.05	14.2	12.7	7.6	15.0	10.9	15.9	8.6	32.5

*, **, *** = Treatment differences and interactions are significant at P = 0.05, 0.01, 0.001 level, respectively.

ns = Treatment differences and interactions are not significant at P = 0.05 level.

b, m = bean and maize in rotation system.

Table 27 - Effect of N rates and cropping systems on maize and beans phosphorus uptake (kg/ha)

	Kimutwa				Masii			
Fertilizer (kg N/ha)	LR 1988	SR 1988/89	LR 1989	SR 1989/90	LR 1988	SR 1988/89	LR 1989	SR 1989/90
0	6.0	7.5	3.8	4.8	1.7	3.6	1.8	2.8
25	7.4	8.8	4.8	7.7	3.2	5.7	3.7	5.5
50	8.3	8.3	5.0	8.3	3.4	9.2	4.4	9.5
100	8.6	8.7	4.2	8.0	3.9	8.5	3.8	8.0
Mean	7.6	8.3	4.4	7.2	3.0	6.8	3.4	6.5
F test	*	ns	ns	**	ns	*	**	**
CV %	10	24	14	10	29	25	18	21
LSD 0.05	1.5	-	-	1.5	-	3.4	1.2	2.8
Cropping systems								
MSC	6.4	9.1	4.2	6.4	2.3	10.0	2.6	5.8
M-BISNR	9.7	9.4	5.4	8.6	3.7	8.3	3.8	9.2
M-BISRR	9.9	10.5	5.4	10.2	3.4	10.1	4.2	7.7
M-BIANR	8.0	10.3	5.4	9.3	3.5	9.7	3.8	6.6
M-BIARR	8.3	9.7	4.8	8.1	3.6	10.1	4.4	8.1
Rot-NR	6.9b	10.4m	4.5b	6.4m	3.0m	3.8b	2.8m	6.4b
Rot-RR	6.8b	10.3m	4.3b	7.7m	3.1m	3.3b	2.7m	5.7b
BSCNR	5.9	2.3	3.0	4.5	2.5	3.1	3.4	4.6
BSCRR	6.5	1.9	2.9	3.4	2.5	2.6	3.0	3.9
Mean	7.6	8.3	4.4	7.2	3.0	6.8	3.4	6.5
F test	***	***	***	***	**	***	***	**
CV %	18	23	21	21	34	45	31	50
Interaction	ns	ns	ns	**	ns	**	*	ns
LSD 0.05	1.1	1.5	0.80	1.2	0.80	2.5	0.90	2.6

*, **, ***, = Treatment differences and interactions are significant at P = 0.05, 0.01, 0.001, level respectively.

ns = Treatment differences and interactions are not significant at P = 0.05 level.

b, m = bean and maize in rotation system, respectively.

Table 28 - Effect of N rates and cropping systems on maize and beans potassium uptake (kg/ha).

	Kimutwa				Masii			
Fertilizer (kg N/ha)	LR 1988	SR 1988/89	LR 1989	SR 1989/90	LR 1988	SR 1988/89	LR 1989	SR 1989/90
0	45.8	73.8	27.1	31.2	15.1	20.8	16.1	21.1
25	63.7	64.3	35.6	43.5	29.0	46.8	35.2	40.0
50	69.7	60.0	44.1	53.5	33.3	53.8	44.8	59.4
100	68.4	79.6	34.7	51.3	45.9	53.0	33.0	53.3
Mean	61.9	69.4	35.4	44.9	30.8	43.6	32.3	43.7
F test	**	ns	*	***	**	*	***	*
CV %	10	27	13	8	21	24	13	26
LSD 0.05	11.7	–	8.9	6.9	13.0	20.5	8.3	23.0
Cropping systems								
MSC	57.8	81.6	23.3	40.9	25.5	60.5	22.6	15.9
M-BISNR	68.1	74.9	36.2	60.6	41.5	53.6	39.3	46.0
M-BISRR	80.6	83.4	38.4	57.6	36.1	52.4	37.9	44.2
M-BIANR	60.3	117.9	35.0	52.8	34.4	58.8	40.0	36.5
M-BIARR	72.5	62.0	31.8	53.3	34.6	57.2	40.6	46.2
Rot-NR	64.4b	88.2m	49.3b	37.6m	33.4m	35.3b	32.2m	62.0b
Rot-RR	57.7b	78.2m	47.3b	41.1m	29.7m	28.4b	26.5m	54.0b
BSCNR	45.0	21.1	28.3	33.9	24.4	24.4	27.9	47.0
BSCRR	50.6	17.6	28.8	26.1	19.9	22.0	22.8	40.8
Mean	61.9	69.4	35.4	44.9	30.8	43.6	32.3	43.7
F test	***	**	***	***	*	***	***	***
CV %	22	82	23	22	47	46.9	29	47
Interaction	ns	ns	ns	ns	ns	ns	ns	ns
LSD 0.05	11.1	46.5	6.5	8.1	11.9	16.7	7.7	16.9

*, **, ***, = Treatment differences and interactions are significant at P = 0.05, 0.01, 0.001 level, respectively.

ns = Treatment differences and interactions are not significant at P = 0.05 level.

b, m = bean and maize in rotation system, respectively.

Table 29 - Effect of nitrogen rates and cropping systems on maize and beans magnesium uptake (kg / ha).

Fertilizer (kg N/ha)	Kimutwa				Masii			
	LR 1988	SR 1988/89	LR 1989	SR 1989/90	LR 1988	SR 1988/89	LR 1989	SR 1989/90
0	31.9	8.4	6.3	8.6	6.0	9.7	3.0	3.1
25	50.1	9.9	9.1	11.8	12.8	17.7	6.3	6.0
50	48.0	9.8	9.6	13.5	15.7	21.1	7.7	9.4
100	54.1	11.1	8.4	14.2	17.5	19.7	6.7	8.7
Mean	46.0	9.9	8.3	12.0	13.0	17.0	5.9	6.8
F test	*	ns	*	**	**	*	***	*
CV %	17	17	11	9.2	18	21	11.5	25
LSD 0.05	16.0	-	1.8	2.2	4.7	6.9	0.8	3.5
Cropping systems								
MSC	58.4	6.9	5.4	11.2	14.6	10.7	4.8	3.4
M-BISNR	62.4	12.2	9.1	15.8	16.5	20.6	7.3	8.7
M-BISRR	76.9	13.5	9.4	16.2	14.8	17.7	7.2	7.7
M-BIANR	48.0	12.3	9.1	15.2	14.7	18.6	7.3	6.9
M-BIARR	63.8	9.5	8.4	14.8	15.2	22.4	7.3	7.6
Rot-NR	29.0 b	8.3m	10.4b	10.6m	15.9m	18.4 b	5.4 m	8.5 b
Rot-RR	24.5 b	8.3m	9.8b	11.4m	13.4m	17.2 b	5.3 m	7.2 b
BSCNR	20.9	10.3	6.9	7.1	6.6	15.0	4.8	6.4
BSCRR	20.0	7.4	6.6	7.7	5.4	12.7	3.8	5.1
Mean	46.0	9.8	8.3	12.0	13.0	17.0	5.9	6.8
F test	***	***	***	***	***	**	***	***
CV %	34	28	18	23.1	37	42	23	39
Interaction	ns	ns	ns	ns	ns	ns	*	ns
LSD 0.05	12.8	2.3	1.2	2.3	3.9	5.9	1.1	2.2

*, **, *** = Treatment differences and interactions are significant at P = 0.05, 0.01, 0.001 level, respectively.

ns = Treatment differences and interactions are not significant at P = 0.05 level.

b, m = bean and maize in rotation system, respectively.

Table 30 – Effect of nitrogen rates and cropping systems on maize and beans calcium uptake (kg/ha).

	Kimutwa				Masii			
Fertilizer (kg N/ha)	LR 1988	SR 1988/89	LR 1989	SR 1989/90	LR 1988	SR 1988/89	LR 1989	SR 1989/90
0	10.5	5.2	13.8	6.7	3.4	5.1	7.7	5.7
25	19.0	7.1	18.2	10.9	7.9	8.9	14.3	10.7
50	15.6	6.5	21.0	12.6	9.4	9.8	18.1	19.0
100	17.5	7.9	17.5	11.1	10.1	9.5	14.9	17.5
Mean	15.6	6.7	17.6	10.3	7.7	8.3	13.8	13.2
F test	*	ns	*	**	*	**	**	*
CV (%)	14	17.8	10.0	12.7	27	10.0	12	31
LSD 0.05	4.3	–	3.5	2.6	4.1	1.7	3.3	8.2
Cropping systems								
MSC	14.9	4.7	5.6	8.0	6.3	4.8	10.4	6.7
M-BISNR	19.3	8.4	16.5	14.0	9.1	10.0	18.3	15.9
M-BISRR	22.9	9.1	18.0	13.5	10.2	8.7	16.6	12.2
M-BIANR	16.3	9.4	15.6	12.8	8.2	9.1	17.0	12.4
M-BIARR	18.3	7.0	13.9	12.7	8.0	10.9	17.8	13.7
Rot-NR	14.1b	4.3m	26.2b	6.8m	8.5m	9.3b	12.6m	16.5b
Rot-RR	13.4 b	4.3m	27.1b	9.2m	6.4m	8.1b	11.6m	15.7b
BSCNR	10.0	6.6	18.0	8.8	6.8	7.2	11.4	14.3
BSCRR	11.6	6.3	17.6	7.0	6.0	6.8	8.2	11.7
Mean	15.6	6.7	17.6	10.3	7.7	8.3	13.8	13.2
F test	*	***	***	***	*	**	**	**
CV (%)	33	35	23	25	41	42	31	44
Interaction	ns	ns	ns	ns	ns	ns	ns	ns
LSD 0.05	4.1	1.9	3.4	2.1	2.6	2.8	3.4	4.8

*, **, ***, = Treatment differences and interactions are significant at P = 0.05, 0.01, 0.001 level, respectively.

ns = Treatment differences and interactions are not significant at P = 0.05 level.

b, m = bean and maize in rotation system, respectively.

Table 31 – Effect of N rates and cropping systems on nutrient uptake (kg/ha) by total systems per year at Kimutwa

Fertilizer kg N/ha	N Year 1	N Year 2	P Year 1	P Year 2	K Year 1	K Year 2	Mg Year 1	Mg Year 2	Ca Year 1	Ca Year 2
0	141	110	14	9	100	58	40	15	16	20
25	190	170	16	13	128	79	61	21	26	29
50	206	192	17	13	130	98	59	24	22	33
100	226	170	17	12	145	86	65	23	25	29
Mean	191	160	16	12	126	80	56	20	22	28
F test	**	**	ns	**	*	**	*	**	*	**
CV (%)	9	10	13	10	12	9	15	8	13	10
LSD 0.05	32.4	32.7	–	2.3	29.3	14.0	16.9	3.4	5.9	5.6
Cropping systems										
MSC	181	141	16	11	139	64	65	17	20	14
M-BISNR	230	196	19	14	143	97	73	25	28	31
M-BISRR	240	197	20	16	157	97	92	26	32	32
M-BIANR	216	189	18	15	133	88	73	25	26	28
M-BIARR	207	183	18	13	136	85	73	23	25	26
Rot-NR	225	157	19	11	153	87	37	21	18	33
Rot-RR	202	170	17	12	136	88	32	21	17	36
BSCNR	105	114	8	7	66	62	31	14	16	27
BSCRR	111	96	8	6	68	55	27	12	18	25
Mean	191	160	16	12	126	80	56	20	22	28
F test	***	***	***	***	***	***	***	***	***	***
CV (%)	12	15	15	17	21	18	28	18	27	19
Interaction	ns	ns	ns	*	ns	ns	ns	ns	ns	ns
LSD 0.05	18.7	20	2.0	1.6	21.3	11.7	12.8	3.0	4.9	4.3

*, **, *** = Treatment differences and interactions are significant at P = 0.05, 0.01, 0.001 level, respectively.

ns = Treatment differences and interactions are not significant at P = 0.05 level.

Year 1 = LR 1988 + SR 1988/89; Year 2 = LR 1989 + SR 1989/90

Table 32 – Effect of N rates and cropping systems on nutrient uptake (kg/ha) by total systems per year at Masii.

	N		P		K		Mg		Ca	
Fertilizer kg N/ha	year 1	Year 2	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2
0	46	52	5	5	36	38	16	6	9	13
25	90	112	9	9	75	76	30	12	17	25
50	121	150	13	14	87	104	37	17	20	37
100	126	143	12	12	99	87	37	15	20	32
Mean	96	104	10	10	74	76	30	13	16	27
F test	**	*	*	**	*	**	**	**	**	**
CV (%)	20	23	26	19	21	20	18	18	16	20
LSD 0.05	38.9	53	5.0	3.5	31.3	29.6	10.9	4.6	5.2	10.7
Cropping systems										
MSC	87	77	12	8	86	39	25	8	11	17
M-BISNR	117	140	12	13	97	88	37	16	19	34
M-BISRR	121	131	13	12	89	82	33	15	19	29
M-BIANR	122	127	13	10	93	78	33	14	17	29
M-BIARR	134	127	14	13	89	87	38	15	20	31
Rot-NR	77	118	7	9	69	95	35	14	18	29
Rot-RR	65	111	6	8	57	81	30	13	15	27
BSCNR	75	109	6	8	47	73	21	11	14	26
BSCRR	64	91	5	10	42	64	18	9	13	20
Mean	96	114	10	7	74	76	30	13	16	27
F test	***	**	***	***	***	***	***	***	**	***
CV (%)	30	34	36	40	42	33	35	28	36	32
Interaction	ns	ns	*	ns	ns	ns	ns	ns	ns	ns
LSD 0.05	23.7	31.3	2.9	3.2	25.3	20.3	8.4	2.9	4.8	7.1

*, **, *** = Treatment differences aand interactions are significant at P = 0.05, 0.01 0.001 level, respectively.

ns = Treatment differences and interactions are not significant at P= 0.05 level.

Year 1 = LR 1988 + SR 1988/89 ; Year 2 = LR 1989 + SR 1989/90.

concentration and DMY of the crop. The greater nutrient uptake response to N in Masii than in Kimutwa might be attributed to the lower level of soil mineral N in Masii (Tables 51 and 52) while the greater variation in response to N could be due to the sandy soil of Masii whose retention of moisture during the growth of plants would have been more variable from one season to the other relative to the sandy clay loam soil of Kimutwa.

The relationships between N fertilizer and nutrient uptake by maize and beans in different cropping systems were generally found to be quadratic in nature (Figs. 1 through 9; Tables 33 and 34). Regardless of the cropping systems, the uptake of N, P, K, Mg and Ca by maize was influenced by the seasons and by the help of regression analysis, the maximum uptake of these nutrients was predicted to occur between 75 and 100 kg N/ha fertilizer. When the interaction of N x cropping systems was significant as in the uptake of phosphorus by maize in Kimutwa, the uptake varied with cropping systems. Thus, maximum uptake of P by continuous sole maize and that in rotation occurred at 75 kg N/ha while the maximum uptake by maize intercropped in the same row was predicted at 100 kg N/ha and that in the alternate row occurred at 50 kg N/ha (Fig. 1a). There was a clear trend for maize to take up higher amounts of N and P with the increase in rainfall while high rainfall tended to lower the uptake of K and Ca (Figs. 3a and 4 and Table 1). Regardless of cropping systems, beans were found to take up maximum N, K, Mg and Ca at a fertilizer rate of 75 kg N/ha while the highest uptake of P occurred at 50 kg N/ha in both sites (Figs. 5a, 6a, 7a, 8b and 9b). Where N x cropping systems interactions were significant, beans in different cropping systems were found to require different levels of N rate in order to take up maximum nutrients. Thus, in Kimutwa beans in the continuous sole cropping and the same row intercropping were predicted to take up the highest amount of Mg and Ca at 50 kg N/ha while the highest uptake

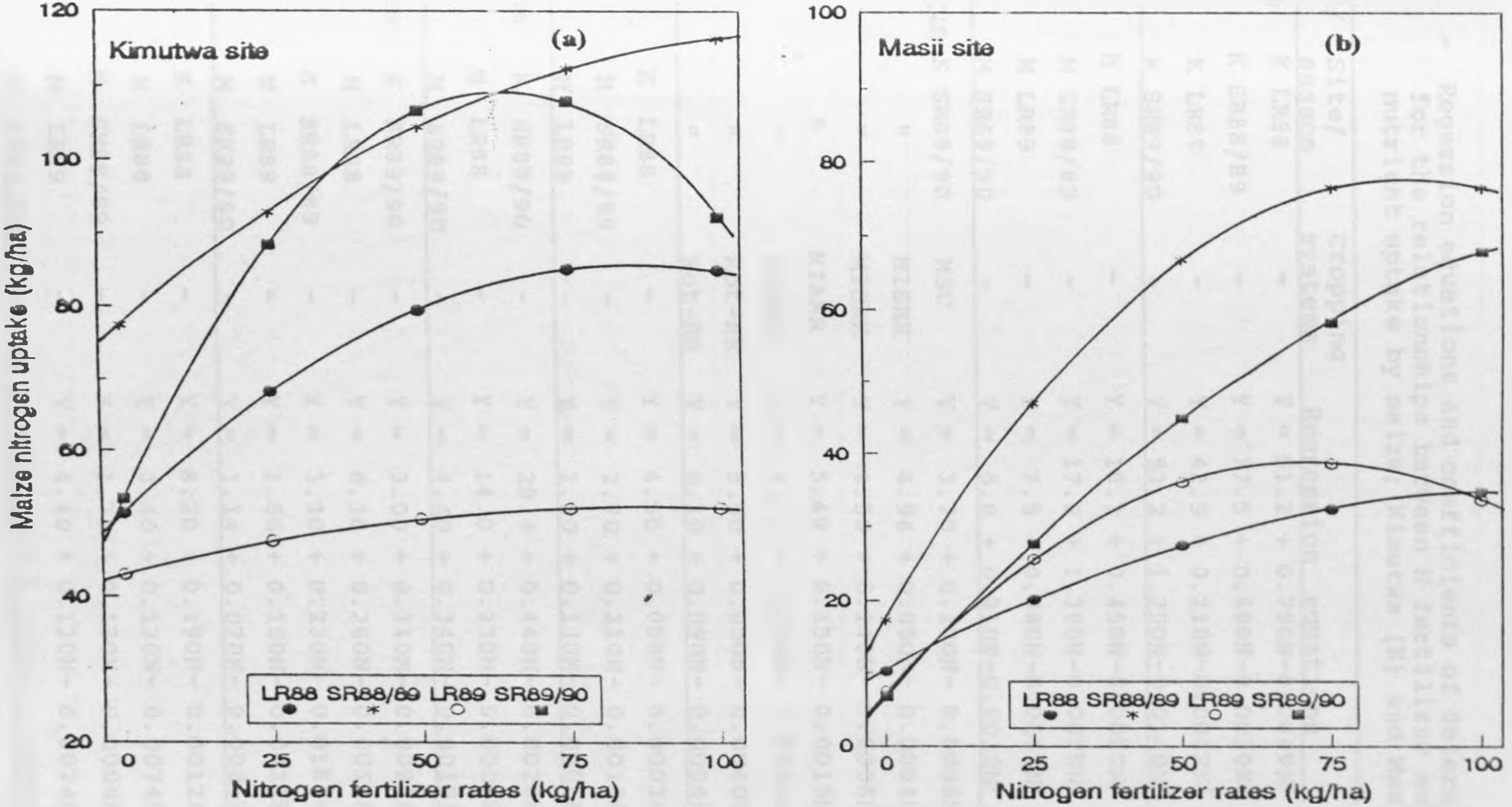

Fig. 1 - Relationships between N fertilizer rates and maize N uptake during the long rain (LR) and short rain (SR) seasons.

*For regression equations and R^2, see Table 33

Table 33 - Regession equations and coefficients of determination for the relationships between N fertilizer and nutrient uptake by maize; Kimutwa (K) and Masii (M).

Nutrient/ Figure	Site/ season	Cropping systems	Regression equations	R^2
Nitrogen	K LR88	-	$Y = 51.2 + 0.796N-0.0049N^2$	0.988
1a	K SR88/89	-	$Y = 77.5 + 0.690N-0.0030N^2$	0.961
	K LR89	-	$Y = 42.9 + 0.210N-0.0012N^2$	0.991
	k SR89/90	-	$Y = 53.2 + 1.750N-0.0140N^2$	0.995
1b	M LR88	-	$Y = 10.3 + 0.450N-0.0020N^2$	0.996
	M SR88/89	-	$Y = 17.2 + 1.390N-0.0079N^2$	0.990
	M LR89	-	$Y = 7.5 + 0.880N-0.0062N^2$	0.988
	M SR89/90	-	$Y = 6.8 + 0.910N-0.0030N^2$	1.000
Phosphorus	K SR89/90	MSC	$Y = 3.70 + 0.100N- 0.0006N^2$	0.975
	"	MISNR	$Y = 4.96 + 0.050N- 0.0001N^2$	0.860
	"	MISRR	$Y = 4.58 + 0.140N- 0.0008N^2$	0.876
2a	"	MIANR	$Y = 5.49 + 0.150N- 0.0015N^2$	0.857
	"	MIARR	$Y = 4.72 + 0.150N- 0.0014N^2$	0.892
	"	Rot-NR	$Y = 5.50 + 0.050N- 0.0040N^2$	0.508
	"	Rot-RR	$Y = 6.10 + 0.090N- 0.0006N^2$	0.647
2b	K LR88	-	$Y = 4.50 + 0.050N- 0.0003N^2$	0.946
	M SR88/89	-	$Y = 2.70 + 0.210N- 0.0013N^2$	0.913
	M LR89	-	$Y = 1.20 + 0.130N- 0.0006N^2$	0.999
Potassium	K SR89/90	-	$Y = 29.4 + 0.440N- 0.0028N^2$	0.998
3a	M LR88	-	$Y = 14.0 + 0.230N- 0.0005N^2$	0.976
	M SR89/90	-	$Y = 4.40 + 0.340N- 0.0015N^2$	0.988
Magnesium	K SR89/90	-	$Y = 3.00 + 0.310N- 0.0021N^2$	0.721
	M LR88	-	$Y = 6.30 + 0.260N- 0.0016N^2$	0.987
3b	M SR88/89	-	$Y = 3.30 + 0.230N- 0.0180N^2$	0.975
	M LR89	-	$Y = 1.66 + 0.150N- 0.0011N^2$	0.995
	M SR89/90	-	$Y = 1.14 + 0.070N- 0.0026N^2$	0.987
Calcium	K LR88	-	$Y = 8.20 + 0.190N- 0.0012N^2$	0.785
	M LR88	-	$Y = 3.40 + 0.120N- 0.0074N^2$	0.952
4	M SR88/89	-	$Y = 1.70 + 0.120N- 0.0009N^2$	0.990
	M LR89	-	$Y = 4.40 + 0.130N- 0.0024N^2$	1.000
	M SR89/90	-	$Y = 0.35 + 0.150N- 0.0005N^2$	0.999

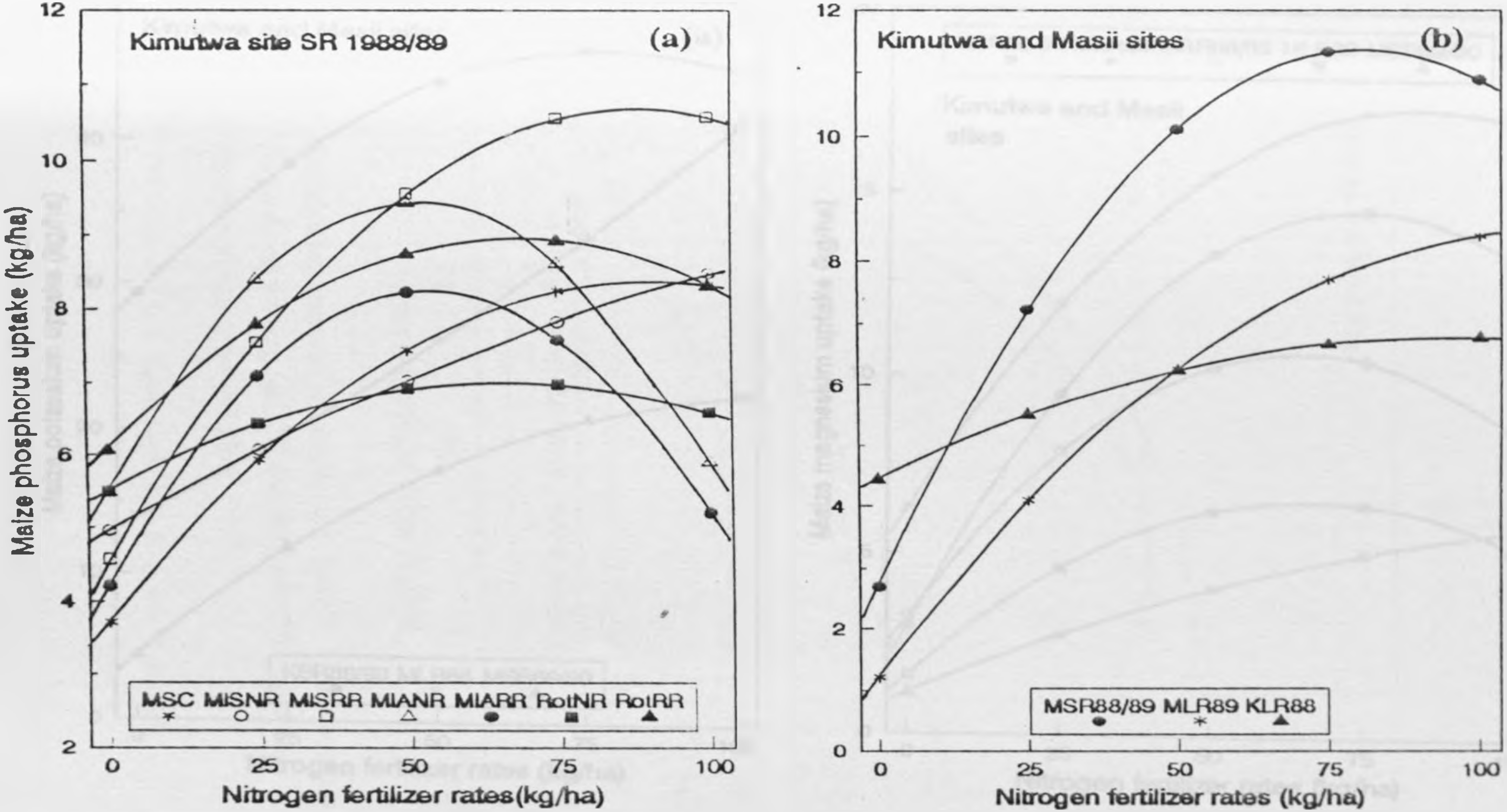

Fig. 2 - Relationships between N fertilizer rates and maize phosphorus uptake during the long rain (LR) and short rain (SR) seasons at Kimutwa (K) and Masii (M) sites. * For regression equations and R^2, see Table 33

M in Fig.1a and Fig.1b stands for maize and Masii site respectively

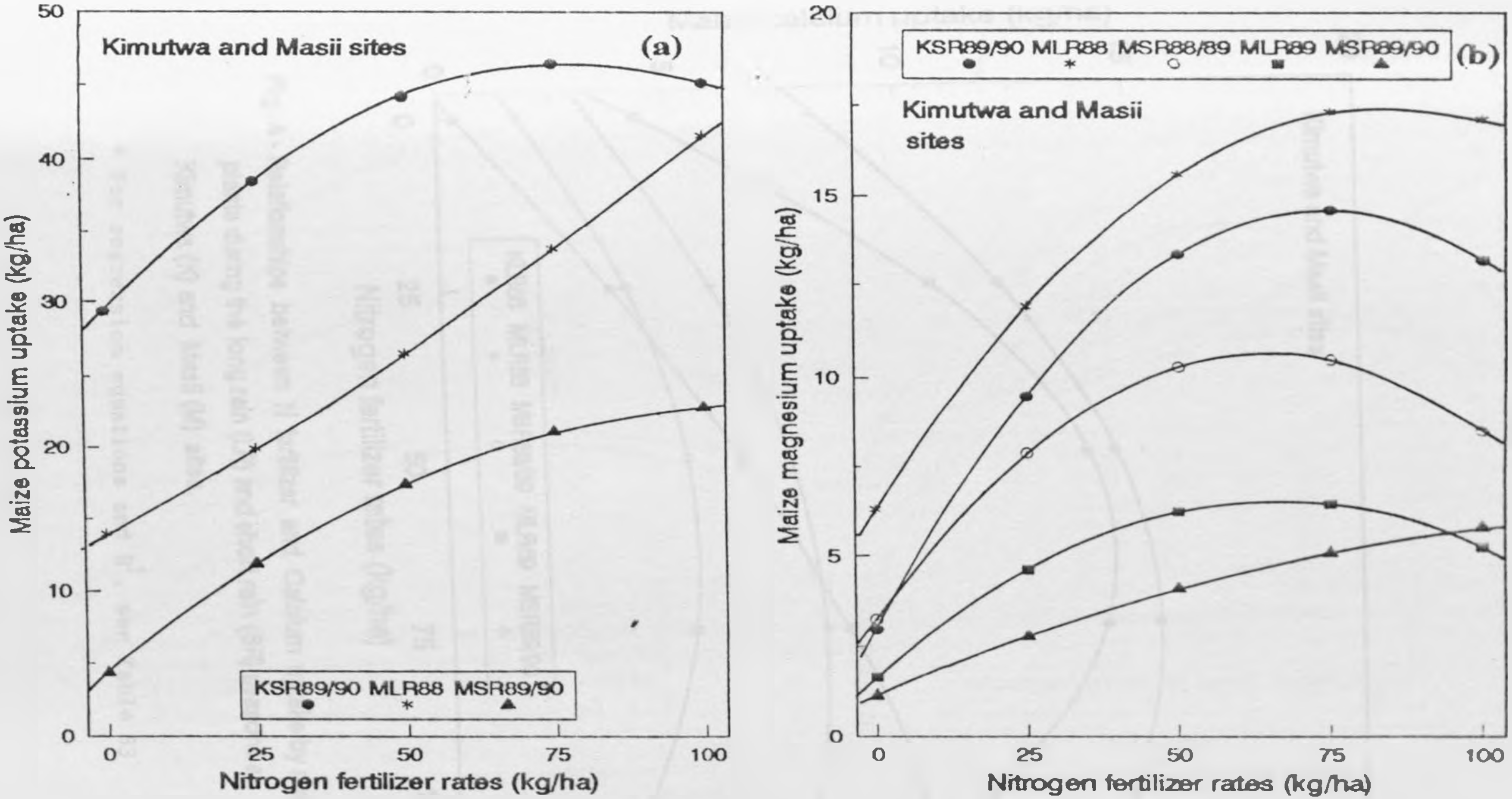

Fig. 3 - Relationships between N fertilizer rates and (a) Potassium and (b) Magnesium uptake by maize plants during the long rain (LR) and short rain (SR) seasons at Kimutwa (K) and Masii (M) sites.

* For regression equations and R^2, see Table 33

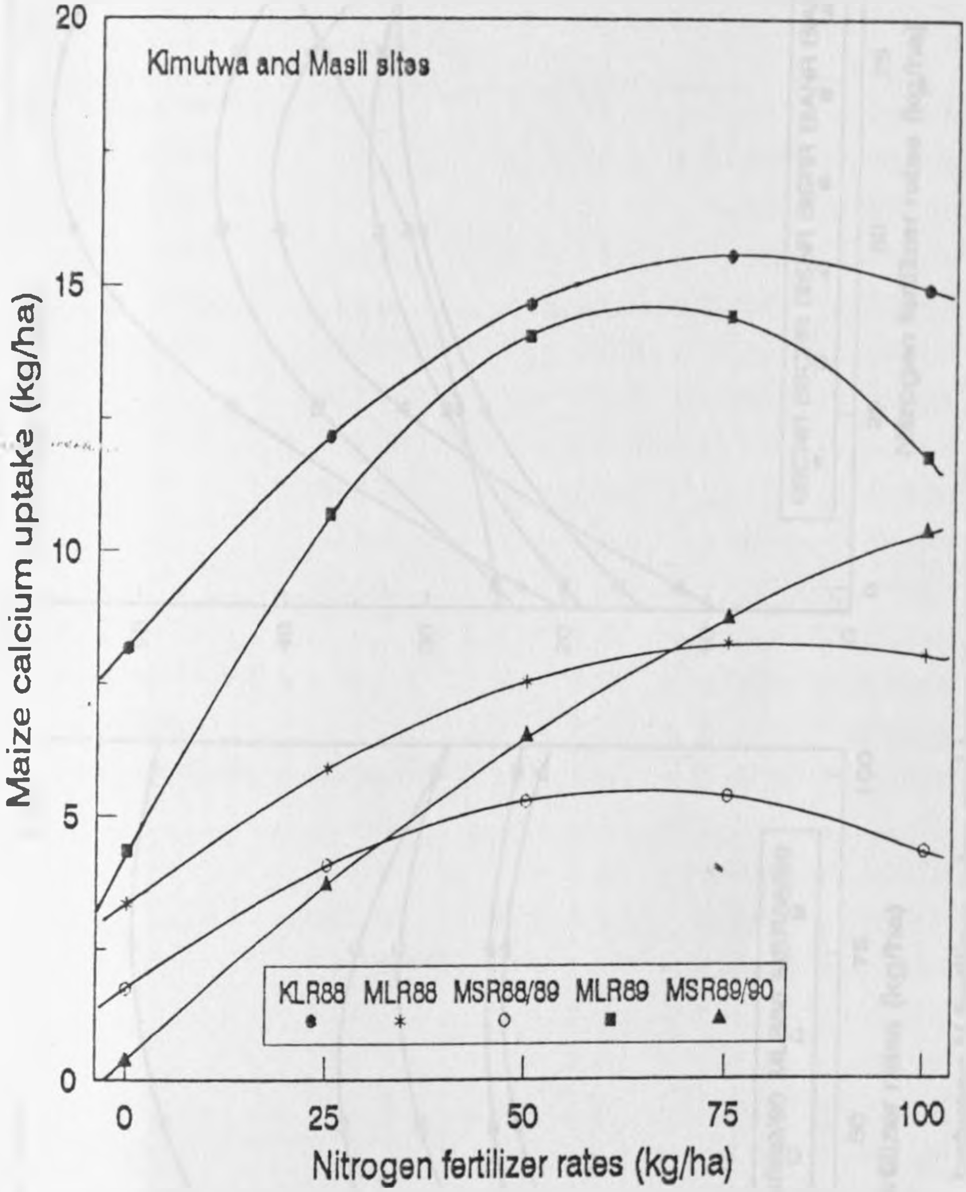

Fig. 4 - Relationships between N fertilizer and Calcium uptake by maize plants during the long rain (LR) and short rain (SR) seasons at Kimutwa (K) and Masii (M) sites.

* For regression equations and R^2, see Table 33

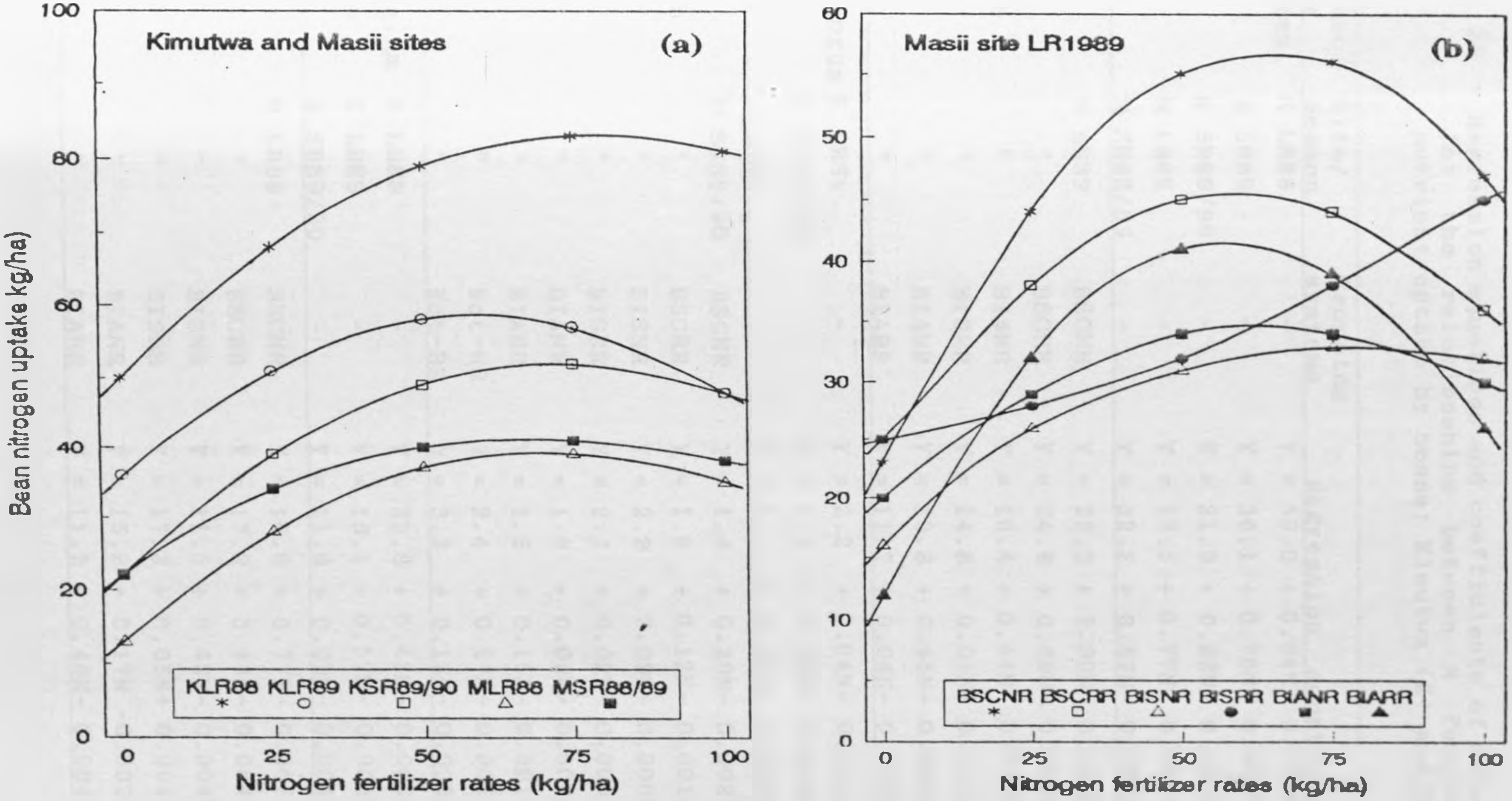

Fig. 5 - Relationships between N fertilizer rates and bean N uptake during the long rain(LR) and short rain (SR) seasons at Kimutwa (K) and Masii (M) sites.

* For regression equations and R^2, see Table 34

Table 34 - Regression equations and coefficients of determination for the relationships between N fertilizer and nutrient uptake by beans; Kimutwa (K) and Masii (M).

Nutrient/ Figure	Site/ Season	Cropping systems	Regression equations	R^2
Nitrogen	K LR88	-	$Y = 50.0 + 0.84N - 0.0050N^2$	0.998
	K LR89	-	$Y = 36.1 + 0.76N - 0.0060N^2$	0.926
5a	K SR89/90	-	$Y = 21.9 + 0.82N - 0.0060N^2$	1.000
	M LR88	-	$Y = 12.5 + 0.77N - 0.0050N^2$	0.973
	M SR88/89	-	$Y = 22.2 + 0.57N - 0.0040N^2$	0.999
	M LR89	BSCNR	$Y = 23.3 + 1.00N - 0.0080N^2$	0.900
	"	BSCRR	$Y = 24.8 + 0.69N - 0.0060N^2$	0.935
5b	"	BISNR	$Y = 16.4 + 0.44N - 0.0030N^2$	0.970
	"	BISRR	$Y = 24.8 + 0.01N + 0.0100N^2$	0.638
	"	BIANR	$Y = 19.8 + 0.45N - 0.0040N^2$	0.975
	"	BIARR	$Y = 11.7 + 0.04N - 0.0090N^2$	0.964
Phosphorus	K LR89	-	$Y = 2.2 + 0.04N - 0.0003N^2$	0.989
6a	K SR89/90	-	$Y = 1.7 + 0.05N - 0.0004N^2$	0.972
	M LR88	-	$Y = 1.1 + 0.04N - 0.0003N^2$	0.964
	M SR89/90	BSCNR	$Y = 1.4 + 0.20N - 0.0020N^2$	0.782
6b	"	BSCRR	$Y = 1.6 + 0.12N - 0.0010N^2$	0.603
	"	BISNR	$Y = 2.2 + 0.09N - 0.0007N^2$	0.682
	"	BISRR	$Y = 2.4 + 0.02N - 0.0001N^2$	1.000
	"	BIANR	$Y = 1.8 + 0.03N - 0.0002N^2$	0.725
	"	BIARR	$Y = 1.5 + 0.15N - 0.0010N^2$	0.962
	"	Rot-NR	$Y = 2.4 + 0.27N - 0.0020N^2$	0.791
	"	Rot-RR	$Y = 3.3 + 0.18N - 0.0020N^2$	1.000
Potassium	K LR88	-	$Y = 32.8 + 0.42N - 0.0030N^2$	0.927
7a	K LR89	-	$Y = 19.1 + 0.57N - 0.0050N^2$	0.952
	K SR89/90	-	$Y = 11.9 + 0.09N - 0.0040N^2$	0.983
7b	M LR89	BSCNR	$Y = 16.8 + 0.77N - 0.0070N^2$	0.914
	"	BSCRR	$Y = 17.2 + 0.43N - 0.0040N^2$	0.912
	"	BISNR	$Y = 11.5 + 0.48N - 0.0040N^2$	0.998
	"	BISRR	$Y = 17.3 + 0.05N + 0.0040N^2$	0.618
	"	BIANR	$Y = 15.2 + 0.17N - 0.0020N^2$	0.576
	"	BIARR	$Y = 11.2 + 0.46N - 0.0040N^2$	0.805

Table 34 - continued

Nutrient/ Figure	Site/ Season	Cropping systems	Regression equations	R^2
Magnesium	K LR89	BSCNR	$Y = 5.0 + 0.17N - 0.0020N^2$	0.905
	"	BSCRR	$Y = 3.9 + 0.18N - 0.0020N^2$	0.980
	"	BISNR	$Y = 3.3 + 0.11N - 0.0009N^2$	0.936
8a	"	BISRR	$Y = 4.0 + 0.05N - 0.0004N^2$	0.651
	"	BIANR	$Y = 2.4 + 0.09N - 0.0008N^2$	0.957
	"	BIARR	$Y = 3.2 + 0.02N - 0.0020N^2$	0.120
	"	Rot-NR	$Y = 8.6 + 0.12N - 0.0010N^2$	0.385
	"	Rot-RR	$Y = 7.2 + 0.13N - 0.0009N^2$	0.943
8b	M LR89	BSCNR	$Y = 3.0 + 0.110N - 0.0010N^2$	0.869
	"	BSCRR	$Y = 2.8 + 0.070N - 0.0006N^2$	0.952
	"	BISNR	$Y = 1.8 + 0.100N - 0.0008N^2$	0.996
	"	BISRR	$Y = 2.9 + 0.003N + 0.0002N^2$	0.894
	"	BIANR	$Y = 2.8 + 0.012N - 0.0005N^2$	0.308
	"	BIARR	$Y = 2.1 + 0.050N - 0.0004N^2$	0.801
	K SR89/90	-	$Y = 3.0 + 0.100N - 0.0006N^2$	0.999
	M SR88/89	-	$Y = 8.8 + 0.260N - 0.0020N^2$	0.983
Calcium	K LR88	BSCNR	$Y = 8.5 + 0.020N + 0.0001N^2$	0.210
	"	BSCRR	$Y = 9.2 + 0.210N - 0.0020N^2$	0.684
	"	BISNR	$Y = 7.2 + 0.070N - 0.0007N^2$	0.938
9a	"	BISRR	$Y = 6.5 + 0.110N - 0.0009N^2$	0.974
	"	BIANR	$Y = 5.3 + 0.120N - 0.0010N^2$	0.469
	"	BIARR	$Y = 5.3 + 0.030N - 0.0007N^2$	0.803
	"	Rot-NR	$Y = 11.6 + 0.12N - 0.0009N^2$	0.910
	"	Rot-RR	$Y = 10.8 + 0.14N - 0.0010N^2$	0.371
9b	M LR89	BSCNR	$Y = 7.0 + 0.34N - 0.0030N^2$	0.932
	"	BSCRR	$Y = 6.1 + 0.16N - 0.0020N^2$	0.985
	"	BISNR	$Y = 4.6 + 0.26N - 0.0020N^2$	0.999
	"	BISRR	$Y = 7.2 + 0.01N + 0.0003N^2$	0.743
	"	BIANR	$Y = 7.2 + 0.02N - 0.0002N^2$	0.240
	"	BIARR	$Y = 5.8 + 0.12N - 0.0010N^2$	0.948
	K LR89	-	$Y = 12.9 + 0.24N - 0.002N^2$	0.959
	M SR88/89	-	$Y = 4.9 + 0.01N - 0.0007N^2$	0.961
	K SR89/90	-	$Y = 3.3 + 0.14N - 0.0010N^2$	0.989

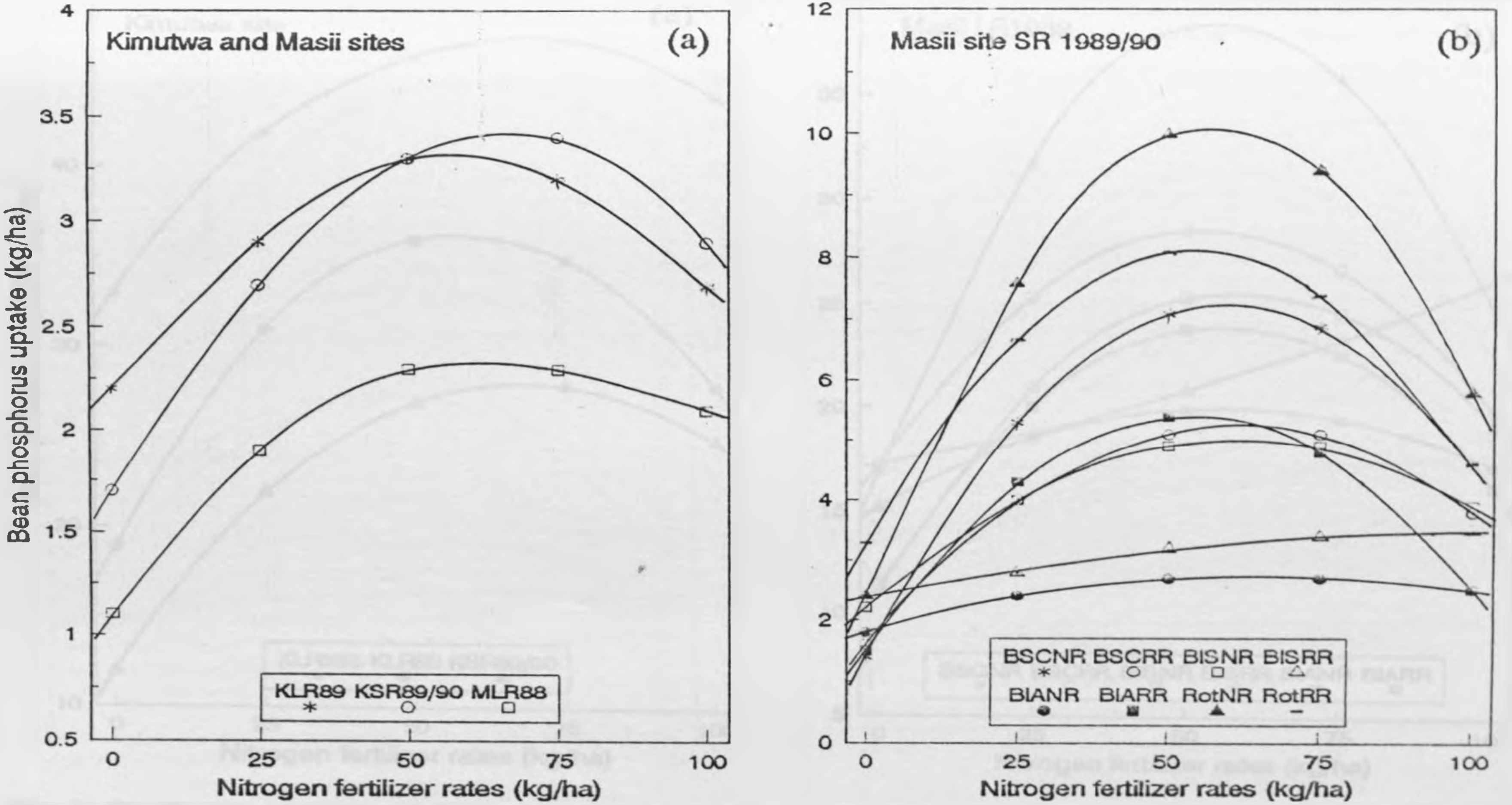

Fig. 6 - Relationships between N fertilizer rates and bean phosphorus uptake during the long rain (LR) and short rain (SR) seasons at Kimutwa (K) and Masii (M) sites. * For regression equations and R^2, see Table 34

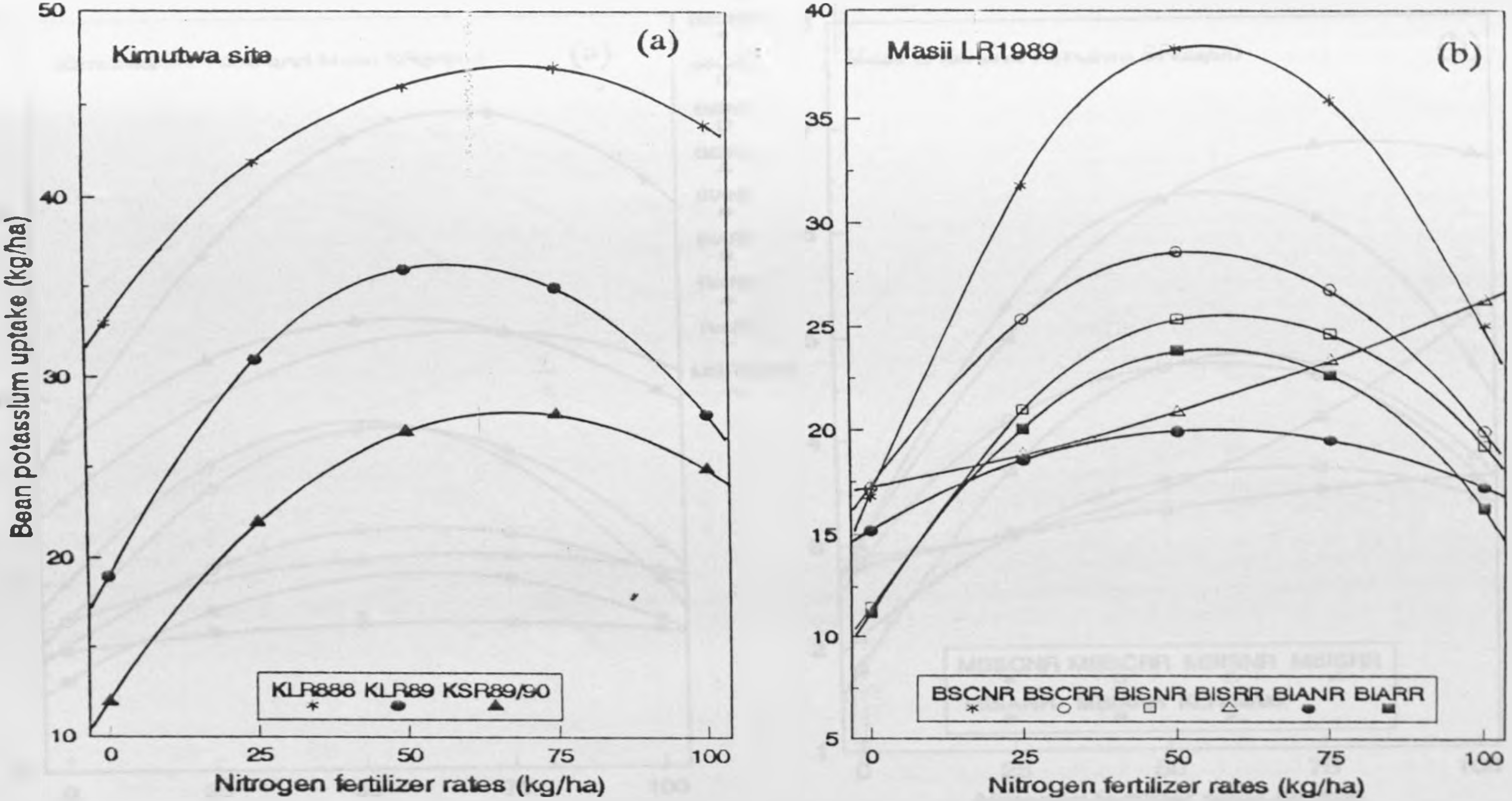

Fig. 7 - Relationships between N fertilizer rates and bean potassium uptake during the long rain (LR) and short rain (SR) seasons at Kimutwa(K) and Masii(M) sites.

* For regression equations and R^2, see Table 34

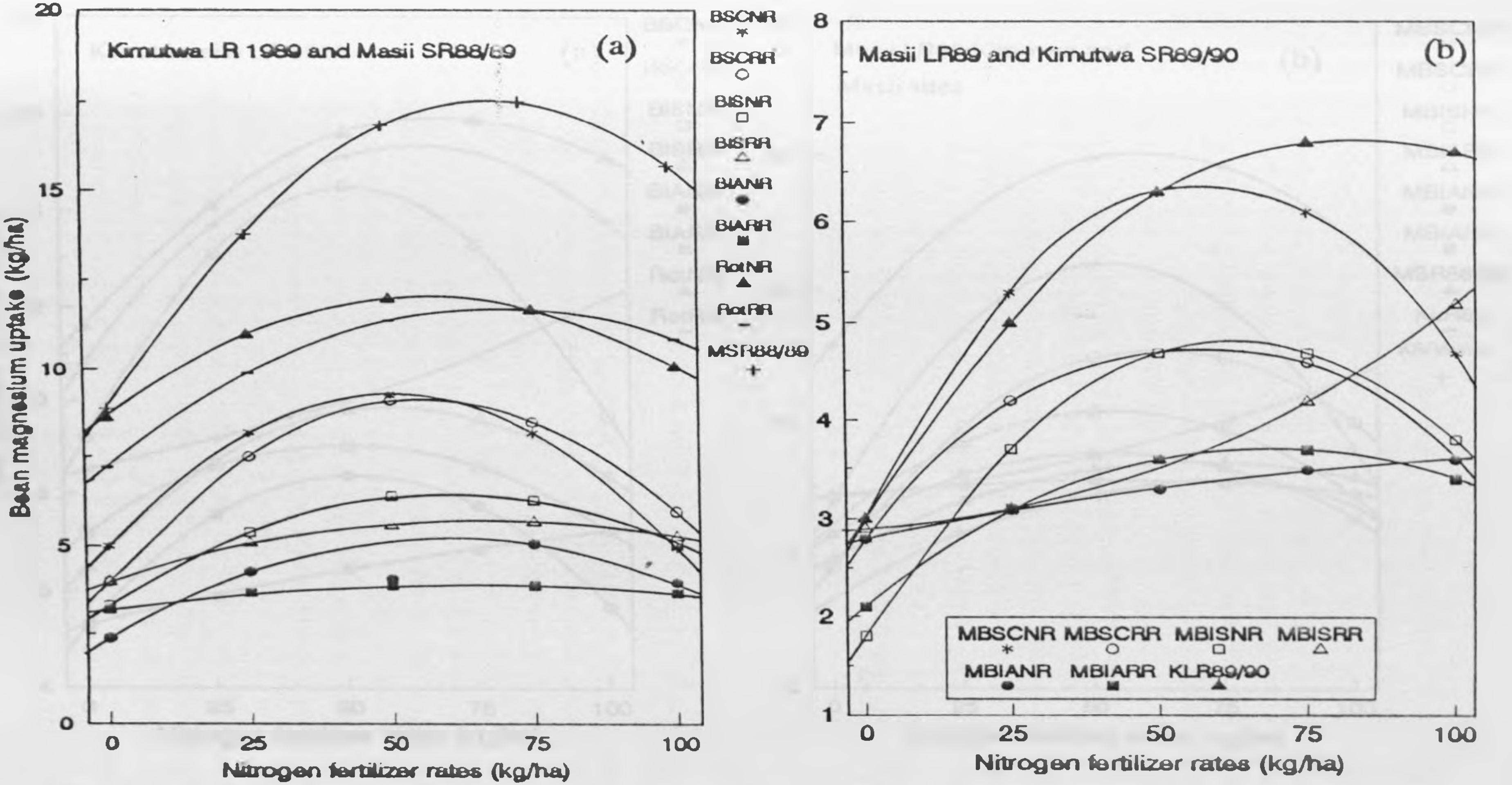

Fig. 8 - Relationships between N fertilizer and bean magnesium uptake during the long rain (LR) and short rain (SR) seasons at Kimutwa (K) and Masii (M) sites. * For regression equations and R^2, see Table 34

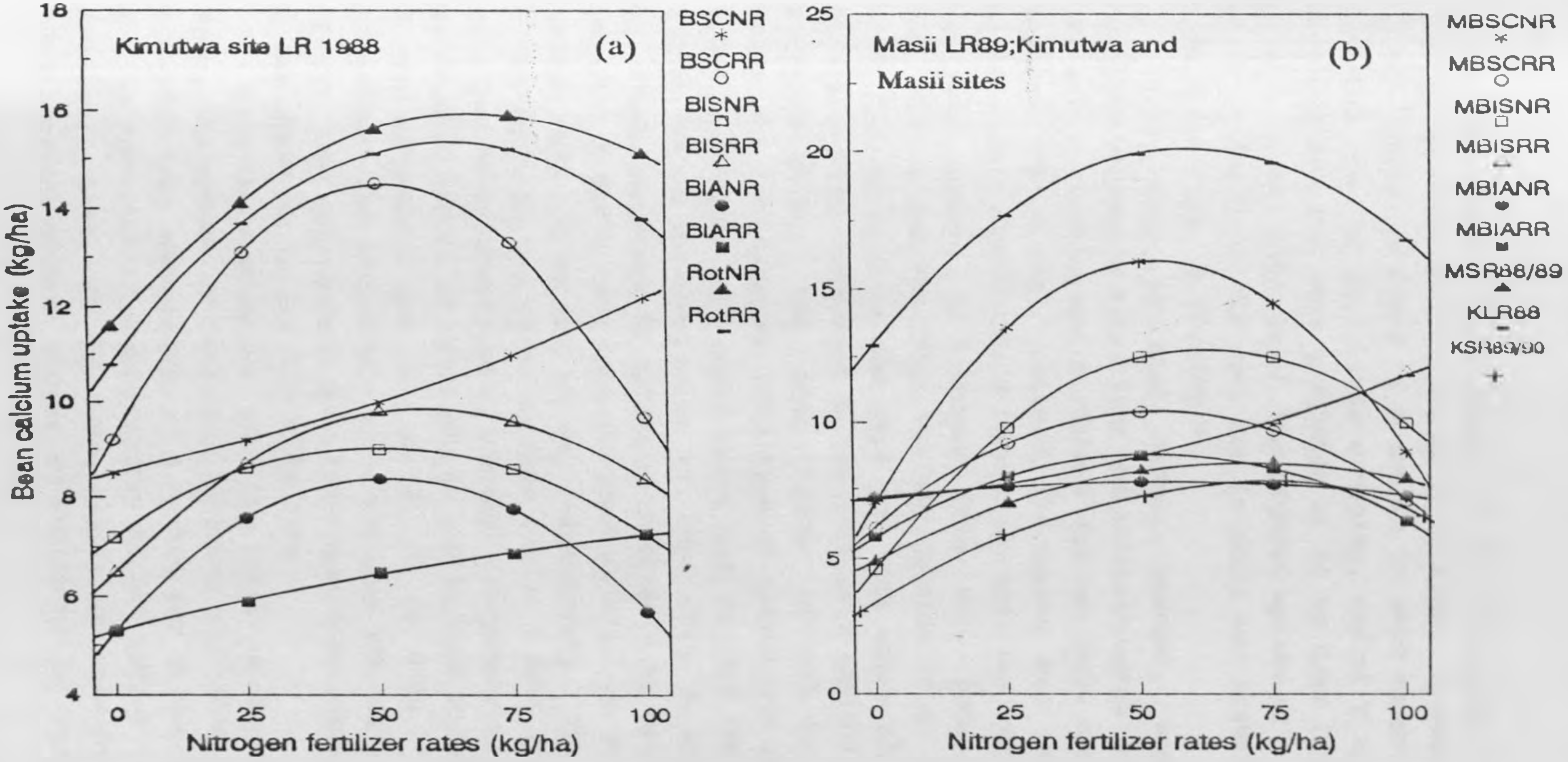

Fig. 9 - Relationships between N fertilizer rates and bean calcium uptake in different cropping systems and seasons (long rain - LR and short rain - SR) at Kimutwa (K) and Masii (M) sites.

* For regression equations and R^2, see Table 34

of the same nutrients by beans in the alternate row and rotation were found to occur at 75 kg N/ha. In Masii, the highest uptake by beans of N and Ca in sole cropping and alternate row, of Mg in sole cropping, and of P and K in the alternate row were predicted at 50 kg N/ha (Figs. 5 and 9). On the other hand, the highest uptake of N, K, Mg and Ca by beans in the same row in Masii was predicted at 75 kg N/ha (Figs. 5 through 9).

There were isolated cases, however, where the relations between N fertilizer and nutrient uptake by beans were not quadratic and therefore did not have optimum N response (Table 34). Instead, the uptake was found to increase more rapidly as N fertilizer rate was increased. Thus, the uptake of nitrogen (Fig. 5b), potassium (Fig. 7b), magnesium (Fig. 8b) and calcium (Fig. 9b) by beans intercropped in the same row with maize plus bean residue (BISRR) increased as the rate of N fertilizer was increased during the long rains of 1989 in Masii (Table 34). In Kimutwa, this type of uptake was observed in the continuous sole beans minus bean residue (BSCNR) on calcium during the long rains of 1988 (Fig. 9a and Table 34). This increase in uptake of nutrients by beans with increase in the N rate occurred when rainfall at Masii and Kimutwa were 355 mm and 362 mm, respectively. The uptake of nutrients by the total systems (maize + bean combined) indicated that intercrops in the same row generally took up the highest amount of nutrients at 100 Kg N/ha while those in the alternate row did so at 50 kg N/ha. Hence, intercrops sown intimately as in the same row were able to exploit the environment more than when they were planted in far apart as in the alternate rows.

With two exceptions, that is, uptake of Mg and Ca by beans, the uptake of nutrients by beans and total systems indicated that application of N fertilizer at the rate 25 kg N/ha resulted in significantly higher uptake than the control. Also, 50 kg N/ha fertilizer resulted in significantly higher uptake of nutrients by beans and total systems than 25 kg N/ha while the uptake due to N rates of 50 and 100 kg N/ha did not differ significantly. Hence, among the three levels of N fertilizer used (25, 50 and 100 kg N/ha), 50 kg N/ha could be regarded as more economical level to use in maize and bean production as far as nutrient uptake by the two crops is concerned. The effect of N fertilizer on the uptake of P, K, Mg and Ca by maize and beans in different cropping systems corresponded well with the findings of Krantz and Chandler (1951) and Viets et al. (1954) who reported that the uptake of such nutrients was influenced by the N fertilizer. In this study, the increase in the uptake of phosphorus by cops as a result of N fertilizer might have been due to enhanced root growth thus increasing the foraging capacity for P (Grunes et al., 1958; Cole et al., 1963). Second, the decline in soil pH by between 0.94 and 1.47 units due to N fertilizer (Tables 50 and 51) might have resulted in more P entering the solution (Rennie and Mitchell, 1954; Miller et al., 1970) thus increasing the accessibility by crops.

The uptake of nutrients by maize, beans and total systems was significantly affected by cropping systems in all seasons except the uptake of Mg and Ca in maize whereby the effect of cropping systems was significant in only one out of four seasons (Tables 15 through 32).

Intercropping reduced the uptake of nutrients in both maize and beans (Tables 14 through 24). The significant reduction by intercropping of nutrient uptake by maize was seasonal. Only the uptake by maize of Mg at both sites and Ca at Masii were not significantly reduced in all seasons. However, the nutrient uptake by intercropped beans was significantly reduced in all seasons at both sites except one season in kimutwa (SR 1989/90) and Masii (SR 1988/89). The percentage reduction by intercropping of nutrient uptake was greater in beans than in maize thus indicating that maize was more competitive than beans. The reduction of P uptake by beans in the intercropping systems was the highest relative to other nutrients and was 59 and 72% of the sole crop in Kimutwa and Masii, respectively. This implies that in a maize-bean intercropping system, phosphorus should be carefully managed in order to supply adequate amount to the beans. The lower seed yields of intercropped maize and beans compared with their sole crops might be due to the reductions in the uptake of nutrients by the intercrops since the relationships between seed yields and uptake of nutrients by either crop were positive and significantly correlated (Tables 38 and 42). Maize in the same row took up more nutrients than that in alternate row in Kimutwa. On the contrary, maize in the alternate rows in Masii was found to take up more nutrients than those in the same row. However, beans intercropped in the same row with maize consistently took up higher nutrients than those in the alternate rows at both sites. The reasons were not clear as to why maize did not respond uniformly to bean competition at the two sites and also why maize in Kimutwa and beans at both sites took up more nutrients when planted at closer proximity where both aerial and edaphic interactions were expected to be higher than where crops were intercropped farther apart (alternate row). However, in the case of maize intercropped in the same row, the higher nutrient uptake than that in alternate rows could be attributed to the fixed N by beans. This is because, beans intercropped in the same row were found to accumulate higher dry matter (Tables 2 through 7) than those in alternate rows and vegetative vigour has been reported to be related to nitrogen contribution by the legumes (Francis, 1976). In the case of beans, although shading of beans by maize reduced the uptake of nutrients, it is clear from our results that in the semi-arid region, a little more shading than the one obtained in the alternate row but found in the same row could be beneficial probably through the reduced evapotranspiration (Allen et al., 1976) or better energy conversion (Midmore et al., 1988).

Nutrient uptake by the total systems on per season or per year basis were significantly affected by cropping systems (Tables 28 through 34). The uptake of nutrients by intercrops combined significantly exceeded that of continuous sole crop maize or beans in all seasons. The difference in the uptake of nutrients between the combined intercrops and the continuous sole crop maize or beans was greater in Masii than in Kimutwa for maize and in Kimutwa than in Masii for beans.

When nutrient uptake by each cropping system in a year was considered (Tables 31 and 32) the combined intercrops once again manifested superiority at the two sites. Continuous sole maize consistently took up more nutrients than beans in Kimutwa in two successive years. However, in Masii the uptake of nutrients by maize and beans in sole cropping systems varied and generally, maize took up more nutrients than beans during the first year (1988-1988/89) while the reverse was true for beans in the second year (1989-1989/90).

Spatial arrangement of crops influenced the uptake of nutrients per year in total systems. The uptake of nutrients by intercrops combined planted in the same row was more than that of intercrops sown in the alternate rows (Tables 31 and 32). The greater uptake of nutrients by both intercrops combined than the continuous sole crop maize or beans seemed to indicate that the higher population of the component crops that was used in the intercropping system was better than that of either sole crop which was assumed optimal for resource use and presumably in the formation of economic yield. Trenbath (1976) reported that intercrops have a better use of resources or "space" and therefore show greater potential to outyield the component sole crops.

The results of nutrient uptake by each cropping system seemed to imply that in soils where soil fertilization is not practised, the intercropping of maize and beans would deplete soil nutrients faster than sole cropping of the component crops. Also, continuous sole maize would in a similar circumstance deplete nutrients more than continuous sole beans. The soil chemical analysis done at the end of seasons indicated such a trend (Tables 51 and 52). The results of soil chemical analysis showed a generally lower level of mineral N, extractable P (AL-solution) and exchangeable K, Mg, and Ca in plots previously occupied by continuous sole maize than plots previously sown to continuous sole beans. Also, lower levels of mineral N in Kimutwa and extractable P at both sites were obtained in soils from plots previously occupied by intercrops than those previously sown to sole crops.

Crop rotation was found to improve nutrient uptake by the crops (Tables 31 and 32). The magnitude of increase in nutrient uptake varied with seasons and sites. Comparison of nutrient uptake by continuous sole maize and that in rotation revealed that maize in the latter system took up more nutrients than the former at both sites. The improved performance of maize grown in rotation with a legume is often attributed to the increased availability of mineral N (Jones, 1974; Gakale and Clegg, 1987). In this study, however, probably factors other than N supply by the soil may have contributed to the benefits obtained by maize in rotation because soil chemical analysis did not reveal increased mineral N due to the previous bean crop (Tables 51 and 52). Instead, the soil from plots previously under bean crop in rotation gave higher extractable P, exchangeable K at both sites, exchangeable Mg and Ca in Masii relative to soils from plots under continuous sole maize. Probably, the higher level of these nutrients could partly have contributed to the beneficial effects of rotation on maize. The uptake of N, P, K, Mg and Ca by beans in rotation, that is, beans planted after maize, was significantly increased relative to the continuous sole beans (Tables 18 through 25). The percent increase in nutrient uptake by beans in rotation was greater in Kimutwa than in Masii and ranged from 18 to 53% for N, 21 to 50 for P, 26 to 69% for K, 31 to 52% for Mg, and 28 to 70% for Ca (Table 26). The uptake by intercrops combined was significantly more than that of individual maize or bean crop in rotation per given season. Also, when the combined nutrient uptake of maize and beans in a complete rotation cycle was compared with that of intercrops in a year, the uptake by the latter system remained superior to the former cropping system. However, the total uptake by maize and beans in a complete rotation cycle was significantly more than that of either maize or beans in a continuous sole cropping system.

Bean residue was returned to both rotation and intercropping system plots during the long rains of 1988 and 1989 and short rains of 1988/89 and it ranged from 497 to 918 kg/ha. The residue returned to plots under continuous sole beans ranged from 426 to 1029 kg/ha. Higher bean residue was obtained in Kimutwa than in Masii in all cropping systems. Bean residue returned to plots was found to influence the uptake of nutrients by maize and beans in different cropping systems. Regardless of the cropping systems, the effect of bean residue returned on individual nutrient uptake by maize was inconsistent and could either increase or reduce the uptake depending on the season (Tables 14 through 19). However, bean response to bean residue returned was consistent regardless of the cropping system. The residue returned was found to result in the reduction of nutrient uptake by beans at both sites (Tables 18 through 22). The increase in N uptake by maize in some of the seasons as a result of returned bean residue could be attributed to N from the mineralized bean residue since some of the plant residue (haulms) had N concentration of up to 1.83% (Appendix Table 12) which was within the critical value of between 1.2 and 2.26% N at which net mineralization could occur (Harmsen and Schreven, 1955) if environmental conditions were favourable (Peevy and Norman, 1948; Iritani and Arnold, 1960; Weber and Gainey, 1962; Millbank, 1959; Robinson, 1957; Semb and

Robinson, 1969; Tyler, et al 1959).

The reduction of nutrient uptake by beans due to bean residue returned might reflect the existence of allelopathic (toxic) substances from decomposing bean residues in the soil which were relatively inhibitory to nutrient uptake by beans. Allelopathic effects of maize residues on maize itself has been reported and growth of roots was found to be more strongly inhibited than growth of the shoot (Yakle and Cruse, 1983). The causal effect of the reduction of nutrient uptake by beans due to returned bean residue was not identified and needs further investigation.

4.6 Effects of N, bean residue and cropping systems on the seed yields of maize and beans

4.6.1 Maize seed yield: Maize seed yield potential was higher in Kimutwa (3488 Kg/ha) than in Masii (1659 kg/ha) (Tables 35 and 36). The soil types and their inherent fertility (Table 1) in these two sites seemed to be related to this big yield difference of 1829 kg/ha. Infact, where N fertilizer was not applied there was maize leaf yellowing which occurred in Masii but not in Kimutwa, thus reflecting a difference in the soil between the two sites.

Seed yields varied with seasons and ranged from 1668 to 5333 kg/ha in Kimutwa and from 687 to 2793 kg/ha in Masii. The short rainy seasons gave higher yields than long rainy seasons by 89% (2153 kg/ha) in Kimutwa and 174% (1542 kg/ha) in Masii. Hence, rainfall and its distribution (Appendix Table 1) during the crop growing period were found to be some of the major factors which influenced the seed yield at the two sites. Generally, theshort rains had more and better rainfall distribution than the long rains.

Seed yields were significantly increased by N fertilizer during the long rains of 1988 and short rains of 1989/90 in Kimutwa and during the long rains of 1989 and

Table 35 – Effect of N rates and cropping systems on seed yield (kg/ha) of maize at Kimutwa.

	Long rain 1988								Short rain 1988/89							
Cropping systems	N fertilizer kg/ha								N fertilizer kg/ha							
	N0	N25	N50	N100	Mean	F test	CV (%)	LSD 0.05	N0	N25	N50	N100	Mean	F test	CV (%)	LSD 0.05
MSC	2710	3464	3778	4109	3515				3782	5088	6068	6124	5266			
MISNR	2081	3027	3104	3692	2976				3507	4310	5758	5270	4703			
MISRR	2702	2953	3648	3929	3324				3838	5154	4936	5925	4963			
MIANR	2332	3040	3566	2911	2911	*	16	422	3289	5722	5418	5040	4867	***	15	645
MIARR	2885	2580	3319	3052	3052				3668	5201	5429	5770	5017			
Rot–NR	–	–	–	–	–				6351	6700	5767	7015	6458			
Rot–RR	–	–	–	–	–				5159	5726	6427	6905	6055			
Mean	2502	3012	3496	3612	3156				4228	5415	5686	6002	5333			
F test			**								ns					
CV (%)			12								33					
LSD 0.05			544								–					
	Long rain 1989								Short rain 1989/90							
MSC	1709	2232	1783	2511	2059				2219	3272	4328	4241	3515			
MISNR	1426	1534	1328	1380	1417				2483	3315	4193	4702	3673			
MISRR	1296	1556	1461	1747	1515				2234	4144	4563	5058	4000			
MIANR	1652	1691	1643	1633	1655	***	20	269	2835	4307	4769	3085	3749	ns	18	–
MIARR	1937	1332	2139	1362	1692				2705	3358	4676	2861	3400			
Rot–NR	–	–	–	–	–				2906	4550	4424	4267	4037			
Rot–RR	–	–	–	–	–				2785	4568	4735	4685	4193			
Mean	1604	1669	1671	1727	1668				2595	3931	4527	4129	3796			
F test			ns								**					
CV (%)			13								11					
LSD 0.05			–								849					

*, **, *** = Differences of treatment means are significant at P = 0.05, 0.01, 0.001 level, respectively.
ns = Differences of treatment means are not significant at P = 0.05 level.

Table 36 – Effect of nitrogen fertilizer rates and cropping systems on maize seed yield (kg/ha) at Masii.

Cropping systems	Long		rain			1988			Short		rain			1988/89		
	N fertilizer		kg/ha						N fertilizer		kg/ha					
	N0	N25	N50	N100	Mean	F test	CV %	LSD 0.05	N0	N25	N50	N100	Mean	F test	CV %	LSD 0.05
MSC	76	745	883	1188	723				1085	3344	6275	3747	3613			
MISNR	297	292	549	881	505				711	969	4442	3608	1932			
MISRR	202	453	342	913	478				1162	1622	2821	5323	2732			
MIANR	245	509	797	531	521	**	51	210	1720	2014	3835	3445	2754	*	45	1043
MIARR	192	860	501	631	604				607	2023	5031	4070	3933			
Rot–NR	318	408	1365	1396	871				–	–	–	–	–			
Rot–RR	320	804	1188	1404	1104				–	–	–	–	–			
Mean	236	582	904	1025	687				1057	1994	4081	4039	2793			
F test			ns								*					
CV %			42								67					
LSD 0.05			–								1944					
	Long		rain			1989			Short		rain			1989/90		
MSC	129	1536	1890	1845	1350				156	2339	3587	4411	2623			
MISNR	192	759	1269	1405	906				126	978	2393	4909	2075			
MISRR	266	720	1122	972	770				374	1089	1933	4284	1920	ns	71	–
MIANR	334	1019	1363	782	875	**	45	305	267	580	2431	3739	1764			
MIARR	123	1389	1245	985	935				52	2035	2869	2895	1963			
Rot–NR	534	1366	1932	1956	1447				–	–	–	–	–			
Rot–RR	175	1411	1773	1969	1332				–	–	–	–	–			
Mean	250	1171	1531	1416	1088				195	1404	2643	4048	2067			
F test			*								**					
CV %			34								37					
LSD 0.05			740								1536					

*, **, *** = Differences of treatment means are significant at P = 0.05, 0.01, 0.001 level
ns = Differences of treatment means are not significant at P = 0.05 level.

short rains of 1988/89 and 1989/90 in Masii (Tables 35 and 36). The yields increase were between 876 and 1609 kg/ha (35 to 62%) in Kimutwa and between 1115 and 2499 kg/ha (219 to 1284%) in Masii. During these seasons, the seed yields obtained from the N50 and N100 fertilizer treatments were not significantly different. However, the seed yields from these two N rates were significantly more than that from N zero but occasionally so when compared with the N25 fertilizer rate. The fertilizer rate of 25 kg N/ha gave significantly higher seed yields (921 and 1336 kg/ha) than N zero in two seasons out of five but when the N effect was not significant during the other three seasons, the yields were substantially increased by N25 fertilizer and ranged from 510 to 1209 kg/ha at the two sites. These results implied that the soils in this semi-arid region contained low levels of mineral N to give any reasonable maize yield and that a substantial yield increase could be achieved from a small dose of only 25 kg N/ha.

Seed yield response to N fertilizer was influenced by rainfall and site. The yield increase due to N fertilizer was greater during the short rains (2407 kg/ha) than during the long rains (859 kg/ha) in Masii. Probably, this was as a result of the higher and better distribution of rainfall in Masii during the short rains than during the long rains (Appendix Table 1). On the contrary, the seed yield increase due to N fertilizer in Kimutwa was more during the long rains (1178 kg/ha) than during the short rains (847 kg/ha) even though the rainfall and its distribution were better during the latter seasons than the former.

The seed yield increase of 85 kg/ha due to N fertilizer during the short rains of 1988/89 in Kimutwa was quite intriguing since this season received the highest rainfall amongst the four seasons. Probably, this low response to N could have been as a result of the high rainfall which might have caused high leaching of soil mineral N to occur during the growing period. This assumption was ascertained by the chemical analysis of soil sampled at the end of short rains of 1988/89 which gave 19.4 ug N/g soil for N zero treatment and 20.7 ug N/g soil for N applied treatments, thus indicating no difference unlike the results of the end of the long rains of 1988, a season which had a lower and poor rainfall distribution, which were 27.6 ug N/g soil for N zero treatment and 39.5 ug N/g soil for N applied treatments. Hence,it can be concluded that although the short rain seasons have greater potential in maize seed yields increase due to N fertilizer addition, heavy rainfall especially in Kimutwa might be detrimental to this favourable N effect on maize yield.

Maize seed yield response to N fertilizer was influenced by cropping systems (Tables 35 and 36). In Kimutwa, the highest seed yield of maize in both continuous sole and same row systems occurred at 100 kg N/ha while that in the alternate row was achieved at 50 kg N/ha. In Masii, while the majority of maize in the same row and the alternate row continued to have their highest N response at 100 kg N/ha and 50 kg N/ha, respectively, the maize in the continuous sole system had its response influenced by the seasons and had the highest N response occurring at either 50 or 100 kg N/ha in half of the seasons. Maize in rotation had its highest response to N at 100 kg N/ha. However, interactions between N and cropping systems were not significant except in one season (LR 1989, $P < 0.05$) in Kimutwa which was observed to have low (191 mm) and poor distribution of rainfall.

Seed yield of intercrop maize was increased by N fertilizer (Tables 35 and 36). However, the response to N was lowered by intercropping compared to maize in the continuous sole cropping system. Averaged over the four seasons, the seed yield increase of the intercropped maize as a result of N application was by 32% (950 kg/ha) in Kimutwa and by 467% (1438 kg/ha) in Masii while that of continuous sole crop was increased by 49% (1312 kg/ha) and

1204% (2288 kg/ha), respectively, at the two sites. Maize intercropped in the same row showed a better response to N than that in the alternate row in Kimutwa but the reverse was true for intercropped maize in Masii. Thus, sites may change maize response to N fertilizer even though the crop is intercropped at similar spatial arrangements.

Maize following beans in rotation gave higher seed yield than that in the continuous sole cropping system (Table 37a). However, the response of maize in rotation to N application was lower than that in the continuous sole cropping. During the short rains of 1988/89 and 1989/90 in Kimutwa, the yield increase of maize in rotation as result of N application was 12% (668 kg/ha) and 59% (1692 kg/ha) compared to the yield of the continuous sole crop which was increased by 52% (1978 kg/ha) and 78% (1728 kg/ha), respectively. A similar trend in response to N was observed in Masii. During the long rains of 1988 and 1989, N fertilizer resulted in increasing seed yield of maize in rotation by 280% (775 kg/ha) and by 389% (1380 kg/ha) compared to that of the continuous sole crop which was increased by 1130% (863 kg/ha) and 1267% (1629 kg/ha), respectively. Probably, the residual effect of rotation which in this study was partly reflected by the presence of some available N may have resulted in lowering the maize response to N fertilizer compared to that in continuous sole cropping. Use of regression analysis and quadratic equations helped to estimate the amount of N needed to achieve certain levels of seed yields in rotation without added N (Appendix Table 21). In this study, the amount of N estimated to be available for maize following beans ranged from 16 to 56 kg N/ha where bean residue was removed and from 14 to 24 kg N/ha where bean residue was returned to plots in Kimutwa. In Masii, the estimated N was 3.2 kg N/ha and 8.6 kg N/ha where bean residue was removed and returned to plots, respectively. Bean residue returned did not perform uniformly across the sites. In Kimutwa, returned residue gave less estimated N than where it was

Table 37a – Maize seed yields at various rates of added N fertilizer when preceeding crop in rotaion was either maize or beans.

Fertilizer kg N/ha	Maize seed yield when following		Increase(+) or decrease (-) for following beans	
	Maize	Beans		
Kimutwa	----------kg/ha	----------	--kg/ha--	-- % ---
SR 1988/89				
0	3783	5756	+1973	+52.0
25	5089	6213	+1124	+22.0
50	6068	6097	+ 29	+ 0.5
100	6124	6960	+ 836	+14.0
Mean	5266	6257	+ 991	+18.8
Kimutwa				
SR 1989/90				
0	2219	2846	+ 627	+28.0
25	3273	4559	+1286	+39.0
50	4328	4580	+ 252	+ 5.8
100	4241	4476	+ 235	+ 5.5
Mean	76	4115	+ 600	+19.6
Masii				
LR 1988				
0	76	318	+ 242	+319.0
25	745	606	– 139	– 19.0
50	883	1627	+ 744	+ 84.0
100	1188	1400	+ 212	+ 18.0
Mean	723	988	+ 265	+ 36.7
Masii				
LR1989				
0	129	355	+226	+175.0
25	1536	1388	– 148	– 10.0
50	1890	1852	– 38	– 2.0
100	1845	1963	+ 118	+ 6.0
Mean	1350	1390	+ 40	+ 3.0

removed while the reverse was true in Masii.

In summary, the maize response to N was influenced by site and seasons and was found to vary with N rates and cropping systems (Tables 35 and 36). Out of the 48 highest maize response to added N cases, 26 occurred at 100 kg N/ha, 16 at 50 kg N/ha and 6 at 25 kg N/ha fertilizer, thus indicating that the 25 kg N/ha rate was the least effective in maize production in the semi-arid region where the study was carried out.

Irrespective of cropping systems, the relations between N fertilizer application and seed yield were found to be quadratic (Fig. 10 and Table 37b). Practically, since the seed yield obtained from N fertilizer rates of 50 and 100 kg N/ha were not significantly different, then 50 kg N/ha rate would be more economical to use in maize production by a small scale farmer in the region. However, where N x cropping system interactions were significant, maize in different cropping systems responded to N fertilizer differently and maximum seed yield were obtained at different N levels. According to regression analysis, the maximum seed yield of continuous sole crop occurred at 75 kg N/ha while that in both alternate row and rotation systems was at 50 kg N/ha. However, that in the same row with and without bean residue returned occurred at 75 and 100 kg N/ha fertilizer, respectively (Fig. 10 and Table 37b).

Cropping systems had significant effect on seed yields except one season (SR 1989/90) at both sites (Tables 35 and 36). Intercropping generally resulted in maize seed yield reductions. Orthogonal contrasts indicated that intercropping significantly ($P < 0.01$) reduced seed yield by 25.4% (450 kg/ha) and 30% (489 kg/ha) during the long rains of 1988 and 1989 in Kimutwa, respectively. In Masii, the reductions were significant at $P < 0.05$ and $P < 0.01$ during the short rains of 1988/89 and long rains of 1989 and they were by 22% (777 kg/ha) and 35.3% (478), respectively. Effect of spatial arrangements on seed yield

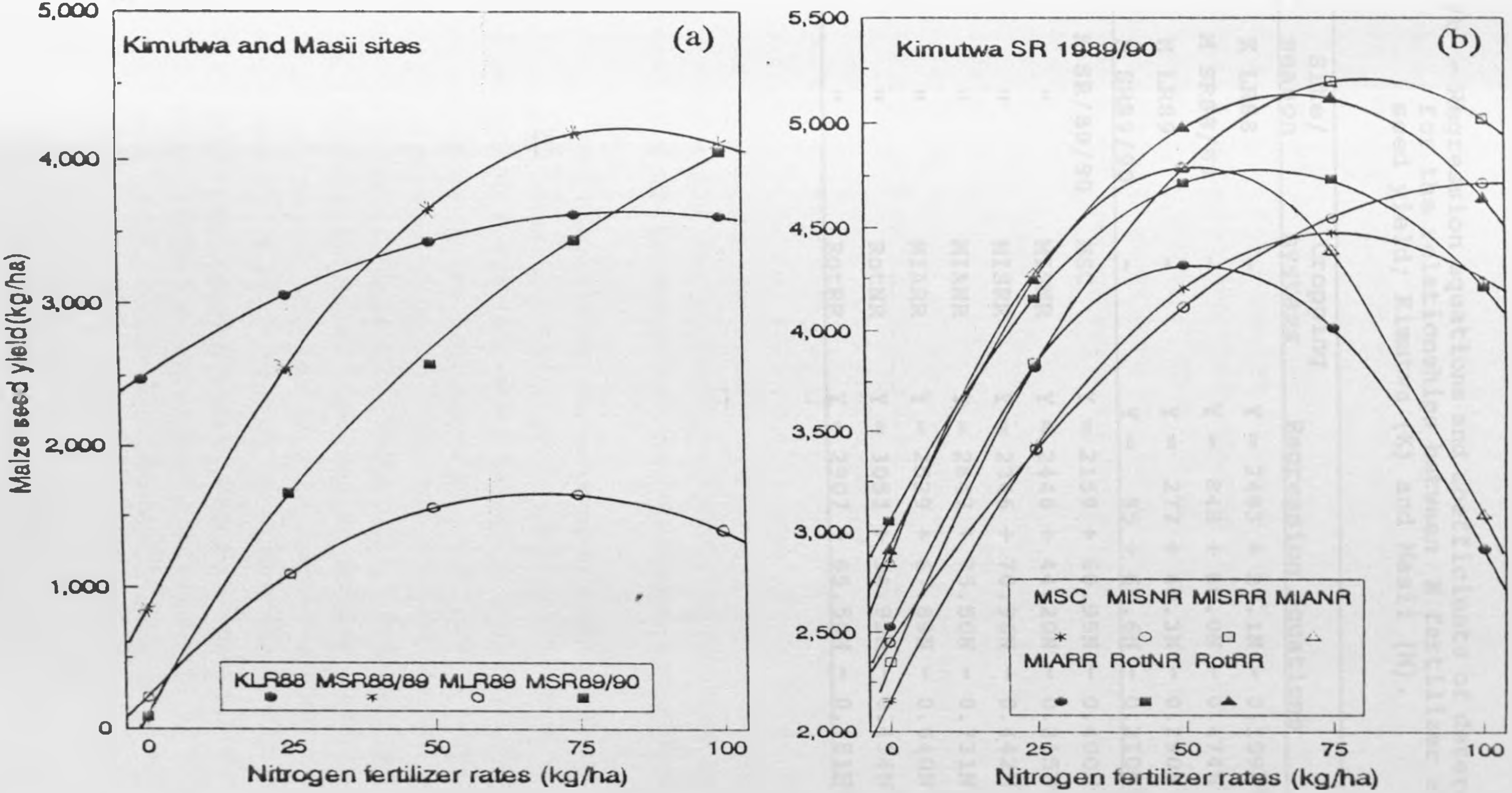

Fig. 10 - Relationships between N fertilizer rates and maize seed yield in different cropping systems and seasons (long rain - LR and short rain - SR) at Kimutwa (K) and Masii (M) sites.

* M in Fig.10a and Fig.10b stand for Masii site and maize crop respectively

*For regression equations and R^2, see Table 37b

Table 37b - Regression equations and coefficients of determination for the relationships between N fertilizer and maize seed yield; Kimutwa (K) and Masii (M).

Figure	Site/ season	Cropping systems	Regression equations	R^2
	K LR88	-	$Y = 2483 + 27.1N - 0.159N^2$	0.994
10a	M SR88/89	-	$Y = 848 + 80.0N - 0.474N^2$	0.922
	M LR89	-	$Y = 277 + 40.3N - 0.290N^2$	0.992
	M SR89/90	-	$Y = 85 + 60.6N - 0.210N^2$	0.998
10b	K SR/89/90	MSC	$Y = 2159 + 60.95N - 0.400N^2$	0.982
	"	MISNR	$Y = 2446 + 44.20N - 0.215N^2$	0.994
	"	MISRR	$Y = 2346 + 70.96N - 0.442N^2$	0.966
	"	MIANR	$Y = 2847 + 75.50N - 0.731N^2$	0.999
	"	MIARR	$Y = 2529 + 67.89N - 0.640N^2$	0.843
	"	RotNR	$Y = 3053 + 54.99N - 0.434N^2$	0.848
	"	RotRR	$Y = 2907 + 65.50N - 0.481N^2$	0.932

was influenced by seasons and sites. Higher seed yields of maize intercropped in the same row than that in alternate row occurred in two seasons (LR 1988 and SR 1989/90) in Kimutwa and in one season (SR 1989/90) in Masii. Also, the yield of maize intercropped in the alternate row was higher than that in the same row in two seasons (SR 1988/89 and LR 1989) in Kimutwa and three seasons (LR 1988, SR 1988/89 and LR 1989) in Masii. Thus indicating that intercropping maize in alternate rows was as good as in the same row in Kimutwa but was superior to intercropping in the same row in Masii.

The seed yield reduction of maize as a result of intercropping was found to correspond very well with the reductions of dry matter yields (DMY) at vegetative stage (40 DAE) and maturity (Tables 2 through 7). In fact, the relation between seed yield was positive and significantly correlated with DMY at 40 DAE and maturity growth stages (Table 9). Hence, DMY even at vegetative stage could be used to predict the seed yield of different intercropping systems since the competition that was observed at 40 DAE persisted up to maturity and was being reflected in the seed yield.

The competition for environmental resources between maize and beans was clear when seed yields were expressed on per plant basis (Appendix Tables 22 and 23). Seed yield per plant of maize in mixtures was lower than that of continuous sole crop by 6 to 29% in Kimutwa and by 18 to 39% in Masii (Appendix Table 22). However, one season (SR 1989/90) in Masii resulted in higher seed yield per plant of maize planted in the same row than continuous sole crop by 8.3%. Spatial arrangements influenced the interspecific competition. Maize intercropped in the same rows suffered more from beans than that in the alternate rows. Probably, beans in the same rows were more competitive than those in alternate rows as revealed by their higher DMY per plant at 40 DAE (Tables 2 through 7) and consequently higher seed yield per plant. The reduction of maize seed yield due to the presence of beans might be attributed to edaphic interactions since beans were shorter than maize and could not shade the taller maize plants. The edaphic interaction between the intercrops was evidenced partly by the reduction of uptake of N, P, K, Mg, and Ca by the intercropped maize (Tables 14 through 19). The relationship between seed yield of maize and uptake of these nutrients were positive and significantly correlated in all seasons at the two sites (Table 38). Thus implying that reduction of uptake of nutrients by maize would lead to lowering of the seed yield.

The presence of beans in intercropping, however, did not always lower the seed yield of intercropped maize. During the short rains of 1989/90 in Kimutwa, maize intercropped in the same and alternate rows gave more but non-significant seed yield than continuous sole crop by 9.2% and 1.7%, respectively. Thus, the presence of beans was not necessarily unfavourable but could under certain circumstances be beneficial to the cereal intercrop. The benefit of legumes to intercropped cereals has been observed elsewhere (Francis et al. 1976; Waghmare and Singh, 1984). This benefit is attributed to N that has probably been transferred from the mineralized sloughed-off and dead nodules and roots (Henzell and Vallis, 1977; Mallarino et al., 1990) or may be from the excretion of some of the legume fixed N (Agboola and Fayemi, 1972). The notion that legumes could excrete N during growth is not new (Wilson and Burton, 1938) and recently soil enrichment with fixed N_2 from beans was reported by Ruschel et al. (1979).

In this study, the possibility that maize planted in the same row with beans may have benefited from N is supported by the fact that during this season (SR 1989/90) in Kimutwa the maize in this spatial arrangement had taken up 11% more N than continuous sole maize (Table 15). Although it may be argued that competition from maize for

Table 38 – Correlation coefficients (r) between nutrient uptake and seed yield of maize during different seasons.

Site/	Long rain 1988					Short rain 1988/ 89					Long rain 1989					Short rain 1989/90				
Nutrient	P	K	Mg	Ca	MSYD	P	K	Mg	Ca	MSYD	P	K	Mg	Ca	MSYD	P	K	Mg	Ca	MSYD
Kimutwa																				
N	0.823**	0.692**	0.724**	0.719**	0.876**	0.511**	0.531**	0.595**	0.485**	0.827**	0.633**	0.734*	0.673**	0.643*	0.832**	0.729**	0.644**	0.551**	0.68**	0.802**
P		0.473**	0.721**	0.640**	0.840*		0.425**	0.455**	0.251*	0.606**		0.502**	0.399**	0.385**	0.760**		0.596**	0.632**	0.360**	0.831**
K			0.603**	0.573**	0.563**			0.798**	0.682**	0.421**			0.524**	0.649**	0.561**			0.817**	0.404**	0.692**
Mg				0.874**	0.550**				0.637**	0.280**				0.617**	0.409**				0.351**	0.655**
Ca					0.499**					0.505**					0.547**					0.355**
Masii																				
N	0.848**	0.77**	0.826**	0.764**	0.893**	0.864**	0.677**	0.741**	0.646**	0.896**	0.865**	0.807**	0.901**	0.787**	0.956**	0.959**	0.908**	0.882**	0.91**	0.987**
P		0.711**	0.674**	0.643**	0.889**		0.672**	0.738**	0.572**	0.966**		0.756**	0.841**	0.747**	0.904**		0.884**	0.838**	0.922**	0.962**
K			0.776**	0.648**	0.591**			0.868**	0.817**	0.632**			0.891**	0.899**	0.765**			0.904**	0.850**	0.894**
Mg				0.837**	0.650**				0.867**	0.515**				0.884**	0.843**				0.814**	0.933**
Ca					0.660**					0.694**					0.737**					0.879**

*, ** = Correlations are significant at P = 0.05 and 0.01 level, respectively.
MSYD = Maize seed yield in kg/ha; Nutrient uptake in kg/ha

light and nutrients could limit N fixation by beans, it has been found that the bean canopy light interception saturates at a relatively low intensity, and it is better suited than most to achieve N fixation under shaded conditions (Graham and Halliday, 1976).

The beneficial effects of beans to the associated maize in this study were obtained where maize and beans were intimately intercropped (same row). This implies that because of intensive overlap of maize and bean root systems due to increased intimacy in the same row, maize probably was able to take up N that was excreted by bean roots or from mineralized sloughed-off nodules more easily. Bean nodules have been found to degenerate by 93% in N added treatments and by an average of 67% in zero N treatments during the period between 50 and 80 days after planting (Chui, 1985). Within this period, maize in the study area was between silking and milk growth stages. During these two growth stages, maize has been shown to have a rapid uptake of N, and a high correlation of N with final grain and yield response to N application (Ritchie and Hanway, 1982). Hence, between 50 and 80 days after planting, maize could benefit from N obtained from any source since it is a time of high N demand.

The seed yield of maize following beans in rotation was higher than that of continuous sole maize by 19% (990 kg/ha) and 17% (600 kg/ha) during the short rains of 1988/89 and 1989/90 in Kimutwa and by 37% (265 kg/ha) and 3% (40 kg/ha) during the long rains of 1988 and 1989 in Masii, respectively (Tables 37a). Thus, there was a greater variation effect of rotation on seed yield of maize in Masii than in Kimutwa. Also, only in Kimutwa was there a highly significant increase of seed yield due to rotation during the short rains of 1988/89. The highest per cent increases in seed yield due to residual effect of rotation were observed at zero N treatments (Table 37a). Application of N fertilizer lowered the effect of rotation on seed yield although the yield in the rotation was always higher than that obtained in the continuous sole cropping. Crop rotation reduced N requirement by maize for an equivalent seed yield obtained in the continuous sole maize, thus implying that there was a supplementary effect on N fertilizer (Fig. 10b). The higher seed yields of cereals grown after legumes in rotations than that of continuous cereal crops have often been attributed to the greater availability of soil mineral N (Jones, 1974; Giri and De, 1979; Gakale and Clegg, 1987). Soil analysis by Jones (1974) confirmed that the soil mineral N content was considerably increased after legumes, thus implying that the cereal yields increase were as a result of better N supply of the soil.

In this study, the amounts of N estimated to be available to maize following beans in rotation plots (Appendix Table 21) with and without bean residue returned were 16 and 56 kg/ha, respectively in the first rotation, and 14 and 24 kg/ha, respectively in the second rotation in Kimutwa while in Masii, they were 9 and 3 kg/ha, respectively in the first rotation and 0.7 and 6 kg/ha, respectively in the second rotation. It is clear that where bean residue was returned, the effect of rotation on estimated available N to maize was generally less than where the residue was removed. The reason for this was not clear and this is an area which requires further research.

The higher yields of maize grown after beans in rotation than that obtained from continuous sole cropping did not relate well with the available mineral N obtained at the beginning of seasons because even though the available N in rotation was lower than that from continuous sole cropping plots, (Tables 51 and 52) the seed yield of the former system was higher than that of the latter (Table 37a). Hence, other factors may have influenced maize seed yield in rotations. Probably, the generally higher soil extractable P and exchangeable K, Mg and Ca obtained in plots under beans in rotation than in plots under continuous sole maize (Tables 51 and 52) might have contributed to the positive effect of rotation on yield especially in the zero N treatments where the uptake of P, K, Mg and Ca by maize in rotation was enhanced (Tables 14 through 17). The relationship between maize seed yield and uptake of N, P, K, Mg and Ca were positive and significantly correlated in all seasons at both sites (Table 38).

Where bean residue was returned, maize seed yield was increased by an average of 29 kg/ha (1.8%) in Masii and by 112 kg/ha (3%) in Kimutwa (Tables 35 and 36). The returned residue to maize intercropped in the same row increased seed yield by 6, 13, 2, and 11% (56 - 405 kg/ha) when N rates were 0, 25, 50, and 100 kg/ha in Kimutwa, respectively. With regard to maize intercropped in alternate rows at the same site, bean residue returned improved seed yield by 11, 1, and 3% (42 - 272 kg/ha) when N rates were 0, 50, and 100 kg/ha, respectively but also had a reduction effect of 18% (572 kg/ha) when the N rate was 25 kg/ha. In rotation, although bean residue returned improved seed yield by 10 and 3% (485 and 154 kg/ha) at N rates of 50 and 100 kg/ha, it also reduced it by 17 and 9% (657 and 478 kg/ha) at the N rates of 0 and 25 kg/ha, respectively.

In Masii, the maize seed yield increase due to bean residue returned was by 51, 29, and 6% (169, 221 and 172 kg/ha) when N rates were 0, 25, and 100 kg/ha, respectively for maize in the same row; by 53, 14, and 1% (546, 305 and 21 kg/ha) at the N rates of 25, 50 and 100 kg/ha, respectively for maize in alternate row; and by 25 and 1% (221 and 11 kg/ha) at the N rates of 25 and 100 kg/ha, respectively for maize in the rotation. On the other hand, some maize seed yield reductions due to bean residue returned were also observed: intercropped maize in the same row was reduced by 39% (608 kg/ha) when N rate was 50 kg N/ha and that in alternate row by 163% (398 kg/ha) when N rate was 0 kg N/ha. In rotation, the reduction of seed yield as a result of residue returned was by 72 and 11% (178 and 168 kg/ha) when N rates were 0 and 50 kg/ha, respectively. In Kimutwa, where N x cropping systems interaction on maize seed yield was significant, it was found that returning of bean residue to the same row intercropping and rotation systems, resulted in better maize response to N than where bean residue was removed. However, returning of bean residue to the alternate row intercropping resulted in maize having a slightly lower response to N than where bean residue was removed (Fig.10). Hence, return of bean residue could be beneficial in some cropping systems but not to all where N fertilizer is used in maize production.

4.6.2 Bean seed yield: The average bean production potential was similar at the two sites. Averaged over the four complete seasons, the yields were 991 kg/ha in Kimutwa with a range of 377 to 1808 kg/ha while in Masii the average yield was 925 kg/ha with a range of 666 to 1524 kg/ha (Table 39 and 40). There were big variations from one season to another ranging from 2 to 380% in Kimutwa and 6 to 1288% in Masii. Variations between similar seasons also existed and were found to be 101% and 134% in Kimutwa and 10% and 96% in Masii for the long and short rains, respectively. Thus, short rains had greater yield variations than the long rains in both sites. Although Masii had greater seed yield variations from one season to the other, it had less yield variations between similar seasons, compared to Kimutwa. Higher seed yields were obtained during the long rains than during the short rains in Kimutwa while the reverse was true for Masii.

Irrespective of cropping systems, seed yields of beans were increased by N fertilizer; N response was higher in Masii than in Kimutwa (Tables 39 and 40). The lower level of residual mineral N in Masii compared to that in Kimutwa may explain why there was higher response to N in the former than in the latter site. The seed yield

Table 39 – Effect of nitrogen fertilizer and cropping systems on seed yield (kg/ha) of beans at Kimutwa.

Cropping systems	Long rain 1988								Short rain 1988/89							
	N fertilizer kg/ha								N fertilizer kg/ha							
	0	25	50	100	Mean	F test	CV (%)	LSD 0.05	0	25	50	100	Mean	F test	CV (%)	LSD 0.05
BSCNR	1519	1778	2296	2267	1965	***	23	236	455	713	572	487	557	***	35	63
BSCRR	1696	2415	2711	2815	2409				337	402	473	486	424			
BISNR	1289	1363	1652	1534	1459				233	405	346	383	341			
BISRR	1123	1371	1444	1674	1296				307	360	387	412	366			
BIANR	948	1448	1311	1089	1124				253	373	389	388	351			
BIARR	859	941	1333	1215	1087				215	229	222	223	222			
Rot–NR	2037	2757	2736	3148	2667				–	–	–	–	–			
Rot–RR	1585	2726	2926	2600	2459				–	–	–	–	–			
Mean	1328	1812	2050	2043	1808				300	414	398	396	377			
F test	*								ns							
CV (%)	36								25							
LSD 0.05	438								–							
	Long rain 1989								Short rain 1989/90							
BSCNR	766	995	1238	742	935	***	17	389	962	1525	1856	1662	1501	***	30	178
BSCRR	569	793	1121	923	896				648	1225	1440	1177	1123			
BISNR	454	636	817	700	652				462	738	890	855	736			
BISRR	499	562	842	694	649				321	509	758	1008	649			
BIANR	400	566	667	439	518				416	586	971	592	641			
BIARR	345	481	406	537	442				372	628	883	668	638			
Rot–NR	1162	1905	1604	1738	1602				–	–	–	–	–			
Rot–RR	1002	1567	1716	1649	1484				–	–	–	–	–			
Mean	650	961	1051	928	898				530	868	1133	994	881			
F test	***a								**							
CV (%)	5								15							
LSD 0.05	116								313							

*, **, *** = Differences of treatment means are significant at P = 0.05, 0.01, 0.001 level, respectively.

ns = Differences of treatment means are not significant at P = 0.05

a = N x cropping systems interaction is significant at P = 0.05 level.

Table 40 – *Effect of nitrogen rates and cropping systems on seed yield (kg/ha) of beans at Masii.*

Cropping systems	Long rain 1988 N fertilizer kg/ha 0	25	50	100	Mean	F test	CV (%)	LSD 0.05	Short rain 1988/89 N fertilizer kg/ha 0	25	50	100	Mean	F test	CV (%)	LSD 0.05
BSCNR	311	1333	1026	1426	1024				521	679	1172	913	821			
BSCRR	404	901	1215	921	860				567	638	790	793	697			
BISNR	337	582	1057	726	688				705	659	1004	970	835			
BISRR	437	621	632	861	638	**	42	253	525	734	670	889	705			
BIANR	262	603	818	546	557				437	507	825	684	613	ns	44	–
BIARR	168	1052	635	675	632				248	942	848	586	656			
Rot–NR	–	–	–	–	–				772	1210	1227	930	1035			
Rot–RR	–	–	–	–	–				439	1077	954	935	851			
Mean	320	849	897	868	734				527	806	936	838	777			
F test		*								ns						
CV (%)		30								62						
LSD 0.05		437								–						
	Long rain 1989								Short rain 1989/90							
BSCNR	531	989	1278	927	931				635	1682	3016	1847	1795			
BSCRR	466	905	959	810	785				884	869	2119	1515	1347			
BISNR	341	451	643	676	528				979	934	2166	1359	1359			
BISRR	458	749	463	816	622	***	20	90	963	1086	988	1428	1116			
BIANR	346	618	726	526	554				738	772	1536	988	1008	***	44	443
BIARR	113	899	784	517	578				466	1441	1634	967	1127			
Rot–NR	–	–	–	–	–				1284	2370	3282	2416	2338			
Rot–RR	–	–	–	–	–				974	2678	2531	2233	2104			
Mean	376	768	809	712	666				865	1479	2159	1594	1524			
F test		***a								ns						
CV (%)		7								35						
LSD 0.05		121								–						

*, **, *** = Differences of treatment means are significant at P = 0.05, 0.01, 0.001 level, respectively.

ns = Differences of treatment means are not significant at P = 0.05 level.

a = N x Cropping systems interaction is significant at P = 0.05 level.

increases due to N fertilizer were between 32 and 84% (127 - 771 kg/ha) for continuous sole beans, 27 and 100% (91 - 380 kg/ha) for intercrop beans and 55 and 56% (606 - 996 kg/ha) for the crop in rotation in Kimutwa. In Masii, the increase of yield due to N were between 46 and 218% (250 - 1078 kg/ha) for continuous sole beans, 66 to 167% (316 - 551 kg/ha) for intercrop beans and 85 to 129% (515 - 1456 kg/ha) for beans in rotation. The high response of beans to N fertilizer indicate that N was a yield limiting factor in this semi-arid region. Hence, the levels of residual soil mineral nitrogen from N applied plots which ranged from 12.2 to 45.6 ug N/g soil in Kimutwa and 6.8 to 35.7 ug N/g soil in Masii at the beginning of the season (Tables 51 and 52) were not adequate for bean production in these two sites. Since the N uptake by maize and beans in different cropping systems was higher in Kimutwa than in Masii (Table 26) by 43% when averaged over the four seasons, and because the two sites received similar amounts of N fertilizer, this seemed to indicate that the soil mineral N was lower in Masii than in Kimutwa probably as a result of more leaching in Masii than in Kimutwa. The contributory factors to more leaching in Masii were anticipated to be higher rainfall and the sandy soil type compared to Kimutwa site which had lower rainfall and sandy clay loam soil type (Appendix Table 1 and Table 1). Research has shown that seasons that were preceded by greater rainfall provided a lower carryover N compared to seasons whose previous seasons had low rainfall (van der Paauw, 1963). Also, nitrate is more readily leached from sandy soil than from a loam soil (Wild, 1988).

Although the interaction between N and cropping systems on bean seed yields were not significant, except for one season (LR 1989) in both sites, the bean response to N was found to be influenced by cropping systems. Considering each cropping system and its N response during the four seasons, data from Kimutwa showed that the highest response of continuous sole beans and those intercropped in alternate rows to N occurred at N50, that of beans intercropped in the same row was obtained at N100 while for those in rotation were at either N25 or N100 (Table 39). In Masii, the highest response of continuous sole beans and those in rotation to N was found to occur at N50 while for those intercropped in the alternate or same row systems were obtained at either N25 or N50 and N50 or N100, respectively (Table 40). When data on bean response to N for the two sites were combined, the results showed that out of 28 response to N cases, 17 cases had their highest response to N at N50, 7 cases at N100 and 4 cases at N25. However, one interesting observation was that beans intercropped in the same row persistently had their majority of cases giving the highest N response at N100. Also, beans in continuous sole crop system, rotation and those intercropped in alternate rows indicated that their highest N response generally occurred at N50. The response of beans intercropped in the same row to higher N levels than those in alternate rows could be attributed partly to the higher competition from maize due to their proximity. Cable (1969) and Trenbath (1975) reported that the degree of overlap between component's root-systems determined the intensity of competition between intercrops. Generally, the maize intercropped in the same row was found to take higher N than that in alternate rows (Table 14) and probably this resulted in more depletion of soil available N during the growing period. Hence, beans in the same row could respond to higher levels of N if maize presumably took the bulk of it. Infact, beans in the same rows were found to take higher N than those in alternate rows (Table 14).

The relationships between N fertilizer and seed yields were determined by regression analysis where N effect was significant. These relationships were found to be quadratic in nature with the second order equation accounting for 55 to 99% of the variation in the seed yield means (Fig. 11; Table 41a). When there was no interaction between N x cropping systems, the regression analysis predicted that beans in different cropping systems could generally have their maximum seed yield occurring at the N fertilizer rate of 75 kg N/ha as observed during the long rains of 1988 in both Kimutwa and Masii and during the short rains of 1989/90 at Kimutwa (Fig. 11b). Where interactions of N x cropping systems were significant, beans in the continuous sole cropping and alternate row had their maximum N response at N fertilizer rate of 50 kg N/ha at both sites (Figs. 11a and 11b). However, beans planted in the same row could have their maximum yield response to N fertilizer rate of 75 kg N/ha in Kimutwa and 100 kg N/ha in Masii while for those in rotation could occur at 75 kg N/ha in Kimutwa (Figs. 11a and 11b).

There were two isolated cases, however, where the relationships between bean seed yields and N fertilizer were not quadratic. During the long rains of 1989, beans in the alternate row with bean residue returned (BIARR) in Kimutwa (Fig. 11a; Table 41a) and those in the same row also with bean residue returned (BISRR) in Masii (Fig. 11b) had their seed yields increased with the increase in N rates. A similar relationship was also observed in Masii between N fertilizer and uptake of nutrients and it occurred in the same season when the rainfall was 355 mm while in Kimutwa, this type of relationship for seed yield and nitrogen fertilizer occurred when rainfall was one of the lowest, 191 mm.

The seed yield increases due to N fertilizer application in crop mixtures in this study contradicts the findings of Dalal (1977) and Chui and Shibles (1984) using soybeans and Ahmed and Gunasena (1979) using soybeans, cowpea and mungbean who reported yield depressions of the legumes with increasing rates of N fertilizer due to increasing competition from the maize. The reason given to the yield depression of a legume when

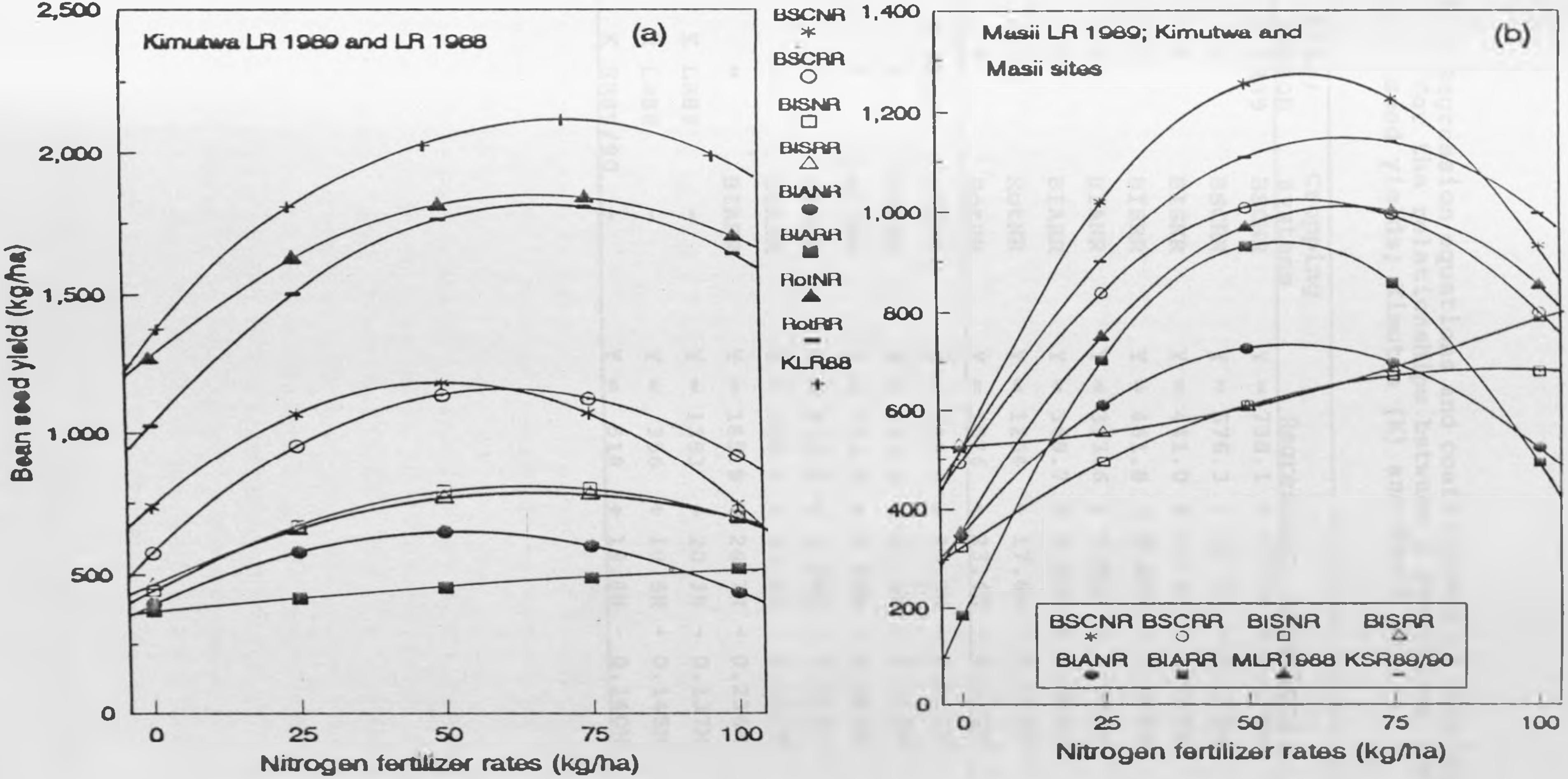

Fig.11 - Relationships between N fertilizer rates and bean seed yield during the long rain (LR) and short rain(SR) seasons at Kimutwa(K) and Masii(M) sites.

* For regression equations and R^2, see Table 41a

Table 41a - Regression equations and coefficients of determination for the relationships between N fertilizer and bean seed yields; Kimutwa (K) and Masii (M).

Figure	Site/ Season	Cropping systems	Regression equations	R^2
11a	K LR89	BSCNR	$Y = 738.1 + 17.7N - 0.175N^2$	0.941
	"	BSCRR	$Y = 576.3 + 18.9N - 0.155N^2$	0.996
	"	BISNR	$Y = 441.0 + 11.4N - 0.087N^2$	0.970
	"	BISRR	$Y = 461.8 + 9.80N - 0.073N^2$	0.757
	"	BIANR	$Y = 393.6 + 9.90N - 0.095N^2$	0.990
	"	BIARR	$Y = 369.7 + 1.90N + 0.003N^2$	0.641
	"	RotNR	$Y = 1268 + 17.6N - 0.132N^2$	0.553
	"	RotRR	$Y = 1026 + 23.4N - 0.170N^2$	0.978
11b	M LR89	BSCNR	$Y = 519.4 + 25.3N - 0.212N^2$	0.994
	"	BSCRR	$Y = 490.4 + 17.6N - 0.145N^2$	0.951
	"	BISNR	$Y = 325.0 + 7.80N - 0.043N^2$	0.957
	"	BISRR	$Y = 530.4 + 0.50N + 0.021N^2$	0.394
	"	BIANR	$Y = 348.1 + 13.5N - 0.117N^2$	0.999
	"	BIARR	$Y = 185.9 + 26.7N - 0.236N^2$	0.824
	K LR88	-	$Y = 1383 + 20.3N - 0.137N^2$	0.999
	M LR88	-	$Y = 356 + 19.5N - 0.145N^2$	0.931
	K SR89/90	-	$Y = 518 + 18.8N - 0.140N^2$	0.991

N is applied in an intercropping system is that the applied N usually favours the growth of maize which result in shading the shorter legume crop (Searle et al., 1981) and consequently the reduction in grain yield of the shorter component (Trenbath and Harper, 1973). In the semi-arid area where this study was conducted, these contradictory results seemed to indicate that even though the growth of maize was improved by N by increasing the height of maize (Tables 12 and 13), the shading effect that may have occurred might have resulted in altering the microclimate of bean plants intercropped in the same row with maize thus giving them more favourable environment to be able to take up more N which was found to be highly correlated with bean seed yield (Table 35). Allen et al. (1976) reported that evapotranspiration would be expected to be less for a lower canopy under polyculture, thus leading to less water stress. Also, Midmore et al. (1988) reported that shaded potato plants by maize were in general 35-39% more efficient than the non-shaded ones in their conversion of available energy to tuber fresh weight. This may help to explain why the beans in alternate rows which were more exposed to direct radiation in this semi-arid region were outperformed by the beans intercropped in the same row which were more shaded by maize. Further research is needed to confirm this hypothesis.

Response of beans in rotation to N was higher than that of continuous sole beans in terms of yields in kg/ha for reasons other than available soil N because soil mineral N in rotation and that in continuous sole beans plots were found to be similar at the beginning of the season (Tables 51 and 52). Also, the response of beans to N was not unusual in this study because beans have been found to fix N inadequately and quite often N fertilization of field-grown beans is recommended (Graham, 1981; Westerman et al., 1981).

Intercropping beans on either alternate or same row with maize significantly reduced the seed yield of beans in all seasons at both sites except one (SR 1988/89) in Masii (Table 39 and 40). In Kimutwa, the bean seed yield reduction was by 42% ($P < 0.01$, 920 kg/ha), 38.3% ($P < 0.01$, 351 kg/ha), 35% ($P < 0.01$, 920 kg/ha) and 49.2% ($P < 0.01$, 646 kg/ha) while in Masii the reductions were generally lower than those of Kimutwa and were 33.2% ($P < 0.01$, 312 kg/ha), 34% ($P < 0.01$, 292 kg/ha), 13.4% (55 kg/ha) and 26.6% ($P < 0.05$, 418 kg/ha) during the long rains of 1988 and 1989 and short rains of 1988/89 and 1989/90, respectively.

The maize in Masii was shorter than that in Kimutwa by an average of 20 cm (Tables 12 and 13) and this could be the season why seed yield of intercropped beans in Masii were less reduced by intercropped maize probably because there was less shading by maize. Height in intercropping systems is an important factor in light interception competition and any slight difference in height has been shown to lead to shading effects resulting in reduction of grain yield of the shorter components (Trenbath and Harper, 1973). The reduction of photosynthetic photon flux density reaching the shorter legume component by a maize intercrop has also been found to reduce N_2-fixation of intercropped legumes such as calopo, greengram, cowpeas, beans, groundnut and soybeans (Agboola and Fayemi, 1971; Graham, and Rosas 1978; Searle et al., 1981) and consequently leading to the observed reduction of seed yields of intercropped soybeans, groundnuts and cowpeas (Searle et al 1981; Agboola and Fayemi, 1971; Mongi et al, 1976).

The seed yields of beans were influenced by spatial arrangements (Tables 39 and 40). Yield of beans in the same row and alternate rows in Kimutwa were reduced by 35 and 48%, respectively while in Masii the yields were reduced by 21 and 30%, respectively. Seed yields of beans planted in the same rows were significantly higher than that of beans intercropped in the alternate row by 35.5% ($P < 0.05$, 323 kg/ha) in Kimutwa during the long rains of

1988 and by 23.5% ($P < 0.05$, 170 kg/ha) in Masii during the long rains of 1989. During these two seasons, the total rainfall were 362.4 mm for Kimutwa and 355.1 mm for Masii which were medium compared with the total rainfall per season which fell during the experimental period which ranged from 103 to 667 mm at the two sites. The better performance of beans planted in the same row seems to contradict the findings of Cable (1969) and Trenbath (1975) which implied that the component crops at closer intimacy may experience higher competition for growth resources because of the degree of overlap between components' root-systems. Also, these findings were not in line with those of Dalal (1977) who reported that the yield of soybean planted in the same row were lower by 67% than that in alternate row. In addition to the effect of intimacy between component crops, Osiru (1974) observed that, with increasing intimacy in an alternate row arrangement of sorghum genotypes of different heights, the shorter genotypes grew poorly and overall yield decreased unlike those planted at less intimate arrangements. Probably, in this study, the change in light interception by the shorter bean crop was a primary factor that determined the performance of the bean intercrop. Once again, the earlier argument will be repeated here that in a semi-arid region where water stress is anticipated, the shading of beans planted in the same row with maize may have altered the microclimate of beans thus resulting in less water stress than those in alternate rows. This reasoning is supported by Allen et al. (1976) who reported that evapotranspiration was expected to be less for a lower canopy under polyculture thus leading to less water stress.

Orthogonal contrasts indicated that rotation compared with continuous sole cropping significantly increased seed yields of beans by 69% (627 kg/ha) in Kimutwa during the long rains of 1989 and by 41% (651 kg/ha) in Masii during the short rains of 1989/90 (Tables 39 and 40). The seed yield increase of beans due to rotation is shown in Table 41b. The non-significant increase in seed yield was by 17% (376 kg/ha) in Kimutwa (LR 1988) and 36% (260 kg/ha) in Masii (SR 1988/89) (Tables 39 and 40). The influence of N applied in rotations on bean seed yields was different from that observed in maize. In beans, the highest beneficial effect of rotation in terms of seed yield increase occurred at N rate of 25 kg N/ha (Table 41b) unlike that of maize which was obtained at zero N rate (Table 37a). The increased seed yield of beans following maize was not due to the effect of maize on the status of soil nitrogen since the soil mineral N measured in rotation was similar to that from continuous sole beans (Tables 51 and 52). Hence, other factors may have contributed towards the seed yield increase in rotation. This increased seed yield was related to higher uptake of N, P, K, Mg and Ca which averaged 33, 30, 42, 36 and 58% in Kimutwa and 32, 37, 34 and 26% in Masii, more than that taken up by continuous sole beans, respectively (Table 42). Also, the higher seed yield in rotation is related to higher soil extractable P and exchangeable K, Mg and Ca in plots previously under maize in rotation than those under continuous sole beans in Kimutwa (Tables 41b and 51).

Return of bean residue which ranged from 224 to 1666 kg/ha resulted in bean seed yield reductions averaging from 2.4 to 19% in all seasons at both sites (Tables 39 and 40). In Kimutwa, the significant ($P < 0.05$) seed yield reductions occurred during the short rains of 1988/89 in continuous sole beans, beans intercropped in the same row and alternate row when the previous season (LR 1988) bean residues amounting to 1333, 771 and 605 kg/ha were returned to the plots respectively; and during the short rains of 1989/90 in continuous sole beans when the previous season bean residue returned was 953 kg/ha. In Masii, the seed yield was significantly ($P < 0.01$) reduced when the previous season bean residue was returned at the rate of 668 kg/ha during the long rains of 1989. The amount of bean

Table 41b – Seed yield of beans at various rates of added N fertilizer when the preceeding crop was either maize or beans.

Fertilizer kg N /ha	Bean seed yield when following		Yield increase for maize following	
	Beans	Maize		
Kimutwa	----------kg/ha	-------------	kg/ha	%
SR 1988/89				
0	1607	1811	204	13
25	2096	2741	645	31
50	2504	2826	322	13
100	2541	2874	333	13
Mean	2187	2563	376	17
Kimutwa				
SR 1989/90				
0	667	1082	415	62
25	984	1736	752	76
50	1180	1660	480	41
100	832	1693	861	104
Mean .	916	1543	627	68
Masii				
LR 1988				
0	544	606	62	11
25	658	1144	486	74
50	891	1228	247	25
100	740	988	248	34
Mean	731	992	261	36
Masil				
LR1989				
0	759	1129	370	49
25	1276	2524	1248	98
50	2565	2907	342	13
100	1681	2325	644	38
Mean	1570	2221	651	42

Table 42 - Correlation coefficients (r) between nutrient uptake and seed yield (BSYD) of beans during different seasons.

Site/ Nutrient	Long rain 1988					Short rain 1988/89					Long rain 1989					Short rain 1989/90				
	P	K	Mg	Ca	MSYD	P	K	Mg	Ca	MSYD	P	K	Mg	Ca	MSYD	P	K	Mg	Ca	MSYD
Kimutwa																				
N	**0.893	**0.910	**0.577	**0.681	**0.949	**0.895	**0.945	**0.811	**0.850	**0.904	**0.807	**0.889	**0.912	**0.874	**0.950	**0.872	**0.872	**0.683	**0.867	**0.853
P		**0.854	**0.488	**0.590	**0.905		**0.898	**0.833	**0.745	**0.889		**0.725	**0.806	**0.669	**0.808		**0.867	**0.753	**0.628	**0.926
K			**0.635	**0.791	**0.906			**0.837	**0.798	**0.908			**0.904	**0.860	**0.933			**0.915	**0.873	**0.846
Mg				**0.660	**0.541				**0.700	**0.918				**0.880	**0.933				**0.908	**0.744
Ca					**0.694					**0.735					**0.885					**0.608
Masii																				
N	**0.915	**0.941	**0.735	**0.738	**0.977	**0.866	**0.902	**0.883	**0.858	**0.940	**0.912	**0.926	**0.883	**0.818	**0.941	**0.874	**0.907	**0.898	**0.900	**0.978
P		**0.888	**0.640	**0.654	**0.937		**0.854	**0.799	**0.771	**0.811		**0.926	**0.883	**0.818	**0.941		**0.874	**0.847	**0.838	**0.901
K			**0.763	**0.796	**0.925			**0.922	**0.888	**0.804			**0.954	**0.921	**.968			**0.926	**0.894	**0.912
Mg				**0.867	**0.650				**0.912	**0.803				**0.898	**0.909				**0.919	**0.916
Ca					**0.657					**0.777					**0.885					**0.904

*, **, = Correlation between parameters is significant at P = 0.05, 0.01, level, respectively.
Nutrient uptake and seed yields were in kg/ha

residue returned was not well related to the yield and could not be used to predict the extent of yield reduction of beans.

Probably, the reduction of bean seed yield as a result of bean residue returned could be due to the tie up of soil nutrients when the bean residue was being decomposed by microbial activity. This hypothesis might be supported by the fact that where bean residue was returned, there were lower levels in the soil of residual soil mineral N, extractable P and exchangeable K, Ca and Mg (Tables 51 and 52) which were accompanied by reduced uptake of the same nutrients by beans (Table 20 through 24). Since nutrient uptake was highly correlated with seed yield (Table 42), then the reduced level of nutrients in the soil as a result of bean residue returned may have contributed towards the low bean seed yield observed.

4.6.3 Total Grain Yield: Total grain yields (TGY) of maize and beans were determined by summing up grain yields of these crops grown in the sole cropping systems or combining grain yields for those grown in rotation or mixtures. The purpose was not to evaluate the productivity of intercrops relative to other cropping systems but to understand how the economic yields of these crops in different cropping systems were affected by N fertilization (Tables 43 and 44).

The TGY of intercrops were significantly increased by N application by 37 to 51% (1276 - 1867 kg/ha) in Kimutwa and by 175 to 351% (1283 - 2892 kg/ha) in Masii in three out of four seasons in both sites (Table 43). In Kimutwa, the effects of rates of N, that is, 25 to 100 kg/ha on TGY during the long rains of 1988 and short rains of 1989/90 did not differ significantly. Also, a comparison showed that N25 rate unlike the N50 and N100 rates did not significantly increase the yield relative to zero N rate although the yields of N25 were higher than that of zero N by 18% and 30%, during the two seasons,

Table 43 – Total grain yield of maize and beans (kg/ha) in continuous sole crop, rotation and intercropping systems per season.

	Kimutwa				Masii			
Fertilizer kg N/ha	LR 1988	SR 1988/89	LR 1989	SR 1989/90	LR 1988	SR 1988/89	LR 1989	SR 1989/90
0	2651	3488	1469	2223	393	1086	448	839
25	3284	4450	1787	3027	1289	1824	1423	2095
50	3765	4651	1864	2694	1154	3100	1690	3387
100	3822	4933	1764	3565	1357	2982	1596	3666
Mean	3380	4381	1726	3127	1048	2248	1284	2497
F test	**	ns	ns	*	ns	*	*	**
CV (%)	7	13	8	15	35	28	25	28
LSD 0.05	488	–	–	923	–	1281	647	1388
Cropping systems								
MSC	3515	5266	2059	3515	723	3614	1289	2623
M-BISNR	4435	5045	2070	3836	1802	2753	1434	3461
M-BISRR	4723	5329	2164	3563	1115	3406	1392	3036
M-BIANR	4035	5134	2173	3107	1078	3313	1428	2707
M-BIARR	4168	5239	2147	3269	1213	3578	1514	3146
Rot-NR	2593b	6275m	1602b	4037m	716m	1019b	1452m	2251b
Rot-RR	2584b	6055m	1484b	4194m	929m	764b	1332m	2104b
BSCNR	2011	557	935	1501	1024	962	931	1795
BSCRR	2361	424	896	1123	835	823	785	1347
Mean	3380	4381	1726	3127	1048	2248	1284	2497
F test	***	***	***	***	ns	***	**	**
CV (%)	16	17	17	24	79	48	38	56
Interaction	ns	ns	*	ns	ns	***	ns	ns
LSD 0.05	452	616	243	610	–	878	402	1135

*, **, *** = Treatment differences and interactions are significant at P = 0.05, 0.01, 0.001 level, respectively.

ns = Treatment differences and interactions are not significant at P = 0.05 level.

b, m = beans and maize in rotation.

Table 44 - Total grain yield of maize and beans (kg / ha / year)

Fertilizer kg N/ha	Kimutwa		Masii	
	Year 1	Year 2	Year 1	Year 2
0	6117	3673	1460	1519
25	7734	4940	2842	3516
50	8452	5557	4253	5077
100	8755	5349	4366	5242
Mean	7765	4880	3230	3839
F test	*	**	*	**
CV (%)	28	10	81	21
LSD 0.05	1441	767	1737	1643
Cropping systems				
MSC	8781	5574	4336	3913
M-BISNR	9480	5905	3948	4895
M-BISRR	10052	5727	4521	4428
M-BIANR	9252	5565	4390	4181
M-BIARR	9407	5417	4797	4659
Rot-NR	9042	5575	1818	4180
Rot-RR	8514	5699	1862	3436
BSCNR	2522	2436	1845	2726
BSCRR	3834	2019	1557	2132
Mean	7765	4880	3230	3839
F test	**	***	**	**
CV (%)	13	16	39	47
Interaction	*	ns	**	ns
LSD 0.05	791	794	1035	1481

*, **, *** = Treatment differences and interactions are significant at P = 0.05, 0.01, 0.001, respectively.

ns = Treatment differences and interactions are not significant at P = 0.05 level.

Year 1 and 2 = LR 1988 and SR 1988/89 ; LR 1989 and SR 1989/90 respectively. During the short rains of 1988/89 in Masii, the N rates of N50 and N100 gave significantly higher seed yield than N25. But, the N rate of N25 did not give significantly higher seed yield than zero N rate although the yield of the former rate was higher than the latter rate by 78%. However, during the short rains of 1989/90 in Masii, comparisons of N rates indicated that although the effect of N50 and N100 rates on seed yield did not differ significantly, that of the latter rate was significantly higher than that of N25 rate. Also, during this season, the seed yield from the N25 rate was significantly higher than that from zero N rate.

The higher TGY obtained due to N application was as a result of positive response to N fertilizer by both the intercrops and more so by beans. The response of intercropped beans to N was unlike that of some findings by Dalal (1977) and Chui and Shibles (1984) on soybeans in intercropping systems whereby application of N fertilizer resulted in depression of seed yield. It was observed that even though the interactions of N and cropping systems were not significant, the highest response of total grain yields to N occurred at N100 for the intercrops in the same row in all four seasons at both sites. Intercrops grown in alternate rows had differed in their response to N: in Kimutwa, the highest N response occurred 3 cases at N50 and 1 case at N25 while in Masii, 2 cases occurred at N50 and the other two cases one at N25 and the other at N100. In continuous sole maize, the highest response to N occurred 2 cases at N50 and the other two at N100 at both sites. These results seem to indicate that spatial arrangements of maize and beans may cause alteration of N fertilizer management of intercrops. Thus, intercrops in the same row may require higher N than those in the alternate row system in order to achieve higher grain yields. These results clearly indicate that since N25 gives the lowest grain yield response, it can not be adequate when applied to either intercrops in the same row or continuous sole maize. The TGY results were closely related to those of uptake of nutrients (Table 45).

Total grain yields from intercropping systems were generally higher than those from continuous sole cropping of maize by between 4 and 60% (Table 43). During the long rains of 1988 in Kimutwa, TGY of intercrops were significantly higher than that of sole maize by 23.5% ($P < 0.01$, 825 kg/ha). In the same season, the TGY obtained from the same row and alternate row intercrops were higher than those obtained from the continuous sole maize by 30 and 17%, respectively. It was found that, in order to obtain higher TGY from the intercropping systems than from continuous sole maize the reduction of maize yield due to intercropping was going to be overcompensated by the yield of beans in the same intercropping system. The percentage yields obtained from the intercrops relative to their sole crops were found not to be good indicators of TGY to be obtained in mixtures. Hence, overcompensation of maize yields reduced in an intercropping system was found to depend on the absolute seed yields of the intercropped beans and the extent of maize absolute seed yield reduction and only occurred where bean seed yields obtained in intercropping systems surpassed the yield reductions of maize in those intercropping systems.

The level of TGY obtained from the maize-bean intercrops indicates that irrespective of the prices attached to either crop, the practice of intercropping has a potential in crop production in small-scale farmers with respect to social aspects such as food diversity (Harwood and Price, 1976; Rachie, 1978), and availability of food at different times during the growing season (Okigbo, 1975) since beans are harvested earlier than maize in this semi-arid region.

The total grain yield/ha/yr was used to compare the productivity of all cropping systems used, that is, continuous sole maize and beans, rotation and intercropping systems (Tables 45). At both sites, TGY/ha/yr were

Table 45 - Correlation coefficients (r) between nutrient uptake and total grain yield (TGY) of cropping systems in different seasons.

Site/ Nutrient	Long rain 1988					Short rain 1988/89					Long rain 1989					Short rain 1989/90				
	P	K	Mg	Ca	TGY	P	K	Mg	Ca	TGY	P	K	Mg	Ca	TGY	P	K	Mg	Ca	TGY
Kimutwa																				
N	0.821**	0.809**	0.588**	0.031 ns	0.819**	0.860**	0.460**	0.391 ns	0.291 ns	0.945**	0.764**	0.686**	0.783**	0.745**	0.741**	0.864**	0.858**	0.798**	0.797**	0.689**
P		0.652**	0.631**	0.056 ns	0.824**		0.460**	0.262 ns	0.147 ns	0.877**		0.482**	0.549**	0.991**	0.817**		0.820**	0.832**	0.642**	0.672**
K			0.636**	0.042 ns	[illegible]**			0.274**	0.270**	0.411**			0.789**	0.474**	[illegible]**			0.909**	0.740**	0.661**
Mg				0.108 ns	[illegible]**				0.770**	[illegible]*				0.526**	[illegible]**				0.646**	[illegible]**
Ca					[illegible] ns					0.876 ns					0.788**					0.411**
Masii																				
N	[illegible]**	0.768**	0.867**	0.778**	[illegible]**	[illegible]**	0.802**	0.880**	0.647**	[illegible]**	[illegible]**	0.817**	0.867**	0.778**	[illegible]**	[illegible]**	0.825**	0.896**	0.862**	[illegible]**
P		0.780**	0.866**	0.806**	[illegible]**		0.791**	0.823**	0.480**	0.96**		0.808**	0.818**	0.780**	[illegible]**		0.862**	0.800**	0.778**	[illegible]**
K			0.803**	0.738**	[illegible]**			0.716**	0.658**	[illegible]**			0.916**	0.916**	[illegible]**			0.866**	0.872**	[illegible]**
Mg				0.780**	[illegible]**				0.913**	[illegible]**				0.909**	0.781**				0.906**	[illegible]**
Ca					[illegible]					[illegible]					[illegible]					[illegible]

*, ** = Correlations between parameters are significant at P = 0.05 and 0.01 level, respectively.
ns = Correlations are not significant at P = 0.05 level. Nutrient uptake and total grain yields were in kg/ha.

significantly increased by N fertilizer by an average of 36% (2202 kg/ha) in year 1 and by 44% (1616 kg/ha) in year 2 in Kimutwa and by 162% (2365 kg/ha) and by 204% (3099 kg/ha) in Masii during year 1 and year 2, respectively (Table 44). Total grain yield/ha/yr response to N in the rotation were influenced by rainfall. When rainfall was higher in year 1 than year 2, the highest TGY/ha/yr response to N occurred at N100 but when rainfall was lower by 28 and 22% in year 2 than in year 1 in Kimutwa and Masii, respectively, the highest response to N occurred at N50. This indicates that, when rainfall was not high, the crops highest response to N occurred at a lower rate of N thus indicating an economic use of N fertilizer in the rotation and that rotation could probably leave a higher residual mineral N.

Cropping systems significantly affected TGY/ha/yr at the two sites (Tables 44). Orthogonal contrasts showed that, intercropping had significantly higher TGY/ha/yr than continuous sole maize by 16% ($P < 0.01$, 628 kg/ha) in year 2 in Masii, rotation by 9% ($P < 0.01$, 770 kg/ha) in year 1 in Kimutwa, and continuous sole beans by 159 and 87% ($P < 0.01$, 2713 and 2112 kg/ha) in Masii and by 200 and 154% ($P < 0.01$, 6370 and 3426 kg/ha) in Kimutwa in year 1 and year 2, respectively. However, continuous sole maize gave more TGY than continuous sole beans by between 25 and 179% in both sites but it had equal TGY/ha/yr to rotation in Kimutwa and lower than rotation by 3 to 50% in Masii. The TGY/ha/yr got from rotation was significantly higher than that obtained in continuous sole beans by 153 to 228% in Kimutwa and by 30% in Masii. The return of bean residue to plots did not significantly affect the TGY/ha/yr. However, it insignificantly increased TGY in year 1 by 10 to 21% but decreased the same in year 2 by 3 to 8%.

It is clear from these results that intercropping is superior to continuous sole maize and beans and rotation in terms of TGY/ha/yr. Although rotation was better than sole beans at the two sites, and equal to continuous sole maize in Kimutwa, it was not better than continuous sole maize in Masii. The return of bean residue was not found to result in higher percentage TGY increase than reduction and for this reason it is a practice that can be adopted in crop production because of the other known long-term advantages attached to organic matter in relation to soil fertility (Greenland and Dart, 1972; Stevenson, 1982; Jeffrey,1987).

4.7 <u>Effects of N, bean residue and cropping systems on Productivity of intercropping:</u> Since the seed yields of maize and beans as well as their selling prices are not comparable, intercrops evaluations are better made in relative terms than in absolute terms.

There are various concepts of evaluating the biological efficiency of intercropping systems relative to sole crops (Willey, 1979). Land Equivalent Ratio (LER) is one of the most commonly used methods despite some criticisms on land occupation by the intercrops of different growth duration and thus introducing the term Area x Time Equivalency Ratio (ATER) (Hiebsch and McCollum, 1987). In this study, the LER was used because the time difference between bean and maize harvests was short, 20 to 49 days, and could not be utilized in growing any other crop in this semi-arid region. Infact, from the time of harvest of the shorter duration crop, the bean, to that of maize, there was no rainfall but only a dry period. The ATER is, therefore, justified if there exists prospects for utilizing the land after one of the component crops is harvested.

A LER greater than unity indicates a more efficient use of land by intercrops. When LER is greater than unity, the amount that exceeds unity is the percent more land that must be planted to the monocrops in order to produce a total yield equal to that of the intercrops (Willey, 1979).

The results found in the literature with regard to

LERs of cereal-legume intercrops are inconsistent and depends on the climatic conditions, plant densities used and the management and are usually higher than that from the monoculture. This is because yield of the cereals in intercropping could be maintained or increased (Willey and Osiru, 1972; Wahua and Miller, 1978; Remison, 1978). On the other hand, Beets (1977), Dalal (1977) and Allen and Obura (1983) examining "high level management" of maize and soybeans and maize-cowpea found yield reduction of the maize component but LERs were still higher than sole crops because maize yield depression was overcompensated by the yield obtained from the legumes.

In this study, the relative yields (RYs) of maize (Appendix Tables 24 and 25) indicate that seed yields of intercropped maize was lower (86 - 97% of sole crop) in Kimutwa but higher (141 - 179% of sole crop) in Masii than that of sole maize in three out of four seasons in both sites. In the case of beans, the RYs from both sites (Appendix Table 26) showed that the bean yields were generally lower in intercropping than in sole cropping and they ranged between 63 and 99% of the sole crop.

Since the LER is the summation of two RYs of the component crops in similar intercropping systems, the high RYs obtained from both crop species resulted in higher LERs than unity which ranged from 1.15 to 1.86, in Kimutwa and 1.18 to 5.37 in Masii (Tables 46 and 47).

Nitrogen fertilizer application was found to insignificantly lower the LERs although the differences on average were high. The highest LER values were found at 0 kg N/ha level. The values of land equivalent ratio for 0, 25, 50 and 100 kg N/ha fertilizer levels averaged 1.61, 1.36, 1.43 and 1.35, in Kimutwa and 3.85, 1.76, 1.70 and 1.54 in Masii, respectively. Thus the LER values decreased with increasing N rates. It can be said that, lower soil fertility was associated with greater LER values and this may explain why greater LER values were obtained in Masii than in Kimutwa since soil from the former site

Table 46 – Effect of nitrogen rates and cropping systems on land equivalent ratio (LER) during different seasons at Kimutwa.

Cropping systems	Long rain 1988								Short rain 1988/89							
	N fertilizer kg/ha				Mean	F test	CV (%)	LSD 0.05	N fertilizer kg/ha				Mean	F test	CV (%)	LSD 0.05
	0	25	50	100					0	25	50	100				
MSC	1.00	1.00	1.00	1.00	1.00	***	21	0.249	1.00	1.00	1.00	1.00	1.00	***	16.3	0.208
ISNR	1.62	1.29	1.31	1.27	1.37				1.57	1.47	1.67	1.63	1.59			
ISRR	1.54	1.26	1.43	1.36	1.40				1.96	1.91	1.68	1.88	1.86			
IANR	1.36	1.25	1.32	0.92	1.21				1.49	1.68	1.65	1.60	1.61			
IARR	1.59	1.05	1.27	1.19	1.28				1.84	1.60	1.43	1.49	1.69			
Mean	1.42	1.17	1.27	1.15	1.25				1.57	1.53	1.49	1.52	1.53			
F test		ns								ns						
CV (%)		23								15.3						
LSD 0.05		–								–						
	Long rain 1989								Short rain 1989/90							
MSC	1.00	1.00	1.00	1.00	1.00	***	15.5	0.210	1.00	1.00	1.00	1.00	1.00	***	25	0.320
ISNR	1.60	1.32	1.44	1.54	1.48				1.97	1.54	1.50	1.67	1.67			
ISRR	1.72	1.30	1.60	1.47	1.52				1.96	1.68	1.61	2.09	1.84			
IANR	1.65	1.36	1.48	1.29	1.45				2.31	1.76	1.68	1.12	1.72			
IARR	1.96	1.10	1.56	1.15	1.44				2.06	1.55	1.78	1.27	1.67			
Mean	1.59	1.22	1.42	1.29	1.38				1.86	1.51	1.52	1.43	1.58			
F test		ns								ns						
CV (%)		20								35						
LSD 0.05		–								–						

*, **, *** = Differences of treatment means are significant at P = 0.05, 0.01, 0.001 level, respectively.
ns = Differences of treatment means are not significant at P = 0.05 level

Table 47 – Effect of nitrogen rates and cropping systems on land equivalent ratio (LER) during different seasons at Masii.

	Long rain 1988								Short rain 1988/89							
Cropping systems	N fertilizer kg/ha 0	25	50	100	Mean	F test	CV (%)	LSD 0.05	N fertilizer kg/ha 0	25	50	100	Mean	F test	CV (%)	LSD 0.05
MSC	1.00	1.00	1.00	1.00	1.00	ns	147	–	1.00	1.00	1.00	1.00	1.00	*a	28	0.535
ISNR	12.61	0.96	2.97	1.37	4.48				2.14	1.61	1.56	2.24	1.89			
ISRR	3.29	1.33	1.82	1.47	1.98				2.32	1.71	1.34	2.93	2.08			
IANR	3.73	1.66	3.39	0.89	2.42				2.35	1.39	1.40	1.88	1.76			
IARR	6.21	2.19	2.08	1.17	2.91				1.30	2.34	1.89	2.05	1.90			
Mean	5.37	1.43	2.25	1.18	2.56				1.82	1.61	1.44	2.02	1.72			
F test	ns								ns							
CV (%)	68								17							
Lsd 0.05	–								–							
	Long rain 1989								Short rain 1989/90							
MSC	1.00	1.00	1.00	1.00	1.00	ns	68	–	1.00	1.00	1.00	1.00	1.00	*a	91	1.98
ISNR	4.49	1.22	1.39	1.53	2.16				3.63	2.07	2.43	2.10	2.56			
ISRR	5.37	1.54	1.30	1.54	2.44				10.60	3.60	1.70	2.10	4.50			
IANR	5.20	1.66	1.22	1.37	2.36				5.73	1.27	1.17	1.57	2.44			
IARR	2.40	2.23	1.73	1.19	1.89				1.53	4.47	2.57	1.43	2.50			
Mean	3.69	1.53	1.33	1.33	1.97				4.50	2.48	1.77	1.64	2.60			
F test	ns								ns							
CV (%)	68								73							
LSD 0.05	–								–							

*, **, *** = Differences of treatment means are significant at P = 0.05, 0.01, 0.001 level, respectively.

ns = Differences of treatment means are not significant at P = 0.05 level

a = N x cropping systems interaction is significant at P = 0.05 level.

contained lower levels of soil nutrients, organic C and CEC than the latter site (Tables 51 and 52, Table 1).

Application of N fertilizer lowered LER values of the intercropping because N fertilizer increased the seed yield of sole crops more than that of the intercrops thus resulting in lower RY values. But, intercropping without N fertilization generally resulted in RY values higher than unity in maize and about unity in beans thus providing both intercrops with very high RY values. Since LER values were dependent on the RY values of the component crops the intercrops without N fertilization, therefore, provided higher LER values than those fertilized.

The higher LER values at 0 kg N/ha fertilizer level indicate greater advantage of maize-bean intercropping when little or no fertilizer is applied. Low or lack of fertilization of crops is a situation most common on small-scale farms of subsistence farmers and results here demonstrate the importance of intercropping in low-input agriculture since the highest advantages of mixtures are expressed in low-input agriculture. This trend of low LER values in intercropping systems where N fertilizer was applied, validates the belief that intercropping is less advantageous at higher soil fertility. This is not true because absolute seed yields were increased by N fertilizer and although the LER declined, the absolute value of the advantage, that is, total grain yield of intercrops was higher at higher N fertility levels (Table 43).

The effect of cropping systems on LER for all seasons at Kimutwa and Masii are shown in Tables 46 and 47. Orthogonal contrasts showed that LER values found in intercropping systems were significantly larger than those in monocultures in all seasons in Kimutwa and in two out of four seasons in Masii. The LER values averaged 1.59 and 1.51 in Kimutwa and 2.76 and 2.27 in Masii for intercrops in the same row and for those in alternate row, respectively (Tables 46 and 47). Hence, intercrops in the same row gave higher LER values than those in the alternate rows. The higher LER values obtained in intercrops sown in the same row may be attributed to greater RY values of both intercrops in Masii (Appendix Tables 25 and 26), and to intercropped beans alone in Kimutwa (Appendix Table 26). The RY values of maize in the same row and alternate row averaged 0.97 and 0.98 in Kimutwa and 1.78 and 1.34 in Masii, respectively. On the other hand, the RY of beans in the same row and alternate row averaged 0.70 and 0.56 in Kimutwa and 0.97 and 0.94 in Masii, respectively. These relative yields indicate that even where maize yields were depressed as in the case of Kimutwa, the seed yields of intercropped beans were able to overcompensate that reduced in maize and resulted in higher LER values compared to that of continuous sole maize. Also, the greater RYs than unity observed in Masii indicated that intercropping maize with beans here was a better practice than sole cropping it. Probably, intercropped maize was accruing some benefits from the bean in association. Several investigators reported substantial advantages from intercropping maize with soybeans (Ahmed and Rao, 1982), maize with cowpeas (Allen and Obura, 1983), and sorghum with soybeans (Osiru and Willey, 1972; Wahua and Miller, 1978).

Return of bean residue after harvest generally increased LER values of intercrops by 5 to 40% compared with treatments where bean residue was removed (Tables 46 and 47). This bean residue effect was not related to the mineral N status in the soil where residue was returned (Tables 51 and 52).

The greater productivity of intercrops represents greater resource use by the intercrops than either one of their sole crop. Intercrops were found to significantly take up more N, P, K, Mg and Ca than either continuous sole maize or beans. Intercrops planted in the same row took up more nutrients than those in alternate rows (Tables 26 through 32). The pattern of uptake of nutrients by the intercrops in different spatial arrangements corresponds well with the LER values. Thus, closer proximity of component crops like the one found in the same row intercropping suggested a possibility of close intermingling of root systems which might result in a greater exploitation of available nutrients. Other important factors reported that could have been responsible for higher productivity by the intercrops than the monocrops of component species were the more efficient use of light by the combined intercrop canopy (Trenbath, 1974, Willey, 1979, Marshall and Willey, 1983) and efficient use of water (Hulugalle and Lal,1986).

4.8 Effects of residual N fertilizer, and previous cropping systems on maize performance:

The study in which the effect of residual N fertilizer (CAN) applied from the long rains of 1987 to the short rains of 1989/90 on maize performance was investigated during the long rains of 1990. During the whole duration of this study, that is, six seasons in Kimutwa (LR 1987 to SR 1989/90) and five in Masii (SR 1987/88 to SR 1989/90), N fertilizer was applied at the rates of 0, 25, 50 and 100 kg N/ha to sole crops of maize and beans, maize and beans in rotation and intercropping systems. Bean residue was returned to half the number of plots under continuous sole beans, maize and beans in rotation and intercropping. But, single superphosphate at the rate of 40 kg P_2O_5/ha was applied uniformly to all plots.

During the final season, (SR 1989/90), soil chemical analysis, indicated that different N rates resulted in different amounts of residual mineral N (Tables 51 and 52). In Kimutwa, some differences in residual mineral N due to N fertilizer were significant (Table 51). The residual mineral N from the N rates of 0, 25, 50 and 100 kg N/ha were 8.1, 12.0, 12.9 and 21.5 ug N/g soil. The 0 kg N/ha had significantly lower mineral N than 25 and 50 kg N/ha which in turn had significantly lower N than 100 kg N/ha in Kimutwa. In Masii, the residual mineral N were 11.0, 17.7, 15.9 and 17.5 ug N/g soil. Thus, previous N fertilizer applications at the rate of 25, 50, and 100 kg N/ha gave 48, 59, and 165% higher residual mineral N than zero N treatments in Kimutwa and 62, 45, and 60% in Masii. In Kimutwa, there was a trend that the higher the level of N applied, the higher the residual soil mineral N was found (Tables 51 and 52).

Cropping systems had some influence on residual mineral N and their effect was found to be significant in Kimutwa (Table 51). The plots previously used for the same row intercrops had higher mineral N than plots used for alternate row intercrops by 31 and 13% at Kimutwa and Masii, respectively while continuous sole bean plots gave more mineral N than continuous sole maize plots by 14 and 7% in Kimutwa and Masii, respectively. The other cropping systems affected mineral N differently at the two sites. In Kimutwa, plots previously used for continuous sole beans had higher mineral N than rotation and intercropping plots by 37 and 30%, respectively, while continuous sole maize plots also measured greater mineral N than intercropping and rotation plots by 13 and 20%, respectively. In Masii, plots previously used for intercropping had greater residual mineral N than those of continuous sole maize and beans and rotation by 13, 4 and 6% respectively, while continuous sole maize had lower mineral N than the rotation plots by 9%.

Kimutwa site gave lower residual mineral N than Masii by 9% and this probably reflects the greater depletion of N through higher uptake by crops in Kimutwa than in Masii of 25% (Table 28). Also, with regard to cropping systems, there was a direct relationship between the N taken up by cropping systems and the residual N. There was a trend in Kimutwa which showed that the higher the N uptake by the crops the lower the mineral N at the end of season (Table 28 and Tables 51 and 52). However, in Masii there were positive and highly significant correlations between mineral N at the end of seasons and N taken up by crops in the seasons that followed (Table 54).

Where N fertilizer was applied, there was more extractable P and lower exchangeable K, Mg and Ca by 78, 11, 17 and 8% in Kimutwa while in Masii, except for Mg that was higher by 14%, the rest, that is, P, K, and Ca were lower than at zero N treatment by 18, 8 and 8%, respectively (Tables 51 and 52). The lower levels of exchangeable K, Mg and Ca where N fertilizer was applied could be as a result of leaching. Pearson et al. (1962) reported that surface liming with calcitic limestone followed by heavy application of residually acid nitrogen fertilizer caused leaching of calcium, magnesium and potassium to subsoils.

Return of bean residue to plots after the crop was harvested was found to lower residual mineral N by 9% in Kimutwa and by 10% in Masii (Tables 51 and 52 - SR 1989/90). Residue was also found not to improve the levels of extractable P or exchangeable K, Mg and Ca in the surface soil. Instead, extractable P was lowered by 7% in Kimutwa while in Masii, exchangeable Mg and Ca were lowered by 15 and 9%, respectively (Tables 51 and 52).

Residual mineral N in the soil was found not to have significant effect on maize total dry matter, stover weight, seed yield and uptake of nutrients, that is, N, P, K, Mg and Ca at both sites (Tables 48 and 49). However, there was a trend for residual mineral N to generally increase maize total dry matter by 6%, seed yield by 4.5 (90 kg/ha), uptake of N, P, K, and Mg by 8, 13, 2.6 and 2.6%, respectively in Kimutwa. In Masii, a similar trend occurred but with higher percentages since maize dry matter was increased by 27%, stover weight by 15%, seed yield by 64% (114 kg/ha), and uptake of N, P, K and Mg were improved by 41, 5.6, 32 and 32%, respectively. But, the uptake of Ca by maize was reduced by higher residual mineral N by 3% in Kimutwa and by 15% in Masii.

Irrespective of the previous N fertilizer rate, the previous cropping systems affected maize performance differently (Tables 48 and 49). The effect varied with sites and was significant for all the maize parameters measured at Kimutwa. In Kimutwa, the dry matter yields (DMY) of maize were significantly higher in plots previously used for continuous sole bean than those used for continuous sole maize by 43%; higher in plots previously used for intercropping than continuous sole maize by 25% and in the same row than in alternate row plots by 26%. Although not significantly different, the DMY of maize was higher in plots previously used for continuous sole beans than those used for rotation and intercropping by 32 and 14%, respectively, while rotation plots also had higher DMY than continuous sole maize plots by 8%. In Masii, the plots previously used for continuous sole bean plots had non-significantly more DMY of maize than continuous sole maize, rotation and intercropping plots by 33, 32 and 33%, respectively.

Maize stover weight from plots previously planted with continuous sole beans in Kimutwa was significantly higher than that from continuous sole maize, rotation and intercropping plots by 36, 35 and 21%. Plots previously under intercropping produced more stover weight than those of continuous sole maize by 13% with stover from the same row plots being significantly heavier by 28% than that from alternate row plots. In Masii, only plots previously under continuous sole beans produced non-significantly heavier maize stover than continuous sole maize, intercropping and rotation plots by 9, 10 and 8%, respectively.

Nutrient uptake by maize was significantly influenced by the previous cropping systems in Kimutwa but not in Masii. In Kimutwa, maize planted in plots previously used for the same row and alternate row intercrops, rotation and continuous sole beans took up more nutrients than that of previously under continuous sole maize plots by 34, 11, 11 and 42% for N; 56, 16, 22, and 40 for P; 32, 3, 3, and 39% for K; 28, 5, 1 and 28% for Mg and 30, 10, 11 and 54% for Ca, respectively. It is clear that plots previously used for the same row intercrops and continuous sole beans gave the greatest residual effect on nutrient uptake compared to rotation and alternate row plots.

Effect of previous cropping systems on the uptake of nutrients by maize in Masii was different from that in Kimutwa. The plots previously used for the same row and alternate row intercrops and rotation resulted in lower uptake of nutrients by maize than that grown in the previous continuous sole maize plots by 34, 19 and 24% for N; 22, 5 and 2% for K and 30, 13 and 9% for Mg but P uptake was higher by 23, 41 and 18%, respectively. Maize planted in plots which had previously been used for continuous sole beans was found to take up more N, P and K than that from continuous sole maize plots by 3, 55 and 16%, respectively, while uptake of Mg was lower by 4%. Maize planted in the same row and alternate row plots had lower uptake of Ca than that planted in the continuous sole maize plots by 25 and 6%, respectively while uptake in rotation plots was higher by 3%.

Bean residue returned had different effects on the uptake of nutrients by maize since it increased uptake of N, P, K, Mg and Ca in Kimutwa by 10, 8, 13 and 18%, respectively and decreased it by 19, 19, 5, 15, and 8%, in Masii, respectively. This implied that the contribution of bean residue to maize production was not uniform across the sites.

With regard to seed yields of maize in Kimutwa, the yield obtained from plots which were previously used for same row intercrops were significantly higher than those from continuous sole maize and alternate row plots by 52 and 26%, respectively. Also, yields from plots previously used for continuous sole beans were significantly higher than those from continuous sole maize plots by 52%. In Masii, seed yield from continuous sole beans plots was higher than that from continuous sole maize, rotation and intercropping plots by 28, 88 and 83%, respectively. Unlike in Kimutwa, the seed yield of maize in Masii from previous

Table 48 – Residual effect of N fertilizer and the influence of the previous cropping systems on maize yield and nutrient uptake at Kimutwa – LR 1990.

Previous treatment	Dry matter yields	Stover weight	Seed yield	Nutrient uptake (seed + stover)				
				N	P	K	Mg	Ca
Fertilizer	kg/ha							
0 kg N/h	3776	1766	2010	44.1	3.0	32.9	8.2	7.8
25 " "	3873	1782	2091	45.7	3.3	32.7	8.2	8.4
50 " "	3843	1764	2079	46.3	3.6	32.3	8.0	6.6
100 " "	3983	1854	2129	51.1	3.2	36.4	9.0	7.7
Mean	3868	1792	2079	46.8	3.3	33.6	8.3	7.6
F test	ns	ns	ns	ns	ns	ns	ns	ns
CV (%)	12	12	12	13	23	8	13	11
LSD 0.05	–	–	–	– –	–	–	–	–
Cropping systems								
MSC	3162	1583	1579	38.5	2.5	28.7	7.4	6.2
ISNR	3736	1658	2078	42.7	3.4	31.9	8.0	6.7
ISRR	5067	2344	2723	60.4	4.4	43.8	10.9	9.4
IANR	3367	1541	1826	40.8	2.9	28.2	7.0	6.3
IARR	3557	1585	1972	44.3	2.9	30.8	7.8	7.3
Rot-NR	3608	1630	1978	45.9	3.3	32.1	7.5	7.5
Rot-RR	3311	1558	1753	39.5	2.8	27.2	7.5	6.2
BSCNR	4346	2069	2277	51.4	3.1	39.4	9.1	8.2
BSCRR	4667	2159	2508	57.6	3.9	40.3	9.9	10.9
Mean	3868	1792	2076	46.8	3.3	33.6	8.3	7.6
F test	**	***	**	**	*	**	*	**
CV (%)	31	31	35	31	39	32	34	41
LSD 0.05	1005	469	603	12	1.1	9.0	2.3	2.6

*, **, *** = Treatment differences are significant at P = 0.05, 0.01, 0.001 level.
ns = Treatment differences are not significant at P = 0.05 level.

Table 49 – Residual effect of N fertilizer and the influence of the previous cropping systems on maize yield and nutrient uptake at Masii – LR 1990.

Previous treatment	Dry matter yields	Stover weight	Seed yield	Nutrient uptake (seed + stover)				
				N	P	K	Mg	Ca
Fertilizer				kg/ha				
0 kg N/ha	623	445	178	5.7	1.4	5.7	0.61	1.9
25 " "	707	477	230	7.0	1.1	6.9	0.70	1.5
50 " "	1007	632	375	10.0	1.7	9.8	1.05	2.0
100 " "	694	423	271	7.1	1.6	6.0	0.67	1.7
Mean	758	494	264	7.4	1.4	7.1	0.76	1.7
F test	ns	ns	ns	ns	ns	ns	ns	ns
CV (%)	44	45	57	50	53	53	57	47
LSD 0.05	–	–	–	–		–	–	–
Cropping systems								
MSC	796	488	308	8.9	1.1	7.1	0.85	1.8
ISNR	733	486	247	7.1	1.5	6.4	0.70	1.5
ISRR	520	359	161	4.6	1.2	4.7	0.49	1.2
IANR	694	442	252	6.9	1.5	6.2	0.65	1.6
IARR	833	633	200	7.5	1.6	8.7	0.83	2.2
Rot-NR	806	526	280	8.1	1.5	7.7	0.91	2.2
Rot-RR	595	456	139	5.5	1.1	6.8	0.64	1.5
BSCNR	1005	573	432	9.9	1.9	8.9	0.96	1.9
BSCRR	840	487	353	8.4	1.5	7.5	0.80	1.7
Mean	758	494	264	7.4	1.4	7.1	0.76	1.7
F test	ns	ns	ns	ns	ns	ns	ns	ns
CV (%)	64	51	117	78	63	59	72	60
LSD 0.05	–	–	–	–	–	–	–	–

ns = Treatment differences are not significant at 0.05 level continuous sole maize plots was greater than that from intercropping and rotation plots by 43 and 47%, respectively. Also, the previous same row plots gave lower seed yields than alternate row plots by 11%.

Return of bean residue to plots showed different effects on maize performance at the two sites. It increased DMY, stover weight and seed yield by 10, 11 and 10% in Kimutwa and decreased the same parameters in Masii by 14, 5 and 30%, respectively. This effect of bean residue on maize seed yield at the two sites was directly related to that of nutrient uptake, that is, it increased uptake in Kimutwa and decreased it in Masii.

Correlation analysis was performed to study relationships between maize parameters, that is, seed yield, stover weight, dry matter, N uptake and soil chemical properties measured in the soil taken at the end of the previous season of short rains 1989/90, that is, prior to planting the test maize crop during the long rains of 1990 (Tables 50).

Soil mineral N at the beginning of the season (LR 1990) did not have significant relationships with maize parameters in Kimutwa (Table 50). However, in Masii, soil mineral N was found to have positive relationship and highly significant correlations with maize seed yield ($r = 0.247^{**}$), stover weight ($r = 0.218^{**}$), DMY ($r= 0.267^{**}$) and N uptake ($r = 0.270^{**}$) (Table 50). Hence, residual mineral N was more important in Masii with the sandy soil than in Kimutwa with sandy clay loam.

When soil tests other than mineral N of the previous season at Kimutwa were considered, maize seed yield and N uptake were positively and significantly correlated with organic carbon (Table 50). But soil pH and exchangeable Mg had negative and non-significant correlations with seed yield, stover weight, DMY and N uptake. In Masii, the relationship between extractable P and maize parameters were negative and non-significantly correlated while only

Table 50 – Correlation coefficients (r) between seed yield, stover weight, dry matter yield and N uptake (kg/ha) by maize measured during the LR 1990 and soil chemical properties of the previous season, SR 1989/90.

Previous season soil test	Kimutwa				Masii			
	Seed Yield	Stover Weight	Dry matter yields	Nitrogen uptake	Seed Yield	Stover weight	Dry matter yields	Nitrogen uptake
Soil pH (0.01 M $CaCl_2$)	– 0.046 ns	– 0.053 ns	– 0.060 ns	– 0.141 ns	0.385 ***	0.381 ***	0.425 ***	0.384 ***
Ogranic C (%)	0.224*	0.028 ns	0.149 ns	0.193 *	0.408 ***	0.407 ***	0.454 ***	0.436 ***
Mineral N (ug/g soil)	0.120 ns	0.148 ns	0.141 ns	0.187 ns	0.247 **	0.218 *	0.267 **	0.270 **
AL–method extractable P (mg/100 g)	0.108 ns	0.044 ns	0.083 ns	0.102 ns	–0.046 ns	–0.045 ns	–0.051 ns	–0.079 ns
AL–method Exchangeable (mg/100 g)								
K	0.156 ns	0.088 ns	0.140 ns	0.103 ns	0.203 *	0.088 ns	0.174 ns	0.178 ns
Mg	– 0.026 ns	– 0.019 ns	– 0.047 ns	– 0.119 ns	0.622***	0.478 ***	0.624 ***	0.612 **
Ca	0.191 ns	0.062 ns	0.132 ns	0.104 ns	0.382 ***	0.199 *	0.339 ***	0.325 ***

*, **, *** = Correlations between variables are significant at P = 0.05, 0.01, and 0.001 level.
ns = Correlations between variables are not significant at P = 0.05 level.

the relationship between exchangeable K was positive and significantly correlated with maize parameters. Other soil tests, that is, soil pH, organic C, mineral N, exchangeable Mg and Ca had positive relationships and significant correlation with maize seed yield, stover weight, DMY and nitrogen uptake in Masii. These observations seem to indicate that high organic carbon at both sites was important for maize seed yield and N uptake. On the other hand, results in Masii implied that better maize performance occurred in soil with high soil pH, organic matter content, mineral N, exchangeable K, Mg and Ca. The results of this study tally well with the findings of Sparovek (1990) who reported that at 0-20 cm soil depth, the most important edaphic factors which influenced the productivity of maize were levels of organic matter and magnesium.

4.9 Effects of N fertilizer and maize-bean cropping systems on soil chemical properties:

Under long term continuous cropping, the soil productivity has been reported to decline due to the lowering of humus content followed by reduced nutrient availability in savanna soils (Nye and Greenland, 1960). This decline in nutrients availability has been attributed to nutrient removals by harvested plants. The magnitude of nutrients depleted vary considerably between crop species and depends largely on the harvested organ and yield level of the crop. Hence, the aim of doing soil analysis in this study was to evaluate how different cropping systems under different N fertilizer management would affect soil chemical properties that lead to soil productivity.

4.9.1 Soil pH:

Continuous cultivation of maize and beans in different cropping systems without application of calcium ammonium nitrate (CAN) as source of N, but with an application of single superphosphate (40 kg P_2O_5/ha) was found to alter soil pH relative to that of initial surface soil, that is, pH 5.59 and 5.77 for soils from Kimutwa and Masii, respectively (Table 1). In Kimutwa, the soil pH was lowered by 0.26, 0.46 and 0.42 units during the first, third and sixth seasons and was also raised by 0.05 and 0.11 units during the fourth and fifth seasons (Table 51). In Masii, the lowering of soil pH due to use of single suprphosphate alone occurred in all seasons. The decline averaged 0.86 units (from pH 5.77 to pH 4.90), that is, 1.05, 1.19, 0.45, 0.55 and 1.05 units in the 1st, 2nd, 3rd, 4th and 5th season, respectively (Table 52). The pH decline was probably brought about by the applied single superphosphate fertilizer although it has equivalent acidity of zero. This is because the fertilizer contains sulfur (10-13%) (Ombwara, 1972) which might have reacted with soil to form sulfuric acid thus lowering soil pH (Brady, 1990). The difference in pH decline at the two sites could be attributed to the soil types since sandy soil of Masii was less buffered as it had a lower CEC of 6.25 me/100 g compared with 17.5 me/100 g of the sandy clay loam of Kimutwa (Tables 51 and 52).

Nitrogen fertilizer lowered soil pH further and the higher the N rate the greater was the pH decline (Tables 51 and 52). The decline in soil pH due to N fertilizer was between 0.05 and 0.87 units in Kimutwa and between 0.41 and 1.47 units in Masii relative to initial soil pH. Comparison of the effects of N rates on soil pH showed significant differences in one season out of five in Masii and in four seasons out of five in Kimutwa. In Kimutwa, the application of 100 kg N/ha fertilizer resulted in significantly lower soil pH than that obtained at 25 and 50 kg N/ha which in turn were generally and significantly lower than that observed in zero N treatments. This trend was observed also in Masii during the short rains of 1989/90. When the effects of N fertilizer on soil pH were not significantly different in Masii, the soil pH corresponding to 100 kg N/ha was always lower than that for 0 kg N/ha by 0.02 to 0.37 units. The decline in soil

Table 51 – Effect of N rates and cropping systems on soil chemical properties at the end of seasons in Kimutwa.

LR 1987 : End of 1st season (prior to planting LR 1988)

Season treatment	Soil pH	Organic C	Total N	Exch. N Nitrate	Exch. N Amm.	Mineral N	Extrac. P	Exch. K	Exch. Mg	Exch. Ca
		%	%	------	ug/g	------	------	mg/100	g------	------
0 kg N/ha	5.33	0.86	0.113	–	–	38.4	0.33	30.5	34.5	120.7
25 " "	5.27	0.89	0.112	–	–	43.3	0.36	34.4	33.8	119.3
50 " "	5.29	0.85	0.113	–	–	45.0	0.29	29.1	32.8	118.3
100 " "	5.25	0.91	0.111	–	–	60.0	0.48	31.3	32.0	105.7
Mean	5.29	0.88	0.112	–	–	46.7	0.36	31.3	33.3	116.0
LSD 0.05	–	–	–	–	–	–	–	–	–	–
MSC	5.28	0.86	0.109	–	–	50.1	0.29	28.2	32.6	117.1
MBISR	5.29	0.88	0.115	–	–	42.5	0.38	31.0	33.1	119.0
MBIAR	5.27	0.87	0.116	–	–	47.1	0.42	30.1	34.3	113.2
BSC	5.29	0.88	0.113	–	–	47.7	0.34	32.9	33.0	115.6
Mean	5.29	0.88	0.112	–	–	46.7	0.36	31.3	33.3	116.0
LSD 0.05	–	–	– a	–	–	–	–	– a	–	–
LR 1988 : End of 3rd season (prior to planting SR 1988/89)										
0 kg N/ha	5.13	0.90	0.105	14.9	13.1	27.9	0.49	37.1	28.1	60.7
25 " "	4.99	0.91	0.109	16.4	15.9	32.5	0.60	41.4	24.0	67.7
50 " "	5.01	0.91	0.106	15.9	15.8	31.7	0.47	39.5	26.3	55.5
100 " "	4.72	0.97	0.111	25.7	21.1	46.8	1.00	32.5	19.7	54.3
Mean	4.96	0.92	0.108	18.2	16.5	34.7	0.64	37.6	24.5	59.6
F test	**	ns	ns	**	ns	*	ns	ns	ns	ns
LSD 0.05	0.15	–	–	3.7	–	9.4	–	–	–	–
MSC	4.96	0.89	0.105	15.6	16.2	31.8	0.57	34.9	25.4	60.9
MBISNR	5.00	0.95	0.111	15.4	14.5	29.9	0.76	39.3	24.1	62.4
MBISRR	4.94	0.90	0.104	16.4	18.4	34.8	0.69	36.4	24.3	61.7
MBIANR	4.94	0.94	0.111	14.9	16.2	31.4	0.38	38.6	25.1	61.7
MBIARR	5.11	0.92	0.116	14.6	15.4	30.1	0.59	37.2	24.5	57.6
Rot-BNR	4.97	0.95	0.104	21.9	15.4	37.7	0.80	40.2	24.2	62.5
Rot-BRR	4.96	0.92	0.107	22.1	18.6	40.6	0.49	38.6	22.5	51.8
BSCNR	4.93	0.91	0.105	19.9	15.3	34.8	0.60	37.8	27.7	60.3
BSCRR	4.84	0.94	0.108	23.1	18.3	41.4	0.87	35.8	22.9	57.2
Mean	4.96	0.92	ns	18.3	16.5	34.7	0.64	37.6	24.5	59.6
F test	ns	ns	–	*** c	ns	** b	ns	ns	ns	ns
LSD 0.05	–	–		3.6	–	7.3	–	–	–	–

*, **, *** = Treatment differences are significant at P = 0.05, 0.01, 0.001 level, respectively. respectively.

ns = Treatment differences are not significant at P = 0.05 level.

a, b, c = N x cropping systems interaction is significant at P = 0.05, 0.01, 0.001 level, respectively.

Table 51 – cont. Kimutwa.

SR 1988/89 : End of 4th season (prior to planting LR 1989) at Kimutwa.

Season treatment	Soil pH	Organic C	Total N	Exch. N Nitrate	Exch. N Ammon.	Mineral N	Extrac. P	Exch. K	Exch. Mg	Exch. Ca
		%	%	------	ug/g	------	-----	mg/100 g	----	------
0 kg N/ha	5.64	0.84	0.13	10.6	9.0	19.7	6.1	44.4	31.2	101.3
25 " "	5.54	0.85	0.13	11.6	8.8	20.1	4.2	43.5	27.1	101.4
50 " "	5.48	0.85	0.12	10.8	8.6	19.4	5.1	39.7	25.7	91.0
100 " "	5.26	0.87	0.14	14.1	8.6	22.7	3.7	36.6	19.9	75.8
Mean	5.48	0.85	0.13	11.8	8.7	20.5	4.8	41.0	26.0	92.4
F test	***	ns	ns	ns	ns	ns	ns	ns	*	ns
LSD 0.05	0.06	–	–	–	–	–	–	–	4.8	–
MSC	5.49	0.83	0.12	9.6	8.4	18.0	6.2	38.1	25.6	101.7
M-BISNR	5.52	0.86	0.14	11.7	9.0	20.8	5.1	41.1	23.3	95.6
M-BISRR	5.51	0.85	0.14	13.5	8.2	21.7	4.8	40.6	26.1	94.8
M-BIANR	5.49	0.85	0.13	10.7	8.6	19.3	4.7	41.2	27.5	88.9
M-BIARR	5.53	0.86	0.12	9.3	9.1	18.4	4.8	42.5	24.8	85.8
Rot-MNR	5.47	0.88	0.13	10.7	9.1	19.7	5.0	42.0	27.3	95.6
Rot-MRR	5.43	0.85	0.14	9.1	8.7	17.7	4.1	41.8	26.9	94.2
BSCNR	5.51	0.82	0.13	15.6	8.7	24.2	3.9	42.8	25.7	86.2
BSCRR	5.35	0.86	0.13	16.1	8.8	24.2	4.4	39.3	26.7	88.6
Mean	5.48	0.85	0.13	11.8	8.7	20.5	4.8	41.0	26.0	92.4
F test	ns	ns	*	**	ns	**	ns	ns	ns	*
LSD 0.05	–	–	0.01	3.9	–	4.2	–	–	–	9.6
LR 1989 : End of 5th season (prior to planting SR 1989/90)										
0 kg N/ha	5.70	0.89	0.11	3.5	3.2	6.6	1.2	36.0	31.7	76.6
25 " "	5.48	0.90	0.11	8.1	4.8	12.7	3.0	34.7	30.8	86.7
50 " "	5.40	0.85	0.11	7.7	4.4	12.0	1.1	32.4	30.4	86.0
100 " "	5.07	1.04	0.11	21.2	17.7	38.5	2.1	33.2	27.9	72.1
Mean	5.41	0.92	0.11	10.1	7.5	17.5	1.9	34.1	30.2	80.4
F test	***	ns	ns	***	***	***	ns	ns	ns	ns
LSD 0.05	0.09	–	–	2.2	2.7	1.6	–	–	–	–
MSC	5.37	0.91	0.11	12.4	12.3	24.7	1.2	32.9	30.1	83.7
M-BISNR	5.45	0.94	0.11	11.3	7.6	18.8	2.4	32.0	29.3	76.3
M-BISRR	5.40	0.90	0.11	9.4	5.2	14.6	1.1	31.6	30.1	81.8
M-BIANR	5.43	0.95	0.11	11.5	6.8	18.3	0.8	34.5	31.3	81.5
M-BIARR	5.44	0.92	0.11	8.6	6.4	14.9	1.4	36.5	31.7	79.7
Rot-BNR	5.49	1.00	0.11	8.6	6.3	15.6	3.5	37.6	29.8	87.1
Rot-BRR	5.40	0.92	0.11	9.4	5.7	14.3	1.4	35.2	30.3	77.2
BSCNR	5.41	0.86	0.11	9.5	9.2	17.7	3.6	33.3	29.8	77.0
BSCRR	5.34	0.89	0.11		8.0	18.3	1.5	33.0	29.2	78.9
Mean	5.41	0.92	0.11	10.1	7.5	17.5	1.9	34.1	30.2	80.4
F test	ns	ns	ns	ns	ns	ns	*	ns	ns	ns
LSD 0.05	–	–	–	–	–	–	2.0	–	–	–

*, **, *** = Treatment differences are significant at P = 0.05, 0.01, 0.001 level, respectively.

ns = Treatment differences are not significant at P = 0.05 level.

Table 51 Cont.

SR 1989/90 : End of 6th season (prior to planting LR 1990) at Kimutwa.

Season treatment	Soil pH	Organic C	Total N	Exch. N Nitrate	Exch. N Ammon.	Mineral N	Extrac. P	Exch. K	Exch. Mg	Exch. Ca	C E C
		%	%	------- ug/g		--------	------- mg/100		g ----	------	me/100 g
0 kg N/ha	5.17	0.93	0.10	4.7	3.4	8.1	1.1	32.1	23.0	89.5	21.2
25 " "	5.06	0.93	0.12	7.9	4.1	12.0	1.6	31.0	21.2	96.6	19.5
50 " "	4.90	0.94	0.10	8.2	4.7	12.9	1.8	31.1	20.8	96.0	16.0
100 " "	4.65	0.97	0.09	16.8	5.2	21.5	2.5	24.2	15.1	82.1	17.8
Mean	4.94	0.94	0.10	9.4	4.4	13.6	1.7	29.6	20.0	91.1	18.6
F test	***	ns	ns	***	ns	***	*	ns	ns	ns	–
LSD 0.05	0.07	–	–	2.5	–	2.7	0.65	–	–	–	–
MSC	4.95	0.94	0.09	9.5	4.9	14.4	1.7	29.1	19.9	91.5	19.2
M-BISNR	4.89	0.98	0.09	11.1	4.3	15.3	2.4	27.9	19.1	90.4	19.9
M-BISRR	4.97	0.93	0.10	8.4	5.2	13.6	1.5	28.9	20.2	90.4	18.8
M-BIANR	4.97	0.95	0.16	7.1	5.1	12.2	0.9	29.8	21.5	90.0	18.1
M-BIARR	5.00	0.94	0.09	6.0	3.9	9.9	1.0	29.8	21.1	88.8	20.6
Rot-MNR	4.99	0.96	0.10	10.1	3.9	13.0	2.2	29.8	20.0	99.0	17.5
Rot-MRR	5.00	0.92	0.10	7.7	3.7	11.0	1.4	30.0	20.9	91.5	17.5
BSCNR	5.89	0.92	0.10	12.0	4.0	16.1	1.7	30.2	19.4	89.4	17.5
BSCRR	4.84	0.94	0.10	12.5	4.3	16.9	2.8	30.7	18.2	88.6	18.5
Mean	4.94	0.94	0.10	9.4	4.4	13.6	1.7	29.6	20.0	91.1	18.6
F test	ns	ns	ns	**	ns	*	ns	ns	ns	ns	–
LSD 0.05	–	–	–	3.8	–	4.4	–	–	–	–	–
Means of all seasons	5.22	0.90	0.112	12.4	9.3	26.6	1.88	34.7	26.8	87.9	18.6

*, **, *** = Treatment differences are significant at P = 0.05, 0.01, 0.001 level, respectively.
ns = Treatment differences are not significant at P = 0.05 level.

Table 52 – Effect of N rates and cropping systems on soil chemical properties at the end of seasons at Masii.

SR 1987/88 : End of 1st season (prior to planting LR 1988)

Season treatment	Soil pH	Organic C	Total N	Exch. N Nitrate	Exch. N Ammo.	Mineral N	Extrac. P	Exch. K	Exch. Mg	Exch. Ca
		%	%	——	ug/g	——	——	mg/100	g ——	——
0 kg N/ha	4.72	0.56	0.07	–	–	14.0	3.4	13.9	2.4	24.3
25 " "	4.95	0.65	0.08	–	–	21.3	3.3	17.1	3.5	29.0
50 " "	4.96	0.63	0.08	–	–	25.4	2.8	16.5	3.7	31.2
100 " "	4.70	0.76	0.08	–	–	27.2	2.3	12.8	2.3	24.0
Mean	4.83	0.65	0.08	–	–	22.0	2.7	15.1	3.0	27.1
LSD 0.05	–	–	–	–	–	–	–	–	–	–
MSC	4.67	0.61	0.08	–	–	20.1	2.0	14.7	2.7	22.3
MBISR	4.84	0.62	0.08	–	–	18.8	2.6	15.1	2.8	26.0
MBIAR	4.83	0.61	0.08	–	–	26.8	2.8	14.3	2.8	29.4
BSC	4.87	0.70	0.08	–	–	21.7	2.9	15.5	3.2	27.8
Mean	4.83	0.65	0.08	–	–	22.0	2.7	15.1	3.0	27.1
F test	ns	ns	ns	–	–	**	ns	ns	ns	ns
LSD 0.05	–	–	–	–	–	6.6	–	–	–	–
LR 1988 : End of 2nd season (prior to planting SR 1988/89)										
0 kg N/ha	4.58	0.61	0.07	16.6	11.5	27.9	1.2	8.8	3.1	27.7
25 " "	4.67	0.69	0.08	17.0	9.4	26.5	1.6	9.3	4.3	30.0
50 " "	4.61	0.65	0.13	21.1	9.8	30.9	0.8	8.0	4.5	33.1
100 " "	4.30	0.61	0.11	23.3	12.7	36.0	0.7	7.9	2.6	21.0
Mean	4.54	0.64	0.10	19.5	10.9	30.3	1.1	8.5	3.6	28.0
F test	ns	ns	ns	**	ns	ns	ns	ns	ns	ns
LSD 0.05	–	–	–	2.7	–	5.9	–	–	–	–
MSC	4.55	0.62	0.13	19.1	10.7	29.9	1.4	9.3	3.0	27.8
M-BISNR	4.71	0.66	0.09	18.3	9.9	28.2	1.0	9.8	4.5	34.2
M-BISRR	4.48	0.61	0.07	21.0	10.7	31.6	1.2	7.7	3.4	24.9
M-BIANR	4.48	0.62	0.07	17.6	11.2	28.8	0.4	8.2	2.9	24.5
M-BIARR	4.54	0.68	0.09	21.7	11.6	33.4	0.8	10.1	4.3	30.7
Rot-BNR	4.51	0.66	0.08	18.7	10.5	28.9	1.2	8.9	4.3	28.4
Rot-BRR	4.49	0.63	0.08	20.9	11.3	32.3	1.2	7.1	2.9	27.2
BSCNR	4.62	0.65	0.13	18.6	10.6	29.3	1.7	8.4	3.7	29.4
BSCRR	4.47	0.64	0.14	19.5	11.3	30.7	0.9	7.1	3.6	24.8
Mean	4.54	0.64	0.10	19.5	10.9	30.3	1.1	8.5	3.6	28.0
F test	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
LSD 0.05	–	–	–	–	–	–	–	–	–	–

*, **, *** = Treatment differences are significant at P = 0.05, 0.01, 0.001 level

ns = Treatment differences are not significant at P = 0.05 level

Table 52 – Cont. Masii

SR 1988/89 : End of 3rd season (prior to planting LR 1989) at Masii.

Season treatment	Soil pH	Organic C	Total N	Exch. N Nitrate	Exch. N Ammo.	Mineral N	Extrac. P	Exch. K	Exch. Mg	Exch. Ca
		%	%	------	ug/g	------	------	mg/100	g ----	------
0 kg N/ha	5.32	0.41	0.05	6.8	10.0	16.7	3.4	8.8	2.3	32.2
25 " "	5.36	0.49	0.05	7.5	10.4	18.0	4.0	8.7	3.4	40.2
50 " "	5.33	0.45	0.06	7.4	10.4	17.8	3.3	8.6	2.9	38.1
100 " "	5.09	0.45	0.05	6.9	9.3	16.4	3.0	8.8	2.2	24.6
Mean	5.28	0.45	0.05	7.2	10.0	17.2	3.4	8.7	2.7	33.8
F test	ns	ns	ns	ns	ns	ns	ns	ns	ns	*
LSD 0.05	–	–	–	–	–	–	–	–	–	6.8
MSC	5.24	0.45	0.05	8.1	9.8	17.9	3.1	6.7	2.2	30.3
M-BISNR	5.47	0.46	0.05	7.0	10.6	17.6	3.9	8.2	3.4	38.3
M-BISRR	5.24	0.42	0.05	6.7	9.7	16.7	4.3	9.6	2.3	33.3
M-BIANR	5.21	0.43	0.05	7.5	10.1	17.5	2.9	8.0	2.5	30.7
M-BIARR	5.30	0.47	0.06	7.3	9.8	17.1	2.2	9.4	3.4	33.9
Rot-MNR	5.38	0.46	0.06	7.3	10.3	17.7	3.4	8.3	2.9	36.6
Rot-MRR	5.23	0.45	0.05	7.2	10.2	17.4	3.8	9.9	2.5	32.5
BSCNR	5.30	0.45	0.06	6.9	10.4	17.3	3.5	9.8	2.8	37.4
BSCRR	5.14	0.46	0.06	6.4	9.4	15.8	3.7	8.7	2.3	31.2
Mean	5.28	0.45	0.05	7.2	10.0	17.2	3.4	8.7	2.7	33.8
F test	ns	ns	ns	*	ns	ns	*	ns	ns	ns
LSD 0.05	–	–	–	0.6	–	–	1.1	–	–	–
LR 1989 : End of 4th season (prior to planting SR 1989/90)										
0 kg N/ha	5.22	0.47	0.06	2.6	3.9	6.5	1.3	10.5	3.2	23.1
25 " "	5.23	0.53	0.07	3.1	3.7	6.8	1.6	13.7	4.1	34.7
50 " "	5.22	0.51	0.07	4.6	4.3	8.8	1.3	16.4	4.9	36.7
100 " "	5.00	0.64	0.06	6.6	11.9	18.5	1.1	13.3	2.6	24.4
Mean	5.17	0.54	0.07	4.2	5.9	10.1	1.4	13.5	3.7	29.7
F-test	ns	ns	ns	**	*	*	ns	ns	**	ns
LSD 0.05	–	–	–	1.7	4.5	5.9	–	–	0.8	–
MSC	5.11	0.76	0.06	3.6	4.9	8.4	1.3	12.0	3.1	25.0
M-BISNR	5.29	0.53	0.07	4.2	4.3	8.4	1.2	13.9	4.3	30.8
M-BISRR	5.02	0.48	0.06	5.0	6.4	11.4	1.4	11.6	2.5	24.7
M-BIANR	5.12	0.51	0.07	3.3	4.3	7.5	1.0	12.9	3.3	25.3
M-BIARR	5.29	0.55	0.07	4.6	6.6	11.2	1.1	14.8	4.6	29.0
Rot-BNR	5.27	0.50	0.07	4.4	4.5	8.9	1.6	14.6	4.2	31.5
Rot-BRR	5.14	0.48	0.06	3.8	7.9	11.5	1.4	11.8	2.9	26.3
BSCNR	5.23	0.52	0.07	4.2	9.3	13.5	1.7	17.4	5.1	37.4
BSCRR	5.07	0.51	0.07	5.0	5.5	10.5	1.2	12.4	3.4	27.7
Mean	5.17	0.54	0.07	4.2	5.9	10.1	1.4	13.5	3.7	29.7
F test	ns	ns	*	ns	ns	ns	ns	ns	ns	*
LSD 0.05	–	–	0.005	–	–	–	–	–	–	10.4

*, ** = Treatment differences are significant at P = 0.05 and 0.01 level, respectively.

Table 52 Cont.

SR 1989/90 : End of 5th season (prior to planting LR 1990) at Masii.

Season treatment	Soil pH	Organic C	Total N	Exch. N Nitrate	Exch. N Ammo.	Mineral N	Extrac. P	Exch. K	Exch. Mg	Exch. Ca	C E C
		%	%	----	ug/g	--------	------	mg/100	g	----------	me/100g
0 kg N/ha	4.72	0.64	0.08	5.3	5.7	11.0	2.8	11.3	1.7	25.8	8.0
25 " "	4.71	0.75	0.08	9.9	7.8	17.7	2.8	11.3	2.2	25.0	5.1
50 " "	4.66	0.76	0.09	8.6	7.3	15.9	2.1	10.9	2.6	25.4	4.7
100 " "	4.35	0.67	0.08	10.1	7.5	17.5	2.0	8.3	1.0	20.3	5.6
Mean	4.61	0.71	0.08	8.5	7.1	15.5	2.4	10.5	1.8	24.1	5.8
F test	**	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
LSD 0.05	0.19	–	–	–	–	–	–	–	1.1	–	–
MSC	4.48	0.69	0.08	7.4	6.9	14.2	2.7	9.8	1.4	23.1	4.8
M-BISNR	4.62	0.72	0.08	10.1	8.5	18.8	2.5	10.6	1.9	23.8	5.1
M-BISRR	4.59	0.68	0.08	8.4	7.0	15.4	3.5	9.0	1.5	24.2	5.8
M-BIANR	4.64	0.67	0.08	7.6	6.7	14.3	2.1	10.7	1.8	26.3	5.3
M-BIARR	4.71	0.71	0.08	8.7	7.2	15.9	1.8	11.1	2.1	24.8	4.9
Rot-MNR	4.62	0.77	0.08	9.8	7.6	17.4	2.5	9.9	2.0	24.4	5.3
Rot-MRR	4.59	0.70	0.09	7.5	6.2	13.7	1.9	10.3	1.8	22.8	6.4
BSCNR	4.67	0.70	0.08	8.7	7.1	15.6	2.5	10.5	2.5	26.8	7.8
BSCRR	4.56	0.71	0.08	8.1	6.6	14.7	2.4	12.1	1.6	20.9	7.3
Mean	4.61	0.71	0.08	8.5	7.1	15.5	2.4	10.5	1.8	24.1	5.8
F test	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
LSD 0.05	–	–	–	–	–	–	–	–	–	–	–
means of all seasons	4.89	0.60	0.08	9.9	8.5	19.0	2.2	7.9	3.0	28.6	5.8

** = Treatment differences are significant at P = 0.01 level.
ns = Treatment differences are not significant at P = 0.05 level.

acidity was ascribed to the CAN. This is because, the composition of CAN include nitrate and ammonium and when the latter component undergoes nitrification, hydrogen ions are released into the soil; also the leaching of calcium applied in CAN would be replaced by hydrogen ions (Tisdale et al., 1985) and thus result in lowering the soil pH.

The relationships between surface soil pH and other chemical properties, total N uptake (TNU) and total grain yield (TGY) are given in Tables 53 and 54. Soil pH at both sites had positive relationships and significant correlations with exchangeable K, Mg and Ca. However, soil pH was found to have negative relationships and non-significantly correlated with TNU and TGY in Kimutwa while in Masii, the relationship between these two parameters was positive and significantly correlated with the soil pH. In Masii, there were some positive relationships and significant correlations between soil pH and both organic C and extractable P (AL- method). But, the relationships between soil pH and both soil total N and mineral N were positively correlated in three and two seasons each out of four, respectively, whereas in the other seasons the relationships were negatively correlated. In Kimutwa, soil pH was negatively correlated with organic C and mineral N. These observations seemed to imply that the mineral N and organic C, N uptake and total grain yield of cropping systems were reduced at high soil pH levels in Kimutwa. However, exchangeable K, Mg and Ca at both sites, organic C, extractable P, N uptake and total grain yield in Masii were higher at higher soil pH than at lower pH levels. The positive relationships between soil pH and both N uptake and total grain yields of maize and beans in Masii seemed to indicate that with respect to sand soil, the soil pH of between 4.48 and 5.28 was not favourable and that, performance of these two crop species would improve at higher soil pH. Optimum pH for Phaseolus bean is about 6.0 to 7.5 on semi-arid to arid regions (Boswell and Cooke, 1958) while the critical pH value for maize was reported to

Table 53 – Correlation coefficients (r) between end of season (prior to planting the next season) soil chemical properties and total N uptake (TNU, kg / ha) and total grain yield (TGY, kg / ha) of the succeeding cropping systems at Kimutwa.

	Long rain 1987									Long rain 1988								
	Org. C	Total N	Miner. N	Extrac. P	Exch. K	Exch. Mg	Exch. Ca	LR 1988		Org. C	Total N	Miner. N	Extrac. P	Exch. K	Exch. Mg	Exch. Ca	SR 1988/89	
								T N U	T G Y								T N U	T G Y
Soil pH	- 0.11	- 0.06	0.144	- 0.09	0.463**	0.487**	0.236*	- 0.085	- 0.00	- 0.03	0.079	- 0.40***	0.181	0.364**	0.549**	0.522**	- 0.09	0.061
Org. C		0.550**	0.044	0.479**	- 0.01	- 0.26**	0.085	0.208*	0.111		0.317**	0.090	- 0.182	0.083	- 0.16	- 0.159	0.211*	0.154
Total N			0.075	0.306**	0.144	0.040	0.231**	0.180	0.147			0.118	- 0.336**	- 0.10	- 0.03	- 0.105	0.176	- 0.018
Miner. N				- 0.02	0.045	- 0.41**	- 0.236*	0.035	0.019				- 0.130	- 0.05	0.089	- 0.044	0.042	- 0.145
Extrac. P					- 0.10	- 0.06	0.336**	0.093	0.002					0.273**	0.123	0.436**	0.100	0.138
Exch. K						0.354**	0.234*	0.080	0.002						0.353**	0.443**	- 0.020	- 0.003
Exch. Mg							0.506**	0.040	- 0.172							0.476**	- 0.222*	0.210*
Exch. Ca								0.068	- 0.034								0.041	0.068
T N U									0.648***									0.919***

*, **, *** = Correlation between parameters is significant at P = 0.05, 0.01, 0.001 level, respectively.

Table 53 continued – Kimutwa.

	short rain 1988/89									long rain 1989								
	Org. C	Total N	Miner. N	Extrac. P	Exch. K	Exch. Mg	Exch. Ca	LR 1989		Org. C	Total N	Miner. N	Extrac. P	Exch. K	Exch. Mg	Exch. Ca	SR 1989/90	
								TNU	TGY								TNU	TGY
Soil pH	- 0.08	0.048	** - 0.65	0.073	** 0.307	** 0.354	0.177	- 0.056	* - 0.22	- 0.17	- 0.01	** - 0.64	** - 0.368	*** 0.484	*** 0.698	*** 0.394	- 0.338	- 0.046
Org. C		** 0.464	** 0.278	** 0.286	** 0.321	* - 0.226	0.048	0.108	** 0.248		0.176	0.156	0.134	** 0.285	*** - 0.30	0.094	0.077	* 0.224
Total N			0.043	0.186	** 0.285	- 0.117	0.104	- 0.020	0.095			- 0.02	- 0.066	0.124	- 0.04	0.032	* 0.188	* 0.198
Miner. N				0.020	- 0.03	* - 0.222	- 0.165	- 0.073	0.114				** 0.251	*** - 0.30	*** - 0.37	* - 0.215	0.077	0.120
Extrac. P					* 0.239	- 0.12	0.081	0.053	- 0.013					** - 0.26	*** - 0.38	* 0.204	- 0.106	0.108
Exch. K						- 0.001	0.100	0.134	- 0.015						** 0.306	*** 0.314	- 0.099	0.156
Exch. Mg							** 0.325	** - 0.250	- 0.148							** 0.270	- 0.165	- 0.026
Exch. Ca								0.073	0.055								0.062	* 0.191
TNU									*** 0.740									*** 0.721

*, **, *** = Correlation between parameters is significant at P = 0.05, 0.01, 0.001 level, respectively.

Table 54 – Correlation coefficients (r) between end of season (prior to planting the next season) soil chemical properties and total N uptake (TNU, kg / ha) and total grain yield (TGY, kg / ha) of the succeeding cropping systems at Masii.

	Short rain 1987 88									Long rain 1988								
	Org. C	Total N	Miner. N	Extrac. P	Exch. K	Exch. Mg	Exch. Ca	LR 1988 TNU	LR 1988 TGY	Org. C	Total N	Miner. N	Extrac. P	Exch. K	Exch. Mg	Exch. Ca	SR 1988/89 TNU	SR 1988/89 TGY
Soil pH	0.445**	– 0.08	– 0.26**	0.348**	0.408**	0.635**	0.783**	0.299**	0.276**	0.113	0.03	0.058	0.161	0.277**	0.430**	0.655**	0.100	0.276**
Org. C		0.095	– 0.00	0.174	0.263**	0.659**	0.384**	0.254**	0.130		0.47**	0.067	0.024	0.070	0.493**	0.268**	0.186	0.130
Total N			0.037	– 0.05	– 0.10	– 0.10	– 0.08	0.332***	0.241*			0.145	– 0.10	0.265**	0.454**	0.275**	0.038	0.241**
Miner. N				– 0.23	– 0.03	– 0.05	– 0.02	0.330***	0.098				0.002	– 0.03	0.233*	0.280**	0.349***	0.098
Extrac. P					0.092	0.101	0.271**	0.141	– 0.089					0.180	0.017	0.396**	– 0.139	– 0.089
Exch. K						0.386**	0.421**	0.229*	0.095						0.309**	0.255**	0.172	0.095
Exch. Mg							0.639**	0.269**	0.302***							0.613**	0.304***	0.302***
Exch. Ca								0.279**	0.263**								0.236*	0.263**
T N U									0.908***									0.890***

*, **, *** = Correlation between parameters is significant at P = 0.05, 0.01, 0.001 level.

Table 54 continued - Masii.

	Short rain 1988 89									Long rain 1989								
	Org.	Total	Miner.	Extrac.	Exch.	Exch.	Exch.	LR 1989		Org.	Total	Miner.	Extrac.	Exch.	Exch.	Exch.	SR 1989/90	
	C	N	N	P	K	Mg	Ca	T N U	T G Y	C	N	N	P	K	Mg	Ca	T N U	T G Y
Soil pH	0.530**	0.426**	- 0.16	0.263**	0.348**	0.737**	0.673**	0.190*	0.220*	0.360***	0.13	0.028	0.113	0.371***	0.677***	0.598***	0.289**	0.375***
Org. C		0.747**	0.031	0.133	0.374**	0.423**	0.552**	0.146	0.284**		0.70***	0.238**	0.133	0.452***	0.552***	0.571***	0.398***	0.408***
Total N			- 0.00	0.021	0.421**	0.415**	0.471**	0.250**	0.198*			0.333***	0.034	0.276***	0.447**	0.434***	0.319***	0.198*
Miner. N				0.055	0.022	- 0.12	0.014	0.030	0.247**				- 0.02	- 0.17	0.195*	0.031	0.258**	0.247**
Extrac. P					0.057	0.247**	0.350**	- 0.060	- 0.009					- 0.09	- 0.12	0.301***	- 0.073	- 0.046
Exch. K						0.671**	0.574**	0.141	0.314***						0.485**	0.528**	0.402***	0.203*
Exch. Mg							0.765**	0.299**	0.329**							0.560***	0.408***	0.622***
Exch. Ca								0.220*	0.385***								0.505***	0.612***
T N U									0.805***									0.895***

*, **, *** = Correlations between parameters is significant at P = 0.05, 0.01, 0.001 level

be around 5.5 (Wild, 1988).

Cropping systems insignificantly lowered soil pH and when the effect was averaged over all the seasons, the decline in pH was from 5.59 to 5.22 in Kimutwa and 5.77 to 4.89 in Masii (Tables 51 and 52). Some trends, however, were observed and they need mention. Relative to initial soils, continuous sole cropping of maize and beans, rotation and intercropping were found to lower soil pH to 5.21, 5.17, 5.23 and 5.24 in Kimutwa and to 4.81, 4.88, 4.90 and 4.90 in Masii, respectively. These observations implied that sole maize and bean crops lowered soil pH more than crops in rotation and intercropping systems. Also, the extent of decline in soil pH due to identical cropping systems differed with sites and was greater in Masii than in Kimutwa. Return of bean residue to plots slightly lowered soil pH by 0.04 units in Kimutwa and by 0.08 in Masii.

The decline in soil pH due to cropping systems could be attributed to removal of basic cations, that is, calcium, magnesium, and potassium in exchange for hydrogen ions as reported by Tisdale et al. (1985). With regard to bean residue, the decomposition of organic residues would result in the production of organic acids which dissociate releasing hydrogen ions thus lowering the soil pH (Tisdale et al.,1985).

4.9.2 Organic Carbon: Organic carbon of the initial soil was 0.94% in Kimutwa and 0.66% in Masii (Table 1). Data on soil chemical properties of soil taken at the end of every season for the whole experimental period gave an average organic C content of 0.90% in Kimutwa and 0.60% in Masii (Tables 51 and 52) thus indicating a general decline in organic carbon at both sites. In the first four seasons at both sites, continuous cropping of maize and beans in different cropping systems and application of different N rates resulted in organic C being lowered by between 2.1 and 9.6% in Kimutwa and 1.5 and 31.8% in Masii, relative to the initial organic C content in the soil. However, during the last season, the organic C at Kimutwa was similar to that of initial soil while in Masii the level was raised by 7.6%, that is, from 0.66 to 0.71% organic C. This observation implied that there existed a higher variation of organic C content in the sandy soil of Masii than in the sandy clay loam of Kimutwa when both soils were subjected to similar cropping systems and N management. Also, organic carbon could be stabilized or increased as cropping under different management continues.

Cropping of maize and beans with or without N fertilizer resulted in lower organic C than the initial soil by an average of 0.04% C in Kimutwa and 0.06% C in Masii. The effect of N fertilizer rates (25, 50, 100 kg N/ha) on organic C did not differ significantly. However, application of N fertilizer raised organic C more than zero N by 2.3% in Kimutwa and by 14% in Masii. Hence, use of N fertilizer in continuous cropping tended to maintain the surface soil organic matter better than cropping without N fertilization.

Cropping systems resulted in lower surface soil organic C by an average of 0.05% C (5.25%) that is, from 0.94% C to 0.89% C in the first five seasons in Kimutwa and by 0.11% C (17.75%), that is, from 0.66% C to 0.54% C in the first four seasons in Masii. Although the influence of different cropping systems on organic C did not differ significantly, continuous sole maize, continuous sole beans, intercropping systems and rotation reduced organic C relative to initial level by an average of 7.3, 5.4, 4.3 and 4.0%, respectively, in Kimutwa. Also, in the same site, rotation (LR 1989) and intercropping systems (SR 1989/90) were found to slightly raise the organic C by 2.1% each. In Masii, continuous sole maize, rotation, intercropping systems, and continuous sole beans were found to lower soil organic C by 21, 19, 16, and 15% except in one season, SR 1989/90, when these cropping systems raised the organic C by 5, 12, 5, and 8%, respectively. These results implied that cultivation of maize and beans in sandy soil in Masii lowered organic C more than in sandy clay loam in Kimutwa. This difference due to the soil types conforms with the findings reported by Jenny (1980) that clay soils have more organic matter than sandy soils because clay soils have a protective aspect of organic matter thus becoming less available to the soil population for decomposition. Also, it can be concluded that continuous sole maize lowers organic C more than any other cropping system which had beans including intercropping and rotation.

Generally, return or removal of bean residue did not improve organic C but instead it was found to have a lowering effect. Similar levels of organic C were observed where bean residues were either returned or removed. These two practices had lowered organic C relative to initial level by 3.9% in Kimutwa and by 13% in Masii. Only in one season (SR 1989/90) in Masii was there an increase in organic C due to return and removal of bean residue by 6 and 8%, respectively. This last observation seemed to indicate that the improvement in soil organic C cannot be ascribed to the haulms of beans returned but more likely to other factors like the roots. Because where beans were included in a cropping system, the organic C was higher than that of continuous sole maize. This needs further investigation in order to confirm this hypothesis. However, Dhillon and Dhillon (1991) reported an increase in organic carbon content of the soil when double the amount of residues from groundnut plants were added.

Organic C was positively correlated with pH, total N, mineral (exchangeable) N, extractable P, exchangeable K, Mg and Ca, total N uptake and total grain yield in both sites. Except for soil pH and exchangeable Mg which were negatively correlated, the rest of the soil chemical properties were positively correlated (Tables 53 and 54). This observation implied that organic C could be limiting in crop production in these two locations since it was positively correlated to total N uptake and total grain yield which in turn were positively and significantly correlated with each other at both sites.

4.9.3 Nitrogen:

Total N: Total N of the initial soil was 0.114% in Kimutwa and 0.075% N in Masii. Nitrogen fertilizer at the rate of 25 to 100 kg N/ha slightly increased total N by 3%, that is, from 0.0750% N to 0.0774% N in Masii but did not alter the one in Kimutwa (Tables 51 and 52). Cultivation of crops without N fertilizer (0 kg N/ha) was found to lower total N by 2%, that is, 0.114 to 0.112% N in Kimutwa and by 12%, that is, from 0.075 to 0.066% N in Masii. Compared to initial soil total N, continuous sole maize and beans were found to lower total N by 9 and 2% while intercropping and rotation slightly increased it by 2 and 1.3% in Kimutwa, respectively. In Masii, contrary results were obtained since continuous sole maize and beans increased soil total N by 7 and 15% while intercropping and rotation plots decreased it by 4 and 3%, respectively. Although cropping systems did not differ significantly in their effects on total N, it was observed in Kimutwa that intercropping, rotation and continuous sole bean plots had greater total N than continuous sole maize by 8.2, 7.9 and 4.7%, respectively. In Masii, it was continuous sole bean plots which had higher total N than continuous sole maize plots by 13% while the latter system had greater total N than intercropping and rotation plots by 10 and 9%, respectively. Total N was positively and significantly correlated with organic C, soil pH, extractable P, exchangeable K, Mg, Ca and total grain yield in some seasons in both sites (Tables 53 and 54).

Mineral N: Continuous cropping without N fertilizer application but with an addition of 40 kg P_2O_5/ha for five to six seasons increased mineral N (NO_3-N + NH_4-N) from the initial 0.39 to 20.1 ug N/g soil in Kimutwa and from the initial 2.99 to 15.2 ug N/g soil in Masii. This change in mineral N could be attributed to organic matter mineralization during the cultivation period of the study.

When N fertilizer was added at the rate of 25, 50 and 100 kg N/ha the increase in mineral N relative to zero N rate was by an average of 28 ug N/g in Kimutwa and 20 ug N/g in Masii (Tables 51 and 52). Hence, continuous cropping plus N fertilizer had more residual mineral N at the end of season than N rate of 0 kg N/ha by 40% in Kimutwa and 34% in Masii. The increase of mineral N due to N fertilizer was as a result of increased exchangeable N, that is, nitrates (NO_3-N) and ammonium (NH_4-N) in the soil by 63% and 40% in Kimutwa and by 35% and 11% in Masii, respectively. This improved level of mineral N at the end of seasons corresponds well with the findings of Ssali (1990) who reported that 34 to 43% of the applied N fertilizer was found to remain in the soil at the end of the season, most of which remained in the top soil.

The influence of cropping systems on nitrates and mineral N was significantly different in Kimutwa but not in Masii (Tables 51 and 52). Rotation and continuous sole bean plots gave more soil nitrates than those of continuous sole maize by 6 and 26% in Kimutwa and by 5 and 2% in Masii, respectively. Intercropping plots gave higher nitrates than continuous sole maize plots by 5% in Masii but had lower levels of the same than the latter plots at Kimutwa by 4%. With regard to ammonium-N, the results obtained at the two sites were contradictory. More ammomiun-N was obtained from plots under continuous sole maize than those under intercropping, rotation and continuous sole bean plots by 16, 17 and 47% in Kimutwa whereas these similar cropping system plots in Masii gave higher levels of ammonium-N than continuous sole maize plots by 36, 30 and 33%, respectively. Again, except for continuous sole beans plots which gave higher mineral N than continuous sole maize plots at both sites by 3.6 and 6% for Kimutwa and Masii, respectively, the mineral N obtained at continuous sole maize plots compared to the other cropping systems was found to differ with sites. Higher mineral N was obtained from plots under continuous sole maize than from intercropping and rotation plots by 10 and 24% in Kimutwa while in Masii the former cropping system provided lower mineral N levels than the latter ones by 6 and 2%, respectively. These results indicate that there is less mineral N left in plots previously undercontinuous sole maize than in intercropping, rotation and continuous sole beans in Masii. Also, less mineral N was generally found in plots under intercropping and rotation than in continuous sole maize in Kimutwa. These results of mineral N in these cropping systems were the reverse of the results obtained for total N at both sites. There was a positive and significant correlation between mineral N and total N in one season in Masii.

Occasionally, the relationship between mineral N and exchangeable Mg and Ca at both sites, total N uptake (TNU) and total grain yield (TGY) in Masii were positive and significantly correlated (Tables 53 and 54).

The amount of residual nitrates and ammonium-N at the end of seasons varied with seasons (Tables 51 and 52). Averaged over all the seasons, however, nitrates were more than ammonium-N by 33.4% in Kimutwa and 15.0% in Masii. Differences existed between sites and Kimutwa (sandy clay loam soil) gave higher residual nitrates and ammonium-N than Masii (sandy soil) by 22 and 12%, respectively.

The end of season mineral N was influenced by seasons. In Kimutwa, mineral N ranged from 13.6 to 46.7 ug N/g soil while that of Masii ranged from 10.1 to 30 ug N/g soil. The residual mineral N averaged over the four seasons was 26.6 ug N/g soil in Kimutwa while that of Masii averaged 19.0 ug N/g soil. Thus, regardless of N rates, Kimutwa soil (dystric Nitisol) therefore had higher residual mineral N than that of Masii (Acrisol) by 40%. Hence, under identical N fertilizer levels and cropping systems management, sandy soil had a lower residual mineral N than sandy clay loam soil. This phenomenon could be attributed to the fact that Masii site received higher rainfall than Kimutwa and since the soil was sandy, there might have occurred more leaching than in Kimutwa which had sandy clay loam soil. Nitrate was found to leach more readily from a sandy soil than from a loam soil and for each centimetre of rainfall, nitrate has been reported to be displaced downward by about 10 cm in sandy soil compared with 3 cm in a loam (Wild, 1988).

Return of bean residue to plots did not affect total N. But, its effect on mineral N varied with seasons. In Kimutwa, return of bean residue improved mineral N by 10% in one season (LR 1988) while there was a decline in mineral N in three seasons that followed (SR 1988/89 to SR 1989/90) by an average of 8%. In Masii, there was a clear seasonal consistency in the effect of bean residue returned on mineral N because during the long rains of 1988 and 1989, mineral N was increased by 11 and 17% while during the short rains of 1988/89 and 1989/90, the same practice was found to lower soil mineral N by 4 and 9%,respectively.

4.9.4 <u>Cation Exchange Capacity (CEC):</u> The CEC of the initial soil was 17.5 me/100 g in Kimutwa and 6.25 me/100 g in Masii. Data of CEC were not statistically analyzed but differences due to treatments were clear and substantial (Tables 51 and 52). Continuous cropping of maize and beans without N fertilizer for six and five seasons in Kimutwa and Masii, respectively, increased CEC on average by 21% in the former and by 28% in the latter site. But, application of N fertilizer at the rate of 25 to 100 kg N/ha had mixed effects on CEC; it raised CEC by 2% in Kimutwa while in Masii, it was lowered by 18%. Probably, the greater percent increase in uptake of cations (K, Mg, Ca) by crops in Masii than in Kimutwa due to N fertilizer (Tables 28, 29 and 30) and the relatively lower initial level of CEC in Masii may have caused this higher decline in CEC. Comparison of initial surface soil CEC with that obtained from different cropping systems in Kimutwa showed that intercropping systems improved soil CEC more than the continuous sole maize and beans. Intercropping, continuous sole maize and bean cropping systems increased CEC by 11, 9 and 3 me/100 g, respectively while rotation did not alter it. In Masii, except for continuous sole beans where CEC was increased by 20%, continuous sole maize, intercropping systems and rotation decreased soil CEC after five cropping seasons by 1.5, 1.0 and 0.44 me/100 g. Probably, the reduction of organic C (matter) by these cropping systems resulted in the decline in CEC.

Variation was found to exist between sites with regard to the effect of bean residue on CEC. In Kimutwa, return and removal of bean residue to plots resulted in higher CEC than that of initial soil by 1.4 and 1.05 me/100 g, respectively. In Masii, however, return or removal of beans residue were both found to lower soil CEC by 0.20 and 0.44 me/100 g, respectively.

The increase in CEC in Kimutwa and a decrease in Masii due to N fertilizer and different cropping systems relative to initial soil CEC reflects the different soil types at both sites: sandy clay loam of Kimutwa and sandy soil of Masii in which the latter soil was found to possess less clay and organic matter (C) than the former (Tables 1; 51 and 52). Since soil from Masii had a lower organic carbon, in the initial soil (Table 1), further decrease of the same by N fertilizer and cropping systems may have (Table 52) led to the decline of soil CEC in Masii unlike that of Kimutwa whose organic carbon was initially higher and was only slightly lowered by both N fertilizer and cropping systems (Table 51). Organic carbon has been found to be positive and highly correlated with CEC of nine soils of different classifications (Manrique et al. 1991).

4.9.5 Phosphorus: Extractable P (AL-method) of the initial soils were 0.70 and 0.43 mg P/100 g, in Kimutwa and Masii respectively. A dose of 40 kg P_2O_5/ha as single superphosphate was applied to all plots prior to planting in all seasons. The effect of cropping systems and N levels on soil extractable P prior to planting varied with seasons and sites (Tables 51 and 52).

At the end of long rains of 1987 and 1988 in Kimutwa, cropping of maize and beans without N fertilizer application lowered extractable P by 57 and 36%, in the former and latter seasons, respectively. But, when N fertilizer at the rate of 25 to 100 kg N/ha was applied during these two seasons, the reduction of extractable P in the soil was less although the level was still lower than that of initial soil by 46 and 1.4%, respectively. In the seasons that followed, that is, short rains 1988/89 and 1989/90 and long rains of 1989, cropping without N fertilizer resulted in a higher residual extractable P than the initial soil by an average of 2.3 mg/100 g for measuring 6.1, 1.1 and 1.2 mg P/100 g, respectively. Also, during the same three seasons, application of N fertilizer (25 to 100 kg N/ha) gave higher residual extractable P than the initial soil by measuring 4.3, 2.0 and 2.1 mg P/100 g, respectively.

In Masii, cropping with or without application of N fertilizer left high residual extractable P (Table 52). Where no N fertilizer was applied, the residual extractable P averaged 2.4 mg P/100 g whereas plots applied with N fertilizer had an average residual extractable P of 2.2 mg P/100 g. Generally, there was a slightly less residual extractable P where N was applied than at zero N treatments at both sites (Tables 51 and 52).

Variation in residual extractable P obtained from the two sites reflects the existing differences in the soil types for these two sites. The dystric Nitisol soil type (sandy clay loam) of Kimutwa although gave higher initial soil extractable P by 63% than that of Masii, it showed a lower extractable P than the Acrisol soil type (sandy soil) of Masii by 17% by the time the experiment ended. During the first few seasons at Kimutwa, the extractable P even after 40 kg P_2O_5/ha was applied was found to be less than that of initial soil. This was an evidence that the dystric Nitisol of Kimutwa was fixing the applied P unlike the Acrisol of Masii whereby P in the fertilizer was added to the pool of extractable P. Okalebo (1987) found that Nitisols had higher sorption of P than Luvisols whose morphological characteristics are similar to that of Acrisols. The higher sorption of P in the Nitisols was attributed to high clay and organic matter content. In this study, the dystric Nitisol of Kimutwa had higher clay content at the beginning of the experiment by 414% (Table 1) and higher organic carbon at the end of experiment by 50% than the Acrisol of Masii (Tables 51 and 52) thus reflecting the importance of these soil chemical properties in P sorption. Although positive and significant correlations between organic carbon content and P adsorption have been obtained in Kenya soils (Hinga, 1973; Okalebo, 1987), the results obtained in this study showed positive and sometimes significant correlations between organic C and extractable P (Tables 53 and 54). Okalebo (1987) found a negative and significant correlation between adsorbed P and available P extracted by the AL-method of Egner -Riehm (1960) used in this study. This method is known to extract mainly the aluminum bound-P in Kenya soils (Hinga, 1974). Hence, the negative correlation indicated a decreasing P sorption from falling Al content in soils.

In Masii, the low level of extractable P at the end of season where N fertilizer was applied probably indicates the difference in P removal by crops. Where N was applied in Masii, the uptake of P was greater by 130 % than where no N fertilizer was applied.

The effect of cropping systems on extractable P varied with seasons. Averaged over all the seasons, the residual extractable P obtained in each cropping system followed this descending order: continuous sole beans > rotation > intercropping systems = continuous sole maize in Masii and in Kimutwa the order was : rotation > continuous sole beans > continuous sole maize > intercropping systems. This residual extractable P in each cropping system was more less related to the uptake, that is, the lower the uptake of P by a cropping system the higher the residual P in the soil of that cropping system at the end of that season.

Return of bean residue to plots resulted in lower soil extractable P by between 3 and 48% in Kimutwa and between 2 and 7% in Masii than where residue was removed. These results contradict the findings of Dhillon and Dhillon (1991) who reported increased levels of available P in the soil after applying residues of groundnut plants. However, our results seem to indicate that the bean residue returned may have undergone microbial decomposition and during this process the available phosphorus was immobilized because bean residue returned generally did not improve P uptake by maize or beans but instead it lowered the P uptake by these crop species. Brady (1990) reported that when organic residues low in P but high in other nutrients are added to a soil, rapid microbial activity takes place and available P in the soil solution is temporarily immobilized.

Extractable P at the beginning of season was positively and significantly correlated with the beginning of season total nitrogen, organic carbon, exchangeable K and Ca in Kimutwa and with soil pH and exchangeable Ca in Masii (Tables 53 and 54). There was also negative and significant correlations between beginning of season soil extractable P and soil pH in Kimutwa during the long rains of 1989 and short rains of 1989/90. The negative correlation between extractable P and soil pH showed a decreasing P availability with increasing soil pH and thus the importance of soil pH in Kimutwa. Phosphorus availability in most soils has been found to be at a maximum in the pH range of 6.0 to 6.5 because at low pH values there is adsorption of P by iron and aluminum and their hydrous oxides (Tisdale et al., 1985). This is a possibility that may have occurred in Kimutwa because the average soil pH was 5.22. The positive correlation between beginning of season extractable P and soil pH in Masii, probably reflects the difference in mineral composition of soils at the two sites. In Masii the soil pH averaged 4.89 and it has been found that raising the pH of clays above 4 of some soils can reduce phosphorus adsorption where interlayer hydroxyaluminum polymers exist (Tisdale et al., 1985).

4.9.6 Potassium, Magnesium and Calcium: In this study, potassium was the only mineral nutrient that was not applied. Calcium and magnesium were applied together with the calcium ammonium nitrate (CAN) and single superphosphate because they are some of the components comprising these two fertilizers (Ombwara, 1972). Application of single superphosphate to all plots, therefore, might have influenced soil Ca and Mg contents even where CAN was not applied (0 kg N/ha) to plots.

Growing of maize and beans and application of CAN and single superphosphate fertilizers were found to lower soil exchangeable potassium by 18.0% in Kimutwa and by 40.2% in Masii relative to initial soil level. But, calcium and magnesium were increased by an average of 180% and 10.3%, respectively in Kimutwa over the seasons by the same practices while in Masii only calcium was increased by 128.9% since Mg was lowered by 17% relative to initial soil levels (Table 1; Tables 51 and 52).

A trend existed whereby application of N fertilizer always resulted in lower soil exchangeable K, Mg and Ca by 5, 13 and 13% in Kimutwa and by 8, 23 and 10% in Masii, respectively than where no N fertilizer was applied. This observation reflects the higher removal of these nutrients by crops under N fertilization than those grown without N fertilizer. This was evidenced by the fact that application of N fertilizer increased dry matter yields of plants (Tables 3 through 8) which consequently resulted in higher uptake of K, Mg and Ca by 25, 51 and 52% than where N fertilizer was not applied in Kimutwa and by 137, 128 and 128% in Masii, respectively (Tables 28, 29 and 30).

Generally, the effects of cropping systems on soil exchangeable K, Mg and Ca did not differ significantly. However, some differences occurred between cropping systems within the site and between sites for the identical cropping systems. In Kimutwa, rotation, continuous sole beans and intercropping gave greater exchangeable K than continuous sole maize by 13, 7 and 6 % while in Masii only intercropping resulted in higher exchangeable K by 6.7% than continuous sole maize. However, rotation and continuous sole beans also gave slightly lower residual exchangeable K by 4 and 2% than continuous sole maize, respectively. With regard to the exchangeable Mg and Ca in Kimutwa, continuous sole maize gave higher residual Ca than rotation, continuous sole beans and intercropping by 10, 6 and 4% and also higher Mg by 7, 13 and 7%, respectively. Unlike in Kimutwa, continuous sole maize gave the lowest residual exchangeable Mg and Ca in Masii compared with the other cropping systems. Continuous sole beans,intercropping and rotation in Masii, therefore resulted in higher residual exchangeable Mg by 28, 21 and 19% and higher exchangeable Ca by 13, 11 and 12% than continuous sole maize, respectively. These results did not tally with the magnitude of uptake of K, Mg and Ca since intercrops took up the highest amount of these nutrients followed by rotation crops while uptake of the same nutrients by continuous sole maize was generally higher than that of continuous sole beans at both sites. Probably, other site-specific-factors influenced the level of these nutrients in each cropping system since continuous sole maize gave the lowest residual exchangeable K in Kimutwa and exchangeable Mg and Ca in Masii. Also, plot with rotation crops and continuous sole beans gave lower exchangeable Mg and Ca than continuous sole maize in Kimutwa.

Return of bean residue to plots was found to lower exchangeable K, Mg and Ca by 2, 1 and 3% in Kimutwa and by 3, 13 and 10% in Masii. The observations from Masii corresponded well with the reduced uptake of these nutrients by the returned bean residues while in Kimutwa, only exchangeable K corresponded well with the uptake of K by crops.

Soil exchangeable K at the beginning of season in the two sites was found to have positive and significant correlations with both exchangeable Mg and Ca. However, there was no significant correlation between soil exchangeable K and N uptake and total grain yield in Kimutwa although positive and significant correlations were observed in Masii in two out four seasons. Exchangeable Mg had positive relationship and highly significant correlation with exchangeable Ca in both sites. In Masii, both Mg and Ca had positive relationships and highly significant correlations with N uptake and total grain yield. In Kimutwa, exchangeable Mg gave negative relationships but significant correlations with total N uptake in two out of four seasons and a positive and significant correlation with total grain yield. There was no significant correlation between exchangeable Ca and either N uptake or total grain yield.

CHAPTER V

5.0 CONCLUSIONS AND RECOMMENDATIONS

1. The surface soils (0 - 20 cm layer) from the two sites located at the semi-arid area of Machakos District in Eastern Kenya were different: Kimutwa soil was sandy clay loam (dystric Nitisol) while that from Masii was sandy (Acrisol). Soil from Kimutwa was more fertile than that from Masii since it contained higher total N, organic C, CEC, Mg and Ca. However, the two soils were both slightly acidic (pH 5.6 - 5.8), had similar extractable P and exchangeable K. There was higher total seasonal rainfall and slightly better distribution in Masii than in Kimutwa.

2. Nitrogen fertilizer was found to be a limiting factor in the production of maize and beans grown in different cropping systems (sole, intercropping and rotation) at both sites and therefore N should be recommended for the production of both crops in this area. Application of calcium ammonium nitrate as source of N was often found to significantly improve the performance of maize and beans through its enhancement of the uptake by both crops of the major nutrients viz: nitrogen, phosphorus, potassium, magnesium and calcium. Improved growth of crops by N fertilizer resulted in greater removal of extractable P and exchangeable K, Mg and Ca nutrients from the soil as evidenced by their lower levels in the soil relative to zero N treatments.

3. The magnitude of maize and bean seed yield response to nitrogen fertilizer was influenced by sites, seasons (rainfall) and cropping systems. Increase of seed yield of beans due to N fertilizer was higher in Masii than in Kimutwa while maize seed yield response to N was higher during the short rains than the long rains at both sites. Majority of beans in different cropping

systems gave the highest seed yield at 50 kg N/ha fertilizer although beans intercropped in the same row with maize had a tendency of requiring a higher N rate of up to 100 kg N/ha for their maximum seed yield. Also, maize intercropped in the same row, continuous sole maize and that in rotation had their maximum response at 100 kg N/ha fertilizer while that in alternate row had its highest N response at 50 kg N/ha. Hence, intercrops in the same row had higher N requirement rate than those intercropped in the alternate rows. But, since N rates of 50 and 100 kg N/ha were not often significantly different, the 50 kg N/ha could be recommended as an economical rate to use on maize and bean production in different cropping systems in this semi-arid region. Regression analysis, however, showed that beans in general, continuous sole maize, maize in rotation and that planted in alternate row could respond to N rate of up to 75 kg N/ha while maize in the same row could respond to 100 kg N/ha. The N rate of 25 kg N/ha fertilizer was not adequate for production of maize or beans although it was better than zero N level by between 4 and 51% in Kimutwa and between 89 and 62% in Masii for maize and by between 36 and 64% in Kimutwa and between 53 and 165% in Masii for beans.

4. Application of N fertilizer was found to increase soil residual mineral N which consequently increased maize dry matter yield, seed yield, uptake of N, P, K, Mg and Ca but a consistent reducing effect on Ca uptake. Also, N fertilizer was found to improve soil total N, had better maintainance of soil organic C but had a decreasing effect on soil pH, extractable P, exchangeable K, Mg and Ca. Continuous cropping without N fertilizer was found to raise CEC more than where N was applied, because the N fertilizer caused greater removal of cations by plants from the soil.

Application of single superphosphate fertilizer alone without CAN was found to lower soil pH but with fewer units than when CAN was added.

5. Crop rotation was beneficial to maize growth and development and dry matter yield, yield components, nutrient uptake and seed yield of both maize and beans. Maize following beans in rotation had greater response to N and took up more nutrients than continuous sole maize and was found to require a lower rate of N fertilizer in order to achieve a yield similar to that obtained in continuous sole maize at a higher N rate than that applied to maize in rotation thus implying a supplementary effect of rotation to N fertilizer. Benefits obtained by beans from rotation were not attributed to N status left by maize but to other higher residual soil nutrients and more so to extractable P, which was highly correlated with bean seed yield. After the five and six seasons were over in Masii and Kimutwa, respectively, plots previously under rotation systems were found to have higher residual mineral N than continuous sole maize plots in Masii although continuous sole beans in Kimutwa and intercropping systems in Masii were superior to continuous sole maize, rotation and intercropping for the former site and continuous sole maize and beans and rotation for the latter site. Maize planted to plots previously under continuous sole beans was superior to that planted in continuous sole maize, rotation and intercropping system plots in terms of dry matter yield, uptake of N, P, K, Mg and Ca and seed yield. The high levels of extractable P and exchangeable K and Ca in plots previously under beans in rotation could have contributed to the effects of rotation on maize. Hence, rotation of maize and beans would

improve yields of both maize and beans and therefore it is a practice that could be adopted instead of growing these crops as continuous sole crops.

6. Return of bean residue to plots was found to reduce bean dry matter yield, yield components, nutrient uptake and seed yield. Also, it lowered soil pH, extractable P and exchangeable K, Mg and Ca. On the other hand, it had improved the uptake of N, P, K, Mg and Ca by maize in Kimutwa although it generally reduced the uptake of nutrients in Masii. Bean residue returned was also found to enhance response to N fertilizer by maize intercropped in the same row and that in rotation in its dry matter yield and uptake of P in Kimutwa and it also resulted in higher land equivalent ratio. Generally, the effects of bean residue returned on maize perfomance, mineral N, CEC, and organic C were influenced by seasons, sites and cropping systems and could either lower or improve them. However, bean residue may be returned to rotation and intercropping systems.

7. Intercropping resulted in higher LER whose magnitude was influenced by sites and bean spatial arrangements. However, N fertilizer lowered the LER. This implied that intercropping at low-input agriculture is very important because of the advantage accrued to it. However, use of N fertilizer on intercropping systems of maize and beans is necessary in this region because of the high absolute advantage achieved, that is, high total grain yield compared to zero N treatments.

8. Competition between maize and beans in intercropping systems for the environmental resources was manifested in the reduction of component crops dry matter yield, development, yield components, seed yield and

nutrients uptake. Competition was found to commence very early and by 20 DAE it was already expressed in both component crops dry matter yield and N uptake. Maize planted in the same row with beans had accumulated more dry matter and had taken up more nutrients than maize in the alternate rows in Kimutwa while in Masii, it was that in alternate row which had performed better. Beans planted in the same row with maize accumulated more dry matter and took up more nutrients than those planted in the alternate rows at both sites. Hence, with regard to total systems performance, the same row intercrops were found to take up more nutrients and provided more total grain yields than continuous sole maize, maize in rotation and continuous sole beans. Thus, the same row intercropping of maize and beans is better than alternate row intercropping in this region.

9. Bean response to N fertilizer seemed to occur where soil mineral N was 23 ug N/g soil and below in Kimutwa and 18 ug/g and below in Masii. Also, the dry matter yield response of maize to N rate of 25 kg/ha for the first 20 days after seedling emergence even where the soil mineral N had mearured 60 ug N/g in Kimutwa and 36 ug N/g in Masii at planting time seemed to indicate that, the first rains were able to leach mineral N to the extent that more N was needed by maize and beans for their growth. Hence, N starter dose in this region is needed.

10. The amount of residue mineral N in the soil was influenced by maize-bean cropping systems. Continuous sole beans gave higher nitrates and mineral N than continuous sole maize at both sites. There was more ammonium-N left in plots by continuous sole maize than those of intercropping, rotation and continuous sole beans in Kimutwa (sandy clay loam soil) while

the reverse was true at Masii (sandy soil). Plots under continuous sole maize had less mineral N than those of intercropping and rotation in Masii while in Kimutwa the reverse was true. These results were the opposite of the total N obtained in those cropping systems. Return of bean residue to plots did not affect total N. However, it influenced the level of mineral N. The practice generally declined mineral N in Kimutwa but was found to inrease and to decrease it during the long rains and short rains, respectively in Masii.

Reduction of soil extractable P after the application of phosphate fertilizer at the start of the experiment seemed to indicate that the soil of Kimutwa (dystric Nitisol) was capable of fixing P unlike that of Masii (Acrisol) which did not show this symptom. Also, the lower level of residual mineral N observed at Masii than in Kimutwa while both sites received the same levels of N seemed to indicate that Acrisol soil (Masii) was more prone to leaching than dystric Nitisol (Kimutwa).

5.1 SUGGESTED FURTHER RESEARCH

1. Investigate on whether there are some differences in the leaching rate of nitrogen fertilizer in the Acrisol (sandy soil) and dystric Nitisol (sandy clay loam) soil types in Machakos District.

2. Investigate on the reason why beans intercropped in the same row with maize performed better than those in alternate row with regard to dry matter yield, nutrient uptake and seed yields in the semi-arid area.

3. Investigate the reason why return of bean residue to plots where beans were to be planted in either sole,

intercropping and rotation resulted in the reduction of dry matter yield, nutrient uptake and yields of beans.

4. Investigate why there was a lower equivalent N estimated to be available for maize production in rotation plots where bean residue was returned than where it was removed.

5. Investigate on the causal effect of the decline in the soil pH when single superphosphate and calcium ammonium nitrate were applied to Acrisol and dystric Nitisol in the semi-arid region of Machakos District.

6. Investigate why the return of bean residue to plots lowered soil organic carbon and soil exchangeable potassium, calcium and magnesium.

CHAPTER VI

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Appendix Table 1 – Precipitation (mm) (14 – 16 days totals) during the growing seasons.

Month	March		April		May		June		July		total
Days	1–15	16–31	1–15	16–30	1–15	16–31	1–15	16–30	1–15	16–31	mm
Kimutwa											
Long Rain											
1988	4.3	84.3*	64.8*	208.9	0.0	0.0	0.0	0.0	0.0	0.0	362.4
1989	0.0	39.6	90.2*	58.5	2.4a	0.0b	0.0c	0.0	0.0	0.0	190.7
1990	123.1	27.9*	206.0	10.1	25.8	0.0	0.0	0.0	0.0	0.0	393.5
Month	October		November		December		January		February		
Days	1–15	16–31	1–15	16–30	1–15	16–31	1–15	16–31	1–14	15–29	
Short Rain											
1987/88	0.0	0.0	44.2*	48.9	9.6a	0.0b	0.0	0.0	0.0	0.0	102.7
1988/89	0.0	20.8*	51.7	64.0a	49.6	124.7b	21.5 c	71.6	0.0	0.0	403.9
1989/90	0.0	80.5*	10.5	86.7	91.1 a	0.0	45.8	0.0	40.3	12.3	361.6
Masii											
Month	March		April		May		June		July		
Days	1–15	16–31	1–15	16–30	1–15	16–31	1–15	16–30	1–15	16–31	
Long Rain											
1988	116.8	152.7*	63.1*	174.6	0.7b	0.0c	0.0	0.0	0.0	0.0	507.9
1989	0.0	65.7	173.6	62.5	36.1 a	7.6b	7.5c	0.0	1.9	0.0	355.1
1990	9.8	93.1*	139.2	41.4	46.7	2.1	0.0	0.0	0.0	0.0	520.5
Month	October		November		December		January		February		
Days	1–15	16–31	1–15	16–30	1–15	16–31	1–15	16–31	1–14	15–29	
Short Rain											
1987/88	0.0	0.0	38.5*	56.1	32.2 a	0.0b	20.5c	7.8	5.4	0.0	160.5
1988/89	0.0	46.0	151.6	72.0a	52.8	150.8b	126.0c	68.2	0.0	0.0	667.4
1989/90	0.0	111.2	63.2*	136.9	96.3	75.0b	82.5	0.0	0.0	0.0	565.1

*,a,b,c = Time of planting, first sampling – 20 DAE, 2nd sampling – 40 DAE, 3rd sampling – 60 DAE.

Appendix Table 2 – Effect of N rates and cropping systems on maize seed N concentration (%) and uptake (kg/ha) at maturity.

Fertilizer kg N/ha	Kimutwa								Masii							
	L R 1988		S R 1988/89		L R 1989		S R 1989/90		L R 1988		S R 1988/89		L R 1989		S R 1989/90	
	%	kg/ha	%	kg/ha	%	kg/ha	%	kg/ha	%	kg/ha	%	kg/ha	%	kg/ha	%	kg/ha
0	1.52	37.8	1.41	59.2	1.80	28.6	1.45	37.2	1.44	3.6	1.49	15.7	1.49	3.5	1.53	2.8
25	1.63	49.0	1.42	76.7	1.81	29.9	1.78	69.9	1.64	9.6	1.59	32.1	1.63	19.5	1.47	20.7
50	1.58	55.4	1.44	82.7	1.93	32.1	1.76	79.2	1.64	12.7	1.60	65.0	1.54	22.7	1.50	40.2
100	1.65	59.4	1.46	87.5	1.93	33.2	1.64	67.5	1.65	16.4	1.60	64.2	1.48	20.9	1.47	60.3
Mean	1.60	50.4	1.43	76.5	1.87	31.0	1.66	63.5	1.60	10.6	1.57	44.3	1.54	16.7	1.49	31.0
F test	ns	**	ns	ns	ns	ns	ns	*	ns	*	ns	*	ns	**	ns	**
CV (%)	3.3	8.0	2.8	13.4	3.6	11.3	15.3	20.4	13.1	36.5	4.1	38.4	6.7	25.2	5.2	40.5
LSD 0.05	–	8.0	–	–	–		–	25.9	–	7.7	–	33.9	–	8.4	–	25.1
Cropping systems																
MSC	1.66	58.2	1.45	76.1	1.87	38.5	1.69	59.5	1.70	12.1	1.55	55.9	1.58	21.4	1.47	39.8
MISNR	1.55	46.3	1.51	70.9	1.85	26.1	1.63	61.1	1.58	8.2	1.51	29.8	1.44	13.0	1.54	31.5
MISRR	1.59	53.1	1.42	70.6	1.93	29.4	1.78	73.1	1.55	7.8	1.57	42.9	1.56	11.7	1.45	28.6
MIANR	1.60	46.4	1.41	68.4	1.78	29.2	1.54	58.7	1.58	8.7	1.59	44.9	1.48	12.3	1.50	26.2
MIARR	1.58	48.2	1.34	66.4	1.89	31.6	1.65	56.3	1.54	9.1	1.63	48.0	1.63	15.3	1.50	28.9
Rot-NR	–	–	1.45	93.7	–	–	1.56	61.5	1.71	13.7	–	–	1.50	21.9	–	–
Rot-RR	–	–	1.46	89.6	–	–	1.73	73.6	1.64	14.4	–	–	1.58	20.9	–	–
Mean	1.60	50.4	1.43	76.5	1.87	31.0	1.66	63.5	1.60	10.6	1.57	44.3	1.54	16.7	1.49	31.0
F test	ns	**	ns	***	ns	***	ns	*	ns	**	ns	*	ns	**	ns	ns
CV (%)	5.9	16.7	9.2	18.3	8.0	18.3	15.9	24.4	26.5	49.2	7.5	43.2	14.8	49.6	8.00	72.6
Interaction	ns	ns	ns	ns	ns	*	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
LSD 0.05	–	7.0	–	11.6	–	4.7	–	12.7	–	4.3	–	11.3	–	6.8	–	–

*, **, *** = Treatment differences and interactions are significant at P = 0.05, 0.01, 0.001 level, respectively.

ns = Treatment differences are not significant at P = 0.05 level

Appendix Table 3 – Effect of N rates and cropping systems on maize stover N concentration (%) and uptake (kg/ha) at maturity.

Fertilizer kg N/ha	Kimutwa								Masii							
	L R	1988	S R	1988/89	L R	1989	S R	1989/90	LR	1988	S R	1988/89	L R	1989	S R	1989/90
	%	kg/ha	%	kg/ha	%	kg/ha	%	kg/ha	%	kg/ha	%	kg/ha	%	kg/ha	%	kg/ha
0	0.57	11.3	0.65	16.7	0.99	14.2	0.72	15.1	0.69	6.3	0.59	3.3	0.66	3.3	0.80	4.0
25	0.73	21.4	0.76	20.7	1.04	18.0	0.80	20.9	0.67	11.5	0.68	9.8	0.62	8.0	0.71	7.1
50	0.68	22.6	0.71	18.6	10.6	18.7	0.89	26.1	0.73	14.3	0.67	11.8	0.61	11.8	0.59	6.3
100	0.78	25.9	0.86	29.4	1.16	18.9	0.90	25.2	0.76	187.4	0.72	11.8	0.77	12.9	0.62	7.8
Mean	0.69	20.3	0.75	21.4	1.06	17.5	0.83	21.8	0.71	12.6	0.67	9.2	0.67	9.0	0.68	6.3
F test	ns	**	ns	*	ns	ns	ns	**	ns	**	ns	**	ns	***	*	*
CV (%)	12.0	17.0	13.1	19.2	11.7	17.0	13.5	12.4	11.5	22.2	12.3	22.8	11.6	17.1	8.80	17.7
LSD 0.05	–	6.9	–	6.8	–	–	–	5.4	–	5.6	–	2.5	–	2.5	0.006	2.2
Cropping systems																
MSC	0.69	24.6	0.66	22.5	1.11	21.3	0.81	22.4	0.77	15.3	0.59	11.8	0.67	8.5	0.67	6.2
MISNR	0.75	20.0	0.73	18.8	1.04	14.1	0.78	22.2	0.69	11.0	0.68	7.3	0.69	8.6	0.68	6.0
MISRR	0.66	21.2	0.68	20.3	0.97	15.5	0.90	25.4	0.67	10.4	0.66	6.7	0.67	7.6	0.75	7.6
MIANR	0.68	16.9	0.81	22.1	1.09	18.9	0.80	21.0	0.79	13.4	0.64	8.9	0.68	9.2	0.67	5.9
MIARR	0.66	18.8	0.74	16.8	1.10	17.5	0.84	21.3	0.65	9.9	0.77	11.3	0.64	8.4	0.63	5.7
Rot–NR	–	–	0.83	27.4	–	–	0.80	18.1	0.73	16.0	–	–	0.62	10.4	–	–
Rot–RR	–	–	0.76	21.5	–	–	0.87	22.6	0.68	12.4	–	–	0.68	10.1	–	–
Mean	0.69	20.3	0.75	21.4	1.06	17.5	0.83	21.8	0.71	12.6	0.67	9.2	0.67	9.0	0.68	6.3
F test	ns	*	ns	ns	ns	***	ns	ns	ns	*	*	ns	ns	ns	ns	ns
CV (%)	20.0	29.5	23.0	36.3	15.6	22.4	25.0	33.6	17.8	35.8	17.7	56.6	19.1	28.5	25.0	29.4
Interaction	ns	ns	ns	ns	ns	ns	ns	*	ns	ns	ns	ns	ns	ns	ns	ns
LSD 0.05	–	5.0	–	–	–	3.3	–	–	–	3.7	0.07	–	–	–	–	–

*, **, *** = Treatment differences and interactions are significant at P = 0.05, 0.01, 0.001 level, respectively.
ns = Treatment differences and interactions are not significant at P = 0.05 level

Appendix Table 4 – Effect of N rates and cropping systems on maize seed P concentration (%) and uptake (kg/ha) at maturity.

Fertilizer kg N/ha	Kimutwa								Masii							
	L R	1988	S R	1988/89	L R	1989	S R	1989/90	L R	1988	S R	1988/89	L R	1989	S R	1989/90
	%	kg/ha	%	kg/ha	%	kg/ha	%	kg/ha	%	kg/ha	%	kg/ha	%	kg/ha	%	kg/ha
0	0.15	3.8	0.15	6.5	0.17	2.6	0.16	4.1	0.17	0.4	0.26	2.8	0.20	0.5	0.28	0.5
25	0.16	4.8	0.14	7.7	0.18	3.1	0.18	7.0	0.17	1.0	0.26	5.1	0.15	1.8	0.25	3.3
50	0.15	5.2	0.13	7.3	0.17	2.8	0.15	6.8	0.16	1.3	0.26	8.7	0.13	2.2	0.22	5.9
100	0.15	5.5	0.13	7.7	0.16	2.6	0.17	6.8	0.15	1.5	0.24	9.7	0.14	1.9	0.19	8.0
Mean	0.15	4.8	0.14	7.3	0.17	2.8	0.17	6.2	0.16	1.0	0.26	6.6	0.16	1.6	0.23	4.4
F test	ns	*	ns	ns	ns	ns	ns	*	ns	ns	ns	*	*	ns	*	**
CV (%)	5.20	8.3	8.50	14.7	22.0	2.7	9.9	13.4	10.6	54.6	5.4	30.8	12.9	38.7	10.6	33.5
LSD 0.05	–	0.8	–	–	–	–	–	1.7	–		–	4.1	0.04	–	0.05	2.9
Cropping systems																
MSC	0.15	5.2	0.14	7.1	0.16	3.3	0.17	5.7	0.16	0.9	0.25	7.0	0.15	2.1	0.22	5.3
MISNR	0.16	4.7	0.13	6.2	0.18	2.4	0.16	5.7	0.17	0.8	0.25	4.9	0.17	1.3	0.27	5.0
MISRR	0.15	5.1	0.14	6.7	0.16	2.4	0.18	7.2	0.14	0.7	0.27	7.0	0.16	1.0	0.23	4.0
MIANR	0.15	4.3	0.15	7.0	0.18	3.0	0.17	6.5	0.16	0.9	0.26	7.0	0.13	1.1	0.24	3.8
MIARR	0.15	4.5	0.13	6.6	0.17	2.8	0.16	5.5	0.17	1.0	0.26	7.0	0.17	1.6	0.22	4.1
Rot–NR	–	–	0.14	9.0	–	–	0.15	5.8	0.16	1.3	–	–	0.15	3.2	–	–
Rot–RR	–		0.14	6.3	–	–	0.17	7.0	0.18	1.7	–	–	0.16	2.0	–	–
Mean	0.15	4.8	0.14	7.3	0.17	2.8	0.17	6.2	0.16	1.0	0.26	6.6	0.16	1.6	0.23	4.4
F test	ns	ns	ns	**	ns	*	*	*	ns	**	ns	ns	ns	*	ns	ns
CV (%)	10.0	19.4	22.6	23.7	21.9	29.2	13.6	22.7	28.0	59.6	12.2	41.9	23.2	58.2	21.7	78.9
Interaction	ns	ns	ns	ns	ns	*	ns	*	ns	ns	ns	ns	ns	ns	ns	ns
LSD 0.05	–	–	ns	1.40	–	0.68	0.03	1.2	–	0.4	–	–	–	0.8	–	–

*, ** = Treatment differences and interactions are significant at P = 0.05, 0.01 level, respectively.
ns = Treatment differences and interactions are not significant at P = 0.05 level

Appendix Table 5 – Effect of N rates and cropping systems on maize stover P concentration (%) and uptake (kg/ha) at maturity.

Fertilizer kg N/ha	Kimutwa								Masii							
	L R 1988		S R 1988/89		L R 1989		S R 1989/90		L R 1988		S R 1988/89		L R 1989		S R 1989/90	
	%	kg/ha	%	kg/ha	%	kg/ha	%	kg/ha	%	kg/ha	%	kg/ha	%	kg/ha	%	kg/ha
0	0.03	0.6	0.08	2.0	0.06	0.9	0.16	4.1	0.09	0.9	0.10	0.6	0.07	0.3	0.15	0.7
25	0.04	1.2	0.07	2.1	0.18	0.7	0.18	7.0	0.09	1.4	0.05	0.6	0.05	0.7	0.08	0.7
50	0.03	0.9	0.07	1.7	0.05	0.8	0.15	6.8	0.07	1.3	0.05	0.8	0.05	0.9	0.4	0.4
100	0.04	1.3	0.09	2.3	0.04	0.7	0.17	6.8	0.07	1.7	0.06	1.0	0.05	0.8	0.04	0.5
Mean	0.04	1.0	0.08	2.0	0.08	0.8	0.17	6.2	0.08	1.3	0.07	0.7	0.05	0.7	0.04	0.6
F test	ns	ns	ns	ns	ns	ns	ns	•	ns	•	ns	ns	ns	•	•	ns
CV (%)	35.0	41.7	21.1	24.8	145.8	28.8	9.9	13.4	14.9	18.5	40.4	39.0	23.9	24.0	39.5	38.0
LSD 0.05	–	–	–	–	–	–	–	1.7	–	0.5	–		–	0.3	0.06	–
Cropping systems																
MSC	0.04	1.3	0.06	2.0	0.05	0.9	0.17	5.7	0.08	1.4	0.04	0.9	0.05	0.6	0.07	0.5
MISNR	0.03	0.9	0.07	1.8	0.05	0.6	0.16	5.7	0.07	1.2	0.07	0.6	0.06	0.7	0.08	0.5
MISRR	0.03	1.0	0.07	2.1	0.06	0.8	0.18	7.2	0.08	1.1	0.07	0.6	0.06	0.6	0.09	0.8
MIANR	0.04	1.1	0.08	1.9	0.04	0.7	0.17	6.5	0.08	1.2	0.07	0.8	0.05	0.6	0.07	0.5
MIARR	0.03	0.7	0.07	1.8	0.22	0.9	0.16	5.5	0.07	1.0	0.07	0.9	0.06	0.6	0.08	0.6
Rot–NR	–	–	0.11	2.4	–	–	0.15	5.8	0.09	1.9	–	–	0.05	0.8	–	–
Rot–RR	–	–	0.07	2.0	–	–	0.17	7.0	0.08	1.4	–	–	0.05	0.7	–	–
Mean	0.04	1.0	0.08	2.0	0.08	0.8	0.17	6.2	0.08	1.3	0.07	0.7	0.05	0.7	0.08	0.6
F test	ns	ns	ns	ns	ns	ns	8	•	ns	•	ns	ns	ns	ns	ns	ns
CV (%)	19.8	68.8	68.4	40.2	308.7	42.6	13.6	22.7	29.8	47.8	68.3	69.9	36.7	43.0	47.8	46.3
Interaction	–	ns	ns	ns	ns	ns	ns	•	ns	ns	ns	ns	ns	ns	ns	ns
LSD 0.05	–	–	–	–	–	–	0.26	1.2	–	0.5	–	–	–	–	–	–

• = Treatment differences and interactions are significant at P = 0.05 level.
ns = Treatment differences and interactions are not significant at P = 0.05 level

Appendix Table 6 – Effect of N rates and cropping systems on maize seed K concentration (%) and uptake (kg/ha) at maturity.

Fertilizer kg N/ha	Kimutwa								Masii							
	L R	1988	S R	1988/89	L R	1989	S R	1989/90	L R	1988	S R	1988/89	L R	1989	S R	1989/90
	%	kg/ha	%	kg/ha	%	kg/ha	%	kg/ha	%	kg/ha	%	kg/ha	%	kg/ha	%	kg/ha
0	0.21	5.1	0.30	12.4	0.26	4.3	0.27	6.6	0.30	0.7	0.29	3.0	0.25	0.6	0.36	0.7
25	0.23	7.1	0.26	13.9	0.26	4.2	0.25	10.0	0.32	1.7	02.3	4.1	0.23	2.7	0.32	4.5
50	0.22	7.8	0.25	13.8	0.28	4.7	0.25	11.5	0.30	2.3	0.29	11.6	0.22	3.3	0.30	7.6
100	0.21	7.1	0.23	13.6	0.29	4.9	0.26	10.8	0.30	2.9	0.31	11.9	0.23	3.3	0.27	10.4
Mean	0.22	6.7	0.26	13.4	0.27	4.5	0.26	9.7	0.30	1.9	0.28	7.6	0.23	2.5	0.31	5.8
F test	ns	ns	ns	ns	ns	ns	ns	*	ns	ns	ns	*	ns	*	**	**
CV (%)	19.3	22.0	11.3	14.6	18.1	21.7	10.3	13.9	23.9	45.8	14.3	39.1	5.20	36.5	6.50	36.5
LSD 0.05	–	–	–	–	–	–	–	2.7	–	–	–	5.9	–	1.8	0.04	4.3
Cropping systems																
MSC	0.23	7.8	0.24	12.1	0.28	5.7	0.25	8.7	0.38	2.7	0.28	10.0	0.23	3.0	0.31	7.3
MISNR	0.21	6.3	0.30	13.8	0.26	3.6	0.27	9.5	0.35	1.8	0.30	5.4	0.22	2.0	0.32	6.3
MISRR	0.23	7.6	0.24	11.7	0.28	4.5	0.26	10.5	0.26	1.3	0.29	7.8	0.25	2.0	0.32	5.4
MIANR	0.20	5.9	0.25	11.8	0.28	4.7	0.25	9.3	0.28	1.6	0.28	7.9	0.22	1.9	0.31	4.7
MIARR	0.21	6.2	0.27	13.1	0.25	4.2	0.26	9.2	0.28	1.5	0.25	7.1	0.24	2.4	0.30	5.4
Rot–NR	–	–	0.24	14.8	–	–	0.26	10.0	0.28	2.2	–	–	0.24	3.3	–	–
Rot–RR	–	–	0.29	16.8	–	–	0.25	10.7	0.29	2.3	–	–	0.22	2.9	–	–
Mean	0.22	6.7	0.26	13.4	0.27	4.5	0.26	9.7	0.30	1.9	0.28	7.6	0.23	2.5	0.31	5.8
F test	ns	ns	ns	*	ns	*	ns	ns	*	*	ns	ns	ns	**	ns	ns
CV (%)	27.1	29.4	31.8	27.9	24.4	32.1	13.3	26.7	32.0	22.8	26.0	47.6	16.0	3.8	12.5	75.5
Interaction	*	*	ns	ns	ns	ns	*	*	ns	ns	ns	ns	ns	ns	–	–
LSD 0.05	–	–	–	3.1	–	1.2	–	–	0.08	0.9	–	–	–	0.9	–	

*, ** = Treatment differences and interactions are significant at P = 0.05, 0.01 level, respectively.
ns = Treatment differences and interactions are not significant at P = 0.05 level

Appendix Table 7 - Effect of N rates and cropping systems on maize stover K concentration (%) and uptake (kg/ha) at maturity.

Fertilizer kg N/ha	Kimutwa								Masii							
	L R	1988	SR	1988/89	L R	1989	S R	1989/90	L R	1988	S R	1988/89	L R	1989	S R	1989/90
	%	kg/ha	%	kg/ha	%	kg/ha	%	kg/ha	%	kg/ha	%	kg/ha	%	kg/ha	%	kg/ha
0	1.3	26.8	1.94	46.7	0.86	12.5	1.1	22.9	1.27	12.3	2.02	9.9	1.27	7.4	0.65	3.3
25	1.3	37.7	1.94	54.2	0.78	13.7	1.1	28.2	1.15	20.8	2.22	38.6	1.67	22.9	0.84	8.6
50	1.4	46.3	2.06	53.1	0.86	15.1	1.1	33.1	1.11	22.4	2.10	3809	1.64	32.3	0.85	8.7
100	1.3	44.4	2.15	74.9	0.76	12.8	1.3	34.4	1.50	39.1	2.25	38.6	1.32	21.5	1.02	12.7
Mean	1.3	38.8	2.00	57.2	0.81	13.5	1.1	29.6	1.30	23.6	2.14	31.5	1.48	21.0	0.84	8.3
F test	ns	ns	ns	ns	ns	ns	ns	*	ns	*	ns	ns	ns	**	ns	*
CV (%)	17.2	25.0	9.7	17.4	14.5	20.2	7.9	12.9	12.8	31.0	15.3	49.3	12.1	23.2	18.8	35.8
LSD 0.05	-	-	-	-	-	-	-	7.6	-	14.6	-	-	-	9.7	-	5.9
Cropping systems																
MSC	1.5	50.0	2.02	69.4	0.89	17.7	1.2	32.2	1.07	22.8	2.44	50.5	1.42	19.6	0.87	8.6
MISNR	1.2	31.9	1.94	49.2	0.85	11.7	1.1	32.9	1.34	23.9	2.00	23.4	1.36	18.4	0.80	7.7
MISRR	1.3	41.7	1.99	58.3	0.74	11.4	1.2	30.5	1.24	19.9	1.90	22.4	1.38	14.9	0.80	9.1
MIANR	1.3	31.1	2.00	46.3	0.81	14.1	1.0	26.7	1.22	21.0	2.53	33.5	1.50	21.2	0.84	7.5
MIARR	1.4	39.4	1.97	42.4	0.79	12.7	1.1	27.2	1.27	19.9	1.84	27.8	1.63	20.4	0.89	8.6
Rot-NR	-	-	2.17	73.4	-	-	1.2	27.7	1.36	31.7	-	-	1.62	28.9	-	-
Rot-RR	-	-	2.06	61.5	-	-	1.2	30.4	1.29	26.3	-	-	1.43	23.6	-	-
Mean	1.3	38.8	2.00	57.2	0.81	13.5	1.1	29.6	1.30	23.6	2.14	31.5	1.48	21.0	0.84	8.3
F test	ns	**	ns	*	ns	*	ns	ns	ns	ns	*	*	ns	**	ns	ns
CV (%)	20.6	32.8	12.4	41.1	23.5	35.8	17.2	26.3	27.4	54.2	28.2	66.2	19.8	40.0	20.3	35.9
Interaction	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
LSD 0.05	-	10.6	-	19.4	-	4.0	-	-	-	-	0.50	17.4	-	6.9	-	-

*, ** = Treatment differences and interactions are significant at P = 0.05, 0.01 level, respectively.
ns = Treatment differences and interactions are not significant at P = 0.05 level

Appendix Table 8 - Effect of N rates and cropping systems on maize seed Mg concentration (%) and uptake (kg/ha) at maturity.

Fertilizer kg N/ha	Kimutwa								Masii							
	L R	1988	S R	1988/89	L R	1989	S R	1989/90	L R	1988	S R	1988/89	L R	1989	S R	1989/90
	%	kg/ha	%	kg/ha	%	kg/ha	%	kg/ha	%	kg/ha	kg/ha	%	kg/ha	%	kg/ha	kg/ha
0	0.06	1.6	0.06	1.6	0.08	1.2	0.08	2.1	0.03	0.08	0.06	0.7	0.12	0.3	0.12	0.3
25	0.07	2.2	0.04	2.3	0.08	1.5	0.08	3.2	0.04	0.20	0.05	1.1	0.09	1.1	0.11	1.4
50	0.07	2.3	0.06	2.7	0.08	1.4	0.08	3.8	0.04	0.30	0.06	2.4	0.09	1.4	0.10	2.4
100	0.07	2.5	0.05	2.4	0.08	1.5	0.08	3.5	0.03	0.30	0.06	2.4	0.10	1.4	0.10	4.0
Mean	0.07	2.1	0.05	2.3	0.08	1.4	0.08	3.1	0.04	0.20	0.06	1.6	0.10	1.0	0.11	2.0
F test	*	**	ns	ns	ns	ns	ns	*	ns	ns	ns	*	*	ns	*	***
CV (%)	4.10	10.2	47.8	22.3	3.30	12.5	3.30	13.8	7.8	53.8	13.6	38.6	12.0	43.9	5.20	25.8
LSD 0.05	0.006	0.4	-	-	-	-	-	0.9	-	-	-	1.20	0.02	-	0.01	1.0
Cropping systems																
MSC	0.07	2.4	0.04	2.1	0.08	1.8	0.08	2.8	0.04	0.30	0.06	1.9	0.10	1.2	0.09	2.0
MISNR	0.07	2.0	0.04	2.0	0.09	1.2	0.09	3.1	0.04	0.20	0.06	1.2	0.10	0.9	0.11	2.3
MISRR	0.07	2.4	0.04	2.1	0.09	1.3	0.09	3.6	0.03	0.20	0.07	1.9	0.10	0.7	0.11	2.0
MIANR	0.07	1.9	0.04	1.9	0.08	1.4	0.08	3.2	0.03	0.20	0.06	1.6	0.10	0.8	0.11	1.8
MIARR	0.07	2.0	0.10	2.2	0.08	1.4	0.08	2.6	0.04	0.20	0.05	1.6	0.11	0.9	0.11	2.0
Rot-NR	-	-	0.06	3.0	0.08	-	0.08	3.2	0.03	0.30	-	-	0.10	1.4	-	-
Rot-RR	-	-	0.04	2.5	0.08	-	0.08	3.7	0.04	0.30	-	-	0.10	1.4	-	-
Mean	0.07	2.1	0.05	2.3	0.08	1.4	0.08	3.1	0.04	0.20	0.06	1.6	0.10	1.0	0.11	2.0
F test	ns	*	ns	**	**	**	**	**	ns	ns	ns	*	ns	*	ns	ns
CV (%)	14.5	21.4	118.2	30.5	3.70	25.9	3.7	19.1	31.8	57.9	23.9	39.8	27.3	57.2	15.8	67.1
Interaction	ns	ns	ns	ns	ns	ns	ns	**	ns	ns	ns	***	ns	ns	ns	ns
LSD 0.05	-	0.4	-	0.2	0.007	0.30	0.007	0.5	-	-	-	0.50	-	0.5	-	-

*, **, *** = Treatment differences and interactions are significant at P = 0.05, 0.01, 0.001 level, respectively.
ns = Treatment differences and interactions are not significant at P = 0.05 level

Appendix Table 9 – Effect of N rates and cropping systems on maize stover Mg concentration (%) and uptake (kg/ha) at maturity.

Fertilizer kg N/ha	Kimutwa								Masii							
	L R	1988	S R	1988/89	L R	1989	S R	1989/90	L R	1988	S R	1988/89	L R	1989	S R	1989/90
	%	kg/ha	%	kg/ha	%	kg/ha	%	kg/ha	%	kg/ha	%	kg/ha	%	kg/ha	%	kg/ha
0	0.17	3.3	0.16	4.2	0.19	2.5	0.30	6.3	0.63	5.5	0.49	2.8	0.26	1.3	0.16	0.8
25	0.18	5.5	0.16	4.3	0.19	3.2	0.30	7.8	1.06	12.5	0.40	6.1	0.29	3.7	0.17	1.7
50	0.15	5.2	0.15	3.9	0.20	3.5	0.30	8.5	0.75	14.8	0.45	8.4	0.25	4.8	0.14	1.5
100	0.19	6.3	0.16	5.7	0.21	3.6	0.35	9.9	0.69	16.9	0.38	6.0	0.23	3.9	0.15	1.9
Mean	0.17	5.0	0.16	4.5	0.20	3.2	0.31	8.2	0.78	12.4	0.43	5.8	0.26	3.4	0.15	1.5
F test	ns	ns	ns	ns	ns	ns	ns	**	ns	**	ns	ns	ns	**	ns	ns
CV (%)	16.9	21.7	14.9	23.1	33.9	14.7	7.70	9.9	38.9	17.2	15.1	35.4	9.20	18.4	10.9	32.5
LSD 0.05	–	–	–	–	–	–	–	1.6	–	4.3	–	–	–	1.0	–	–
Cropping systems																
MSC	0.16	5.6	0.15	4.8	0.19	3.6	0.31	8.4	0.75	14.4	0.43	7.9	0.29	3.6	0.15	1.5
MISNR	0.16	4.6	0.16	4.1	0.19	2.5	0.31	8.5	0.68	11.0	0.42	4.6	0.26	3.2	0.15	1.4
MISRR	0.18	5.9	0.16	4.5	0.20	3.1	0.31	8.5	0.68	10.3	0.40	3.8	0.24	2.8	0.17	1.8
MIANR	0.16	4.3	0.16	4.1	0.20	3.5	0.30	8.2	0.71	11.6	0.48	6.5	0.25	3.2	0.15	
MIARR	0.18	4.9	0.16	3.3	0.21	3.4	0.31	8.3	0.74	11.3	0.44	6.4	0.26	3.3	0.15	1.4
Rot–NR	–	–	0.15	5.2	–	–	0.31	7.4	0.68	15.6	–	–	0.24	4.0	–	–
Rot–RR	–	–	0.19	5.6	–	–	0.32	8.0	1.23	12.5	–	–	0.26	3.9	–	–
Mean	0.17	5.0	0.16	4.5	0.20	3.2	0.31	8.2	0.78	12.4	0.43	5.8	0.26	3.4	0.15	1.5
F test	ns	ns	ns	*	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	*
CV (%)	21.6	37.4	20.0	38.1	72.8	27.6	17.0	28.6	89.7	39.1	25.9	71.4	19.3	29.4	17.4	24.7
Interaction	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	***
LSD 0.05	–	–	–	1.1	–	–	–	–	–	–	–	–	–	–	–	0.3

*, **, *** = Treatment differences and interactions are significant at P = 0.05, 0.01, 0.001 level, respectively.
ns = Treatment differences and interactions are not significant at P = 0.05 level

Appendix Table 10 – Effect of N rates and cropping systems on maize stover Ca concentration (%) and uptake (kg/ha) at maturity.

Fertilizer kg N/ha	Kimutwa								Masii							
	L R	1988	S R	1988/89	L R	1989	S R	1989/90	L R	1988	S R	1988/89	L R	1989	S R	1989/90
	%	kg/ha	%	kg/ha	%	kg/ha	%	kg/ha	%	kg/ha	%	kg/ha	%	kg/ha	%	kg/ha
0	0.37	7.4	0.12	3.0	0.26	3.6	0.29	5.9	0.33	3.1	0.29	1.7	0.66	4.3	0.23	0.4
25	0.47	14.3	0.17	4.4	0.29	5.0	0.33	8.5	0.38	6.5	0.29	4.3	0.79	10.6	0.27	3.6
50	0.37	13.0	0.13	3.3	0.28	4.9	0.34	9.6	0.36	7.0	0.29	5.1	0.71	14.0	0.26	6.6
100	0.45	15.2	0.16	5.2	0.29	4.9	0.30	8.3	0.34	8.1	0.27	4.3	0.70	11.8	0.28	10.2
Mean	0.41	12.5	0.15	4.0	0.28	4.6	0.31	8.1	0.35	6.2	0.28	3.8	0.71	10.2	0.26	5.2
F test	ns	*	*	ns	ns	ns	ns	ns	ns	*	ns	**	ns	**	ns	**
CV (%)	17.6	21.7	13.8	23.2	11.3	14.1	20.8	15.7	17.4	20.7	13.4	19.7	6.30	15.7	10.9	34.6
LSD 0.05	–	5.4	0.04	–	–	–	–	–	–	2.1	–	1.5	–	3.2	–	3.6
Cropping systems																
MSC	0.42	14.9	0.14	4.7	0.28	5.6	0.31	8.0	0.32	6.3	0.26	4.8	0.69	10.4	0.26	6.7
MISNR	0.41	11.3	0.15	3.8	0.26	3.5	0.30	8.6	0.33	5.1	0.30	3.5	0.70	9.0	0.26	5.6
MISRR	0.44	14.6	0.15	3.7	0.30	4.9	0.30	8.5	0.36	5.6	0.29	3.0	0.69	7.7	0.26	3.8
MIANR	0.37	9.5	0.15	4.2	0.27	4.7	0.31	7.8	0.35	5.7	0.29	3.9	0.68	9.5	0.27	5.0
MIARR	0.43	12.0	0.13	2.8	0.29	4.5	0.30	7.6	0.37	5.7	0.28	4.0	0.78	10.4	0.26	5.0
Rot–NR	–	–	0.15	4.3	–	–	0.32	6.8	0.38	8.5	–	–	0.73	12.6	–	–
Rot–RR	–	–	0.15	4.3	–	–	0.36	9.2	0.36	6.4	–	–	0.72	11.6	–	–
Mean	0.41	12.5	0.15	4.0	0.28	4.6	0.31	8.1	0.35	6.2	0.28	3.8	0.71	10.2	0.26	5.2
F test	ns	ns	ns	ns	ns	*	ns	ns	ns	ns	ns	ns	ns	*	ns	ns
CV (%)	28.1	43.5	23.8	47.5	18.9	32.7	18.8	29.3	18.1	43.3	21.6	61.7	13.1	34.5	16.5	77.7
Interaction	ns	ns	ns	ns	ns	ns	ns	ns	*	ns	ns	ns	ns	ns	ns	ns
LSD 0.05	–	–	–	–	–	1.3	–	–	–	–	–	–	–	2.9	–	–

*, ** = Treatment differences and interactions are significant at P = 0.05, 0.01 level, respectively.
ns = Treatment differences and interactions are not significant at P = 0.05 level

Appendix Table 11 – Effect of N and cropping systems on bean seed N concentration (%) and uptake (kg / ha) at maturity.

Fertilizer kg N/ha	Kimutwa								Masii							
	L R	1988	S R	1988/89	L R	1989	S R	1989/90	L R	1988	S R	1988/89	L R	1989	S R	1989/90
	%	kg/ha	%	kg/ha	%	kg/ha	%	kg/ha	%	kg/ha	%	kg/ha	%	kg/ha	%	kg/ha
0	3.22	44.7	3.52	10.6	3.49	22.3	3.49	18.3	3.19	10.3	3.29	17.3	3.45	13.3	3.22	29.2
25	3.35	60.3	3.62	14.9	3.70	35.6	3.72	32.5	5.06	28.1	3.33	26.7	3.56	26.5	3.23	47.2
50	3.59	72.9	3.75	14.9	3.75	39.3	3.63	40.9	3.53	31.2	3.43	32.0	3.87	31.0	3.32	70.5
100	3.60	72.9	3.92	15.5	3.70	34.2	4.22	39.3	3.63	31.2	3.55	29.0	3.95	28.2	3.50	54.3
Mean	3.44	62.7	3.70	37.8	3.66	32.9	3.77	32.8	3.85	25.5	3.40	26.3	3.71	24.8	3.32	50.3
F test	ns	*	ns	ns	ns	***	***	**	ns	*	ns	ns	ns	ns	ns	ns
CV (%)	5.00	13.2	4.40	8.4	3.60	5.5	1.90	15.2	37.3	29.8	3.10	20.9	22.4	28.6	5.10	35.1
LSD 0.05	–	16.5	–	–	–	3.6	0.14	10.0	–	15.0	–	–	–	–		
cropping systems																
BSCNR	3.41	67.3	3.76	20.9	3.59	33.5	3.64	54.7	3.35	34.4	3.46	28.0	3.58	33.7	3.22	58.3
BSCRR	3.31	78.8	3.74	15.8	3.63	32.6	3.65	41.0	5.96	29.9	3.39	23.6	3.83	29.0	3.43	46.9
BISNR	3.44	51.4	3.52	12.0	3.69	24.1	3.88	30.0	3.41	23.9	3.43	28.1	3.57	18.8	3.29	44.1
BISRR	3.48	49.1	3.75	13.7	3.69	24.0	3.83	22.6	3.44	21.7	3.39	22.7	3.78	24.0	3.48	39.6
BIANR	3.46	37.5	3.78	13.4	3.70	19.5	3.88	24.3	3.53	19.7	3.39	19.0	3.88	21.6	3.49	36.5
BIARR	3.55	39.0	3.66	8.0	3.68	16.4	3.73	23.9	3.43	21.6	3.28	21.2	3.61	21.3	3.26	36.7
Rot–NR	3.45	93.6	–	–	3.58	57.7	–	–	–	–	3.48	38.3	–	–	3.21	72.5
Rot–RR	3.46	84.8	–	–	3.69	54.7	–	–	–	–	3.36	29.3	–	–	3.19	67.5
Mean	3.44	62.7	3.70	37.8	3.66	32.9	3.77	32.8	3.85	25.2	3.40	26.3	3.71	24.8	3.32	50.3
F test	ns	***	ns	***	ns	***	ns	***	ns	*	ns	**	ns	***	ns	***
CV (%)	6.30	22.4	8.50	13.5	6.40	17.6	7.60	29.1	94.8	43.0	7.10	40.1	11.9	24.0	12.9	42.7
Interaction	ns	ns	ns	ns	ns	**	ns	ns	ns	ns	ns	ns	ns	**	ns	ns
LSD 0.05	–	11.5	–	4.2	–	11.1	–	7.9	–	8.9	–	8.6	–	4.9	–	17.6

*, **, *** = Treatment differences and interactions are significant at P = 0.05, 0.01, 0.001 level, respectively
ns = Treatment differences and interactions are not significant at P = 0.05 level.

Appendix Table 12 – Effect of N rates and cropping systems on bean haulms N concentration (%) and uptake (kg/ ha) at maturity.

Fertilizer kg N/ha	Kimutwa								Masii							
	L R	1988	S R	1988/89	L R	1989	S R	1989/90	L R	1988	S R	1988/89	L R	1989	S R	1989/90
	%	kg/ha	%	kg/ha	%	kg/ha	%	kg/ha	%	kg/ha	%	kg/ha	%	kg/ha	%	kg/ha
0	0.67	4.9	1.20	5.8	1.65	12.5	1.07	3.6	0.94	1.4	0.97	4.8	1.20	6.4	0.79	4.8
25	0.76	8.4	1.10	6.6	1.85	18.9	1.13	6.5	0.89	2.6	1.00	7.4	1.09	7.6	0.74	6.9
50	0.69	7.2	1.15	6.9	1.45	16.4	1.11	7.8	0.96	4.1	1.02	8.1	0.90	7.6	0.72	11.0
100	0.76	7.9	1.11	7.6	1.37	11.7	1.26	8.2	0.95	3.7	1.02	8.7	1.12	7.7	0.77	9.2
Mean	0.72	7.1	1.14	6.7	1.58	14.9	1.14	6.5	0.94	3.0	1.00	7.3	1.08	7.3	0.76	8.0
F test	ns	*	ns	ns	ns	ns	*	**	ns	ns	ns	*	ns	ns	ns	ns
CV (%)	8.20	12.1	13.0	24.5	27.0	3.4	4.80	16.9	8.00	47.9	12.6	13.8	11.6	18.1	6.20	32.1
LSD 0.05	–	1.7	–	–	–	–	0.11	2.2	–	–	–	2.0	–	–	–	–
cropping systems																
BSCNR	0.74	8.3	1.06	8.0	1.67	17.6	1.14	8.3	0.87	4.2	1.11	8.4	0.94	8.7	0.69	8.2
BSCRR	0.66	6.9	1.27	9.1	1.72	16.0	1.11	6.8	0.99	4.0	1.03	6.6	1.03	6.9	0.77	8.0
BISNR	0.73	5.7	1.07	5.4	1.59	11.6	1.18	6.3	0.85	2.8	0.94	6.8	1.10	7.4	0.76	7.5
BISRR	0.74	5.7	1.15	6.2	1.49	11.5	1.18	6.0	0.95	2.8	0.98	6.3	1.21	8.4	0.81	6.1
BIANR	0.76	4.6	1.19	6.7	1.83	11.5	1.10	6.0	0.97	1.9	1.10	5.5	1.12	6.4	0.82	5.9
BIARR	0.75	5.0	1.09	4.8	1.76	10.1	1.14	6.0	0.98	2.2	0.91	6.5	1.07	6.0	0.71	5.9
Rot–NR	0.69	10.9	–	–	1.21	20.0	–	–	–	–	0.93	9.1	–	–	0.75	11.0
Rot–RR	0.72	9.9	–	–	1.31	20.7	–	–	–	–	1.02	8.8	–	–	0.71	10.7
Mean	0.72	7.1	1.14	6.7	1.58	14.9	1.14	6.5	0.94	3.0	1.00	7.3	1.08	7.3	0.76	18.0
F test	ns	***	ns	***	8	***	ns	ns	ns	***	ns	*	*	*	ns	***
CV (%)	15.3	33.2	20.0	31.0	27.9	30.1	10.5	34.1	23.0	39.0	21.0	37.4	17.4	30.6	16.5	37.6
Interaction	ns	*	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
LSD 0.05	–	1.9	–	1.7	0.40	3.7	–	–	–	1.0	–	2.2	0.15	1.8	–	2.4

*, **, *** = Treatment differences and interactions are significant at P = 0.05, 0.01, 0.001 level, respectively.
ns = Treatment differences and interactions are not significant at P = 0.05 level.

Appendix Table 13 – Effect of N rates and cropping systems on bean seed P concentration (%) and uptake (kg/ha) at maturity.

Fertilizer kg N/ha	Kimutwa								Masii							
	L R	1988	S R	1988/89	L R	1989	S R	1989/90	L R	1988	S R	1988/89	L R	1989	S R	1989/90
	%	kg/ha	%	kg/ha	%	kg/ha	%	kg/ha	%	kg/ha	%	kg/ha	%	kg/ha	%	kg/ha
0	0.28	3.8	0.26	0.8	0.28	1.8	0.30	1.6	0.30	1.0	0.32	1.6	0.33	1.3	0.25	2.1
25	0.24	4.3	0.27	1.2	0.26	2.4	0.27	2.3	0.22	1.9	0.30	2.3	0.30	2.4	0.22	3.2
50	0.25	5.2	0.26	1.1	0.27	2.7	0.29	3.1	0.22	1.9	0.30	2.7	0.30	2.4	0.26	5.5
100	0.25	5.1	0.25	1.0	0.26	2.3	0.27	2.7	0.22	1.9	0.31	2.4	0.32	2.1	0.20	3.2
Mean	0.26	4.6	0.26	1.0	0.27	2.3	0.28	2.4	0.24	1.7	0.30	2.3	0.31	2.1	0.23	3.5
F test	•	ns	ns	ns	ns	••	ns	•••	••	ns	ns	ns	ns	•••	ns	ns
CV (%)	4.30	14.2	8.60	29.3	5.90	6.9	10.3	9.0	7.60	35.3	3.70	23.6	8.30	7.0	11.9	36.3
LSD 0.05	0.02	–	–	–	–	0.3	–	0.4	0.04	–	–	–	–	0.3	–	–
cropping systems																
BSCNR	0.27	5.2	0.29	1.5	0.27	2.5	0.29	4.1	0.24	2.3	0.32	2.5	0.31	2.8	0.23	4.0
BSCRR	0.26	5.9	0.27	1.2	0.28	2.4	0.29	3.2	0.27	2.2	0.31	2.2	0.32	2.5	0.24	3.0
BISNR	0.25	3.7	0.25	0.9	0.26	1.8	0.27	1.9	0.23	1.5	0.30	2.4	0.30	1.6	0.21	3.2
BISRR	0.26	3.5	0.25	1.0	0.27	1.8	0.29	1.7	0.23	1.3	0.30	2.0	0.31	2.0	0.23	2.6
BIANR	0.23	2.5	0.25	0.9	0.27	1.4	0.28	1.8	0.23	1.2	0.30	1.6	0.31	1.7	0.23	2.4
BIARR	0.26	2.7	0.25	0.5	0.28	1.2	0.27	1.6	0.24	1.4	0.30	1.9	0.32	1.8	0.23	3.0
Rot-NR	0.26	6.7	–	–	0.25	3.8	–	–	–	–	0.30	3.1	–	–	0.23	5.0
Rot-RR	0.26	6.5	–	–	0.26	3.7	–	–	–	–	0.30	2.6	–	–	0.26	4.8
Mean	0.26	4.6	0.26	1.0	0.27	2.3	0.28	2.4	0.24	1.7	0.30	2.3	0.31	2.1	0.23	3.5
F test	•	•••	•	•••	••	•••	ns	•••	ns	•••	ns	••	ns	•••	ns	•••
CV (%)	10.4	23.0	13.7	34.6	7.50	16.3	10.0	29.9	13.2	43.3	11.5	41.4	7.00	19.5	16.8	47.0
Interaction	ns	ns	ns	ns	ns	••	–	ns	ns	ns	ns	ns	••	•••	ns	ns
LSD 0.05	0.30	0.9	0.03	0.3	0.02	0.3	–	0.6	–	0.6	–	0.8	–	0.30	–	1.3

•, ••, ••• = Treatment differences and interactions are significant at P = 0.05, 0.01, 0.001 level, respectively.
ns = Treatment differences and interactions are not significant at P = 0.05 level.

Appendix Table 14 – Effect of N rates and cropping systems on bean haulms P concentration (%) and uptake (kg/ha) at maturity.

Fertilizer kg N/ha	Kimutwa								Masii							
	L R	1988	S R	1988/89	L R	1989	S R	1989/90	L R	1988	S R	1988/89	L R	1989	S R	1989/90
	%	kg/ha	%	kg/ha	%	kg/ha	%	kg/ha	%	kg/ha	%	kg/ha	%	kg/ha	%	kg/ha
0	0.04	0.3	0.12	0.6	0.06	0.4	0.05	0.2	0.08	0.1	0.08	0.4	0.10	0.5	0.06	0.3
25	0.04	0.4	0.09	0.5	0.06	0.6	0.03	0.2	0.08	0.2	0.08	0.6	0.07	0.5	0.06	0.5
50	0.04	0.4	0.09	0.5	0.05	0.6	0.04	0.3	0.05	0.2	0.08	0.6	0.07	0.5	0.06	0.9
100	0.04	0.4	0.09	0.5	0.04	0.3	0.04	0.3	0.05	0.2	0.07	0.5	0.07	0.5	0.06	0.6
Mean	0.04	0.4	0.10	0.5	0.05	0.5	0.04	0.2	0.07	0.2	0.07	0.5	0.08	0.5	0.06	0.6
F test	ns	ns	ns	ns	ns	*	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
CV (%)	16.1	15.8	25.8	26.5	15.8	18.2	22.8	40.8	18.4	41.3	24.2	26.3	22.8	28.4	18.6	36.5
LSD 0.05	–	–	–	–	–	0.2	–	–	–	–	–	–	–	–	–	–
cropping systems																
BSCNR	0.04	0.5	0.09	0.6	0.06	0.5	0.05	0.3	0.08	0.2	0.08	0.6	0.06	0.6	0.05	0.6
BSCRR	0.04	0.3	0.11	0.7	0.05	0.5	0.04	0.3	0.07	0.3	0.08	0.5	0.08	0.5	0.06	0.6
BISNR	0.04	0.2	0.10	0.4	0.06	0.4	0.04	0.2	0.05	0.1	0.07	0.5	0.08	0.5	0.06	0.1
BISRR	0.03	0.3	0.10	0.5	0.06	0.4	0.05	0.2	0.06	0.2	0.08	0.5	0.09	0.6	0.05	0.7
BIANR	0.04	0.2	0.11	0.6	0.05	0.3	0.04	0.2	0.06	0.1	0.08	0.4	0.08	0.4	0.06	0.6
BIARR	0.04	0.3	0.09	0.4	0.05	0.3	0.04	0.2	0.07	0.2	0.07	0.5	0.08	0.4	0.06	0.4
Rot–NR	0.04	0.5	–	–	0.04	0.6	–	–	–	–	0.07	0.7	–	–	0.06	0.4
Rot–RR	0.04	0.5	–	–	0.04	0.7	–	–	–	–	0.07	0.6	–	–	0.06	0.4
Mean	0.04	0.4	0.10	0.5	0.05	0.5	0.04	0.2	0.07	0.2	0.08	0.5	0.08	0.5	0.06	0.6
F test	ns	***	ns	***	ns	***	ns	*	ns	**	ns	ns	ns	*	ns	***
CV (%)	22.1	38.3	27.8	33.4	39.6	42.2	44.4	53.3	78.1	45.0	35.7	55.8	29.5	34.8	25.4	50.9
Interaction	ns	ns	ns	*	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	*
LSD 0.05	–	0.1	–	0.1	–	0.2	–	0.09	–	0.06	–	–	–	0.14	–	0.2

*, **, *** = Treatment differences and interactions are significant at P = 0.05, 0.01, 0.001 level, respectively.
ns = Treatment differences and interactions are not significant at P = 0.05 level.

Appendix Table 15 – Effect of N rates and cropping systems on bean seed K concentration (%) and uptake (kg/ha) at maturity.

Fertilizer kg N/ha	Kimutwa								Masii							
	L R	1988	S R	1988/89	L R	1989	S R	1989/90	L R	1988	S R	1988/89	L R	1989	S R	1989/90
	%	kg/ha	%	kg/ha	%	kg/ha	%	kg/ha	%	kg/ha	%	kg/ha	%	kg/ha	%	kg/ha
0	1.45	20.0	1.50	4.3	1.46	9.5	1.51	8.0	1.57	5.1	1.30	6.8	1.54	5.7	1.75	15.0
25	1.48	26.9	1.48	6.2	1.41	13.5	1.43	12.8	1.42	11.9	1.28	10.0	1.54	11.4	1.71	23.6
50	1.39	28.7	1.50	6.0	1.49	15.8	1.55	17.5	1.46	13.0	1.28	12.0	1.51	12.2	1.69	35.1
100	1.40	28.6	1.50	5.9	1.43	13.4	1.46	14.6	1.56	13.5	1.29	11.0	1.49	10.7	1.88	30.2
Mean	1.43	26.1	1.50	5.6	1.45	13.1	1.49	13.2	1.50	10.8	12.9	10.0	1.52	10.0	1.76	26.0
F test	ns	ns	ns	ns	ns	**	ns	**	ns	ns	ns	ns	ns	***	ns	ns
CV (%)	6.90	14.4	3.40	27.0	3.90	8.3	5.90	15.2	5.80	33.0	4.10	27.0	3.20	7.0	12.2	33.8
LSD 0.05	–	–	–	–	–	2.2	–	4.0	–	–	–	–	–	1.4	–	–
cropping systems																
BSCNR	1.43	28.2	1.54	8.6	1.43	13.4	1.51	22.7	1.44	14.6	1.32	10.8	1.45	13.3	1.82	31.0
BSCRR	1.45	35.2	1.51	6.4	1.50	13.2	1.49	17.2	1.56	13.3	1.30	8.9	1.57	12.2	1.98	27.1
BISNR	1.32	19.4	1.45	4.9	1.44	9.4	1.43	10.5	1.52	10.2	1.30	10.6	1.50	7.8	1.77	20.8
BISRR	1.44	19.6	1.50	5.1	1.43	9.3	1.48	9.7	1.49	9.5	1.28	8.7	1.52	9.5	1.74	20.1
BIANR	1.38	15.4	1.46	5.1	1.42	7.4	1.51	9.7	1.51	8.3	1.29	7.2	1.51	8.3	1.59	14.8
BIARR	1.50	16.2	1.51	3.4	1.43	6.3	1.51	9.6	1.50	9.4	1.25	8.1	1.57	9.0	1.85	21.6
Rot–NR	1.48	39.1	–	–	1.45	23.3	–	–	–	–	1.26	13.6	–	–	1.73	40.0
Rot–RR	1.43	35.4	–	–	1.48	22.1	–	–	–	–	1.30	11.6	–	–	1.59	32.3
Mean	1.43	26.1	1.50	5.6	1.45	13.1	1.49	13.2	1.50	10.8	1.29	10.0	1.52	10.0	1.76	26.0
F test	ns	***	**	***	**	***	ns	***	ns	*	ns	**	ns	***	ns	**
CV (%)	12.3	27.3	4.10	36.4	3.70	17.6	6.30	30.1	9.90	43.5	6.20	38.4	7.40	19.1	28.6	51.4
Interaction	ns	ns	ns	ns	ns	**	ns	ns	ns	ns	ns	ns	ns	***	ns	ns
LSD 0.05	–	4.1	0.05	1.6	0.04	1.9	–	3.30	–	3.9	–	2.2	–	1.6	–	10.9

*, **, *** = Treatment differences and interactions are significant at P = 0.05, 0.01, 0.001, level, respectively.
ns = Treatment differences and interactions are not significant at P = 0.05 level.

Appendix Table 16 – Effect of N rates and cropping systems on bean haulms K concentration (%) and uptake (kg/ha) at maturity.

Fertilizer	Kimutwa								Masii							
	L R	1988	S R	1988/89	L R	1989	S R	1989/90	L R	1988	S R	1988/89	L R	1989	S R	1989/90
kg N/ha	%	kg/ha	%	kg/ha	%	kg/ha	%	kg/ha	%	kg/ha	%	kg/ha	%	kg/ha	%	kg/ha
0	1.54	11.5	1.47	7.2	1.34	10.4	1.27	4.4	1.79	2.4	1.69	8.5	1.86	8.9	1.19	7.2
25	1.50	17.0	1.63	10.3	1.43	15.8	1.32	7.9	1.69	5.3	1.83	15.1	1.59	11.8	1.25	13.2
50	1.50	15.9	1.40	8.2	1.80	21.2	1.49	10.7	1.69	7.7	1.96	17.0	1.53	13.5	1.26	21.3
100	1.53	16.1	1.61	10.3	15.8	14.9	1.46	9.8	1.69	6.4	1.83	17.2	1.49	10.1	1.36	16.6
Mean	1.52	15.1	1.53	9.0	1.54	15.6	1.38	8.2	1.72	5.5	1.83	14.5	1.62	8.9	1.26	14.6
F test	ns	ns	ns	ns	ns	*	*	***	ns	ns	ns	ns	ns	ns	ns	ns
CV (%)	14.0	17.2	12.7	17.6	13.0	18.5	5.80	12.0	10.0	49.3	9.80	27.3	10.9	28.0	18.4	36.5
LSD 0.05	–	–		–	–	5.8	0.13	2.0	–	–	–	–	–	–	–	–
cropping systems																
BSCNR	1.51	16.9	1.64	12.5	1.53	15.6	1.47	11.1	1.65	7.8	1.71	13.6	1.53	14.7	1.25	16.0
BSCRR	1.50	15.4	1.60	11.1	1.54	14.9	1.43	9.0	1.62	7.2	1.80	13.0	1.82	10.6	1.24	13.7
BISNR	1.48	11.3	1.42	7.0	1.51	12.4	1.39	7.6	1.72	5.5	1.92	14.2	1.61	11.5	1.34	13.7
BISRR	1.49	11.4	1.49	8.1	1.61	13.1	1.35	7.0	1.70	4.8	1.72	12.1	1.63	11.3	1.17	9.7
BIANR	1.25	7.8	1.52	8.9	1.37	8.7	1.31	7.1	1.75	3.5	1.85	10.1	1.55	9.5	1.15	9.1
BIARR	1.64	10.7	1.50	6.5	1.54	8.7	1.36	7.3	1.84	3.9	1.88	14.1	1.55	8.9	1.22	10.6
Rot–NR	1.64	25.3	–	–	1.57	26.1	–	–	–	–	1.98	21.8	–	–	1.42	22.5
Rot–RR	1.64	22.8	–	–	1.62	25.2	–	–	–	–	1.77	16.8	–	–	1.33	21.4
Mean	1.52	15.1	1.53	9.0	1.54	15.6	1.38	8.2	1.72	5.5	1.83	14.5	1.62	8.9	1.26	14.6
F test	*	***	ns	***	ns	***	ns	**	ns	***	ns	*	–	***	ns	***
CV (%)	19.2	33.3	15.8	33.1	19.3	38.5	9.10	34.4	15.1	44.4	19.8	55.7	25.6	27.4	19.5	53.2
Interaction	ns	**	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	*	ns	ns
LSD 0.05	0.24	4.1	–	2.5	–	4.9	–	2.3	–	2.0	–	6.6	–	2.5	–	6.4

*, **, *** = Treatment differences and interactions are significant at P = 0.05, 0.01, 0.001 level, respectively.
ns = Treatment differences and interactions are not significant at P = 0.05 level.

Appendix Table 17 – Effect of N rates and cropping systems on bean seed Mg concentration (%) and uptake (kg/ha) at maturity.

	Kimutwa								Masii							
Fertilizer	L R	1988	S R	1988/89	L R	1989	S R	1989/90	L R	1988	S R	1988/89	L R	1989	S R	1989/90
kg N/ha	%	kg/ha	%	kg/ha	%	kg/ha	%	kg/ha	%	kg/ha	%	kg/ha	%	kg/ha	%	kg/ha
0	0.09	1.2	0.15	0.4	0.13	0.9	0.19	1.0	0.07	0.2	0.48	2.3	0.19	0.7	0.16	1.3
25	0.08	1.5	0.32	0.7	0.15	1.5	0.19	1.7	0.07	0.6	0.51	4.0	0.18	1.4	0.13	2.1
50	0.08	1.7	0.15	0.6	0.15	1.6	0.20	2.2	0.08	0.7	0.50	4.7	0.17	1.4	0.15	3.2
100	0.07	1.4	0.16	0.6	0.16	1.4	0.20	2.0	0.07	0.6	0.53	4.4	0.18	1.2	0.14	2.2
Mean	0.08	1.4	0.19	0.6	0.15	1.4	0.19	1.7	0.07	0.5	0.51	3.8	0.18	1.2	0.14	2.2
F test	ns	ns	ns	ns	ns	**	ns	**	ns	**	ns	**	**	***	ns	ns
CV (%)	19.8	26.0	72.9	23.4	7.50	9.6	3.90	15.0	13.0	24.6	11.8	15.1	2.90	7.8	11.3	35.3
LSD 0.05	–	–	–	–	–	0.2	–	0.5	–	0.2	–	1.1	0.01	0.2	–	–
cropping systems																
BSCNR	0.07	1.4	0.15	0.9	0.15	1.4	0.20	3.0	0.07	0.7	0.52	4.3	0.18	1.6	0.16	2.8
BSCRR	0.08	1.9	0.39	0.7	0.15	1.4	0.19	2.2	0.08	0.6	0.51	3.5	0.18	1.4	0.55	2.0
BISNR	0.08	1.2	0.15	0.5	0.14	1.0	0.19	1.4	0.08	0.6	0.51	4.2	0.18	0.9	0.14	2.0
BISRR	0.09	1.1	0.15	0.6	0.15	1.0	0.19	1.3	0.07	0.5	0.53	3.2	0.19	1.2	0.14	1.6
BIANR	0.08	0.9	0.16	0.6	0.15	0.8	0.20	1.3	0.07	0.4	0.54	2.8	0.17	0.9	0.15	1.5
BIARR	0.08	0.9	0.16	0.4	0.15	0.6	0.19	1.2	0.07	0.4	0.49	3.4	0.18	1.0	0.14	1.5
Rot–NR	0.08	2.0	–	–	0.15	2.3	–	–	–	–	0.47	4.9	–	–	0.16	3.6
Rot–RR	0.08	2.1	–	–	0.15	2.2	–	–	–	–	0.50	4.4	–	–	0.19	2.7
Mean	0.08	1.4	0.19	0.6	0.15	1.4	0.19	1.7	0.07	0.5	0.51	3.8	0.18	1.2	0.14	2.2
F test	ns	***	ns	***	ns	***	ns	***	ns	*	ns	ns	ns	***	ns	***
CV (%)	19.2	30.9	173.6	36.5	10.9	22.1	8.40	29.2	24.1	51.2	14.6	46.9	7.70	20.8	20.6	44.7
Interaction	ns	ns	ns	ns	ns	**	ns	ns	ns	ns	ns	ns	ns	***	ns	ns
LSD 0.05	–	0.04	–	0.2	–	0.2	–	0.4	–	0.2	–	–	–	0.2	–	0.8

*, **, *** = Treatment differences and interactions are significant at P = 0.05, 0.01, 0.001 level, respectively.
ns = Treatment differences and interactions are not significant at P = 0.05 level.

Appendix Table 18 – Effect of N rates and cropping systems on bean haulms Mg concentration (%) and uptake (kg/ha) at maturity.

Fertilizer	Kimutwa								Masii							
	L R	1988	S R	1988/89	L R	1989	S R	1989/90	L R	1988	S R	1988/89	L R	1989	S R	1989/90
kg N/ha	%	kg/ha	%	kg/ha	%	kg/ha	%	kg/ha	%	kg/ha	%	kg/ha	%	kg/ha	%	kg/ha
0	1.88	13.5	1.73	5.1	0.51	3.9	0.89	2.0	1.29	1.7	1.31	6.3	0.35	1.9	0.27	1.6
25	1.77	19.4	1.72	6.8	0.52	5.6	0.80	3.2	1.26	3.5	1.42	11.0	0.31	2.3	0.29	2.8
50	1.78	18.3	1.63	6.5	0.54	6.2	0.55	4.0	1.31	6.1	1.47	12.2	0.34	3.0	0.31	4.4
100	1.80	17.8	1.69	6.6	0.55	4.8	0.56	3.7	1.42	5.6	1.42	12.5	0.40	2.8	0.33	3.9
Mean	1.81	17.2	1.69	6.3	0.53	5.1	0.70	3.2	1.32	4.2	1.41	10.5	0.35	2.5	0.30	3.3
F test	ns	ns	ns	ns	ns	*	ns	*	ns	ns	ns	ns	*	ns	ns	ns
CV (%)	7.40	15.0	9.40	24.0	7.90	14.2	40.7	17.0	10.6	44.6	8.90	22.5	6.40	19.2	31.2	36.9
LSD 0.05	–	–	–	–	–	1.4	–	1.1	–	–	–	–	0.04	–	–	–
cropping systems																
BSCNR	1.78		1.74	9.5	0.54	5.5	0.58	4.2	1.24	5.3	1.39	10.2	0.34	3.2	0.29	3.6
BSCRR	1.77	19.6	1.57	6.8	0.54	5.2	0.59	3.6	1.33	6.1	1.39	9.3	0.35	2.4	0.28	3.2
BISNR	1.80	13.6	1.65	5.6	0.55	4.1	0.95	3.1	1.34	4.7	1.35	10.7	0.35	2.5	0.30	3.1
BISRR	1.91	14.7	1.79	6.3	0.53	4.0	1.01	2.9	1.32	3.8	1.37	8.8	0.36	2.5	0.30	2.3
BIANR	1.88	12.2	1.76	5.8	0.55	3.4	0.55	3.0	1.30	2.6	1.46	7.3	0.37	2.3	0.31	2.3
BIARR	1.83	12.0	1.65	3.6	0.53	3.0	0.52	2.7	1.39	3.0	1.34	11.0	0.35	2.0	0.30	2.6
Rot–NR	1.73	27.0	–	–	0.50	8.1	–	–	–	–	1.41	14.1	–	–	0.31	4.9
Rot–RR	1.74	22.5	–	–	0.50	7.8	–	–	–	–	1.53	12.7	–	–	0.30	4.5
Mean	1.81	17.2	1.69	6.3	0.53	5.1	0.70	3.2	1.32	4.2	1.41	10.5	0.35	2.5	0.30	3.3
F test	ns	***	ns	***	ns	***	ns	*	ns	***	ns	*	ns	**	ns	***
CV (%)	19.1	33.3	19.5	37.3	12.7	22.1	122.6	34.2	19.9	48.4	11.0	44.2	11.9	27.9	90.5	44.9
Interaction	ns	*	ns	ns	ns	**	ns	ns	ns	ns	ns	ns	ns	*	ns	ns
LSD 0.05	–	4.7	–	1.9	–	0.9	–	0.9	–	1.7	–	1.9	–	0.6	–	1.2

*, **, *** = Treatment differences and interactions are significant at P = 0.05, 0.01, 0.001 level, respectively.
ns = Treatment differences are not significant at P = 0.05 level.

Appendix Table 19 – Effect of N rates and cropping systems on bean seed Ca concentration (%) and uptake (kg/ha) at maturity.

Fertilizer kg N/ha	Kimutwa								Masii							
	L R 1988		S R 1988/89		L R 1989		S R 1989/90		L R 1988		S R 1988/89		L R 1989		S R 1989/90	
	%	kg/ha	%	kg/ha	%	kg/ha	%	kg/ha	%	kg/ha	%	kg/ha	%	kg/ha	%	kg/ha
0	0.15	2.2	0.17	0.7	0.50	3.2	0.11	0.6	0.07	0.2	0.23	1.5	0.12	0.4	0.19	1.6
25	0.16	3.0	0.17	0.7	0.51	4.2	0.12	1.1	0.06	0.5	0.23	1.8	0.10	0.8	0.16	2.3
50	0.12	2.3	0.18	0.7	0.51	5.4	0.12	1.3	0.08	0.8	0.20	1.9	0.11	0.9	0.20	4.6
100	0.12	2.5	0.16	0.7	0.49	4.3	0.13	1.3	0.07	0.7	0.24	2.1	0.09	0.6	0.20	3.2
Mean	0.14	2.5	0.17	0.7	0.50	4.3	0.12	1.1	0.07	0.5	0.22	1.8	0.10	0.7	0.19	2.9
F test	ns	ns	ns	ns	ns	**	*	*	ns	ns	ns	ns	ns	*	ns	ns
CV (%)	42.0	45.9	7.60	25.4	4.50	9.0	6.20	18.3	58.3	97.7	10.2	0.2	12.9	21.2	15.6	47.4
LSD 0.05	–	–	–	–	–	0.8	0.01	0.4	–	–	–	–	–	0.29	–	–
cropping systems																
BSCNR	0.09	1.9	0.17	1.0	0.51	4.5	0.14	2.1	0.07	0.8	0.21	1.8	0.11	1.0	0.21	4.2
BSCRR	0.18	4.4	0.17	0.8	0.49	4.5	0.13	1.4	0.08	0.8	0.23	1.9	0.11	0.9	0.21	2.9
BISNR	0.14	1.9	0.17	0.6	0.51	3.3	0.10	0.8	0.05	0.4	0.29	1.9	0.10	0.5	0.17	2.3
BISRR	0.16	2.1	0.17	0.6	0.50	3.2	0.12	0.8	0.08	0.6	0.23	1.6	0.10	0.6	0.17	2.3
BIANR	0.13	1.5	0.17	0.6	0.51	2.6	0.12	0.8	0.08	0.4	0.24	1.4	0.09	0.5	0.18	1.7
BIARR	0.14	1.4	0.16	0.4	0.49	2.2	0.11	0.7	0.05	0.3	0.21	1.3	0.10	0.6	0.18	2.1
Rot–NR	0.12	3.2	–	–	0.51	6.5	–	–	–	–	0.22	2.5	–	–	0.20	4.0
Rot–RR	0.15	3.5	–	–	0.49	7.3	–	–	–	–	0.22	1.9	–	–	0.18	4.0
Mean	0.14	2.5	0.17	0.7	0.50	4.3	0.12	1.1	0.07	0.5	0.22	1.8	0.10	0.7	0.19	2.9
F test	*	***	ns	***	ns	***	ns	***	ns	ns	ns	ns	ns	***	ns	*
CV (%)	39.5	48.5	6.70	38.1	9.20	29.3	24.7	46.0	72.7	104.5	30.0	59.7	29.1	37.2	41.8	69.2
Interaction	ns	ns	ns	ns	ns	**	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
LSD 0.05	0.04	1.0	–	0.2	–	1.0	–	0.3	–	–	–	–	–	0.2	–	1.7

*,**,*** = Treatment differences and interactions are significant at P = 0.05, 0.01, 0.001 level, respectively.
ns = Treatment differences and interactions are not significant at P = 0.05 level.

Appendix Table 20 – Effect of N rates and cropping systems on bean haulms Ca concentration (%) and uptake (kg/ha) at m

Fertilizer kg N/ha	Kimutwa								Masii						
	L R	1988	S R	1988/89	L R	1989	S R	1989/90	L R	1988	S R	1988/89	L R	1989	S R
	%	kg/ha	%	kg/ha	%	kg/ha	%	kg/ha	%	kg/ha	%	kg/ha	%	kg/ha	%
0	0.67	4.9	0.78	3.8	1.28	10.0	0.77	2.6	0.90	1.3	0.69	3.2	1.09	5.8	0.77
25	0.83	9.5	0.77	4.8	1.21	13.4	0.86	5.3	0.99	3.3	0.72	3.6	1.11	8.3	0.75
50	0.69	7.1	0.84	5.0	1.32	15.1	0.85	6.2	1.16	5.4	0.73	6.0	1.17	10.0	0.81
100	0.72	7.4	0.77	5.1	1.34	12.2	0.84	5.7	1.23	4.8	0.67	6.0	1.16	7.8	0.83
Mean	0.73	7.2	0.79	4.7	1.28	12.7	0.83	4.9	1.07	3.7	0.70	5.2	1.14	8.0	0.79
F test	ns	8	ns	ns	ns	ns	ns	*	ns	ns	ns	*	ns	ns	ns
CV (%)	9.70	20.2	7.50	16.4	10.0	16.1	8.20	21.8	15.6	54.6	11.2	16.8	4.80	20.7	4.00
LSD 0.05	–	2.9	–	–	–	–	–	2.1	–	–	–	2.0	–	–	–
cropping systems															
BSCNR	0.68	7.5	0.75	5.6	1.28	13.3	0.88	6.8	1.02	5.3	0.73	5.4	1.10	10.4	0.82
BSCRR	0.69	7.2	0.75	5.6	1.36	13.4	0.89	5.6	1.13	5.1	0.75	4.8	1.04	7.3	0.81
BISNR	0.79	6.1	0.80	3.9	1.30	9.7	0.82	4.6	0.99	3.5	0.68	4.9	1.17	8.4	0.78
BISRR	0.78	6.2	0.84	4.6	1.27	9.9	0.86	4.2	1.14	3.4	0.67	4.3	1.18	8.3	0.78
BIANR	0.76	5.3	0.81	4.6	1.33	8.3	00.78	4.2	0.97	2.1	0.69	3.6	1.14	6.9	0.76
BIARR	0.75	4.8	0.81	3.5	1.29	7.4	0.76	4.2	1.17	2.7	0.75	5.3	1.18	6.6	0.80
Rot–NR	0.68	10.9	–	–	1.22	19.7	–	–	–	–	0.67	6.9	–	–	0.81
Rot–RR	0.71	9.6	–	–	1.24	19.8	–	–	–	–	0.67	6.2	–	–	0.76
Mean	0.73	7.2	0.79	4.7	1.28	12.7	0.83	4.9	1.07	3.7	0.70	5.2	1.14	8.0	0.79
F test	ns	***	ns	**	ns	***	*		ns	***	ns	*	*	**	ns
CV (%)	19.4	34.5	13.1	29.8	17.1	28.4	14.3	**	21.0	47.1	13.5	54.4	10.3	31.0	9.70
Interaction	ns	*	ns	ns	ns	*	ns	ns	ns	ns	ns	ns	*	*	ns
LSD 0.05	–	2.0	–	1.1	–	2.9	0.09	1.3	–	1.4	–	1.7	0.09	2.0	–

*, **, *** = Treatment differences and interactions are significant at P = 0.05, 0.01, 0.001 level, respectively.
ns = Treatment differences and interactions are not significant at P = 0.05 level.

Appendix Table 21 - Regession Analysis : Estimation of N contribution by rotation to maize.

The second order equations ($Y = c + bN + aN^2$) generated by regression analysis were used to solve for N needed to achieve a certain level of maize seed yield in a rotation. The following quadratic equation was used to calculate for N:

$$\text{(i)} \qquad ax^2 + bx + c = 0$$

$$\text{(ii)} \qquad x = \frac{-b + \sqrt{b^2 - 4ac}}{2a}$$

Example:

Treatment	Second order equation
1) Continuous sole maize (MSC)	1) $Y = 2159 + 60.95N - 0.40N^2$ (R^2=0.985)
2) Maize following beans in rotation	2) $Y = 3053 + 54.99N - 0.43N^2$ (R^2=0.848)

Where Y = seed yield (kg/ha), N = applied nitrogen (kg/ha). The intercept in equation (2) represents the seed yield of maize following beans in rotation and without N added. This yield was substituted as Y into equation (1) and equation (1) solved for the amount of N needed to achieve this yield level.

Calculations

$$3053 = 2159+60.95N-0.40N^2$$

$$3053-2159 = 60.95N-0.40N^2$$

$$894 = 60.95N-0.40N^2$$

$$0 = -0.40N^2+60.95N-894$$

Then from here use quadratic equation (ii) to solve for N. In this example, the amount of N estimated to be available for maize following beans was 16 kg N/ha.

Appendix Table 22 - Maize seed yield (g/plant).

Fertilizer N kg/ha	Kimutwa				Masii			
	LR 1988	SR 1988/89	LR 1989	SR 1989/90	LR 1988	SR 1988/89	LR 1989	SR 1989/90
0	45.5	76.1	28.9	47.0	4.3	19.4	4.5	3.4
25	54.2	96.6	30.0	70.8	12.1	35.9	21.1	25.3
50	62.8	103.3	30.1	81.5	14.5	73.5	27.3	47.5
100	65.0	108.1	31.1	74.3	17.9	72.7	25.5	72.9
Mean	56.7	96.0	30.0	68.4	12.2	50.4	19.6	37.3
F test	**	ns	ns	**	ns	*	*	**
LSD 0.05	9.8	–	–	15.0	–	35.3	13.3	27.6
Cropping systems								
MSC	61.3	94.8	37.1	63.8	12.8	65.5	24.3	47.2
MISNR	54.5	84.6	25.5	66.1	9.1	34.8	16.3	37.7
MISRR	60.8	89.4	27.3	72.0	8.6	49.2	13.9	34.6
MIANR	52.2	87.6	29.8	67.5	9.4	49.6	15.8	31.6
MIARR	54.9	90.3	30.5	61.2	10.4	52.8	16.9	35.3
Rot–NR	–	116.4	–	72.7	15.7	–	26.1	–
Rot–RR	–	109.0	–	75.5	19.6	–	24.0	–
Mean	56.7	96.0	30.0	68.4	12.2	50.4	19.6	37.3
F test	ns	**	** b	ns	***	*	**	ns
LSD 0.05	–	11.6	4.9	–	5.3	18.8	7.3	–

*, **, *** = Treatment differences are significant at P = 0.05, 0.01, 0.001 level, respectively.

ns = Treatment differences are not significant at P = 0.05 level

b = N x cropping systems interaction is significant at P = 0.05 level

Appendix Table 23 – Bean seed yield (g/plant).

Fertilizer	Kimutwa				Masii			
N kg/ha	LR 1988	SR 1988/89	LR 1989	SR 1989/90	LR 1988	SR 1988/89	LR 1989	SR 1989/90
0	6.2	1.4	2.9	2.4	1.4	2.4	1.7	3.9
25	8.2	1.9	4.3	3.9	3.8	3.7	3.5	6.6
50	9.2	1.8	4.7	5.1	4.0	4.2	3.6	9.7
100	9.2	1.8	4.2	4.5	3.9	3.6	3.2	7.2
Mean	8.2	1.7	4.0	4.0	3.3	3.5	3.0	6.9
F test	*	ns	***	**	*	ns	**	ns
LSD 0.05	2.1	–	0.4	1.15	2.4	–	0.4	–
Cropping systems								
BSCNR	8.8	2.5	4.2	6.8	4.6	3.4	4.2	8.1
BSCRR	10.9	1.9	4.0	6.7	3.9	3.1	3.5	6.1
BISNR	6.6	1.5	2.9	3.3	3.0	5.0	2.4	6.1
BISRR	6.3	1.7	2.9	2.9	2.9	4.0	2.8	5.0
BIANR	5.1	1.6	2.3	2.9	2.9	3.7	2.5	4.5
BIARR	4.9	1.0	2.0	2.9	2.5	3.0	2.6	5.0
Rot-NR	12.0	–	7.2	–	–	2.5	–	10.5
Rot-RR	11.1	–	6.7	–	–	2.9	–	9.5
Mean	8.2	1.7	4.0	4.0	3.3	3.5	3.0	6.9
F test	**	***	*** b	***	**	**	** b	***
LSD 0.05	1.4	0.49	0.55	0.98	1.1	1.17	0.5	2.4

*, **, *** = Treatment differences are significant at P = 0.05, 0.01, 0.001 level, respectively.

ns = Treatment differences are not significant at P = 0.05 level

b = N x cropping systems interaction is significant at P = 0.05 level

Appendix Table 24 – Effect of N rates and cropping systems on maize relative yields during different seasons at Kimutwa.

Cropping	Long rain 1988								Short rain 1988/90							
	N fertilizer kg/ha								N fertilizer kg/ha							
systems	N0	N25	N50	N100	Mean	F test	CV (%	LSD 0.05	N0	N25	N50	N100	Mean	F test	CV (%)	LSD 0.05
MSC	1.00	1.00	1.00	1.00	1.00				1.00	1.00	1.00	1.00	1.00			
MISNR	0.97	0.87	0.85	0.90	0.90				1.03	0.87	0.98	0.85	0.93			
MISRR	1.05	0.85	1.09	0.96	0.99	–	18	–	1.05	1.04	0.86	0.97	0.98	ns	17	–
MIANR	0.96	0.91	0.96	0.57	0.85				0.87	1.14	0.92	0.82	0.94			
MIARR	1.12	0.76	0.91	0.89	0.92				1.02	1.05	0.93	0.94	0.99			
Mean	1.02	0.88	0.96	0.87	0.93				1.00	1.02	0.94	0.92	0.97			
F test			ns								ns					
CV (%)			22								16					
LSD 0.05			–								–					
	Long rain 1989								Short rain 1989/90							
MSC	1.00	1.00	1.00	1.00	1.00				1.00	1.00	1.00	1.00	1.00			
MISNR	0.96	0.70	0.77	0.57	0.75				1.42	1.05	1.00	1.17	1.16			
MISRR	0.83	0.71	0.85	0.70	0.77	** a	20	0.14	1.46	1.27	1.06	1.23	1.25	ns	29	–
MIANR	1.08	0.77	0.93	0.68	0.86				1.69	1.34	1.14	0.77	1.24			
MIARR	1.32	0.60	1.20	0.57	0.92				1.41	1.05	1.15	0.70	1.08			
Mean	1.04	0.76	0.95	0.70	0.86				1.40	1.14	1.07	0.97	1.15			
F test			ns								ns					
CV (%)			23								43					
LSD 0.05			–								–					

** = Treatment mean differences are significant at P = 0.01 level

ns = Treatment mean differences are not significant at P = 0.05 level

a = N x cropping systems interaction is significant at P = 0.05 level

Appendix Table 25 – Effect of N rates and cropping systems on maize relative yields during different seasons at Masii.

Cropping systems	Long rain 1988								Short rain 1988/90							
	N fertilizer kg/ha								N fertilizer kg/ha							
	N0	N25	N50	N100	Mean	F-test	C.V. %	Lsd 0.05	N0	N25	N50	N100	Mean	F-test	C.V. %	Lsd 0.05
MSC	1.00	1.00	1.00	1.00	1.00				1.00	1.00	1.00	1.00	1.00			
MISNR	11.15	0.53	0.79	0.79	3.32				0.77	0.27	0.59	1.20	0.71			
MISRR	1.95	0.87	0.52	0.84	1.04				1.14	0.53	0.51	1.89	1.02	ns	36	–
MIANR	2.07	1.19	0.84	0.54	1.16	ns	208	–	1.55	0.66	0.70	1.09	1.00			
MIARR	4.53	1.40	0.76	0.73	1.86				0.60	0.66	0.90	1.23	0.85			
Mean	4.14	1.00	0.78	0.78	1.68				1.01	0.62	0.74	1.28	0.92			
F-test			ns								ns a					
C.V. %			93								28					
Lsd 0.05			–								–					
	Long rain 1989								Short rain 1989/90							
MSC	1.00	1.00	1.00	1.00	1.00				1.00	1.00	1.00	1.00	1.00			
MISNR	3.82	0.74	0.86	0.78	1.55				2.10	1.30	1.73	1.30	1.61			
MISRR	4.38	0.70	0.81	0.54	1.61	ns	90	–	9.63	1.67	1.13	0.97	3.35			
MIANR	4.55	1.02	0.65	0.39	1.65				4.60	0.77	0.63	1.04	1.76	ns	129	–
MIARR	2.15	1.30	0.89	0.55	1.22				0.93	1.67	1.73	0.67	1.25			
Mean	3.18	0.95	0.84	0.65	1.41				3.65	1.28	1.25	0.99	1.79			
F-test			ns								ns					
C.V. %			93								116					
Lsd 0.05			–								–					

ns = Treatment differences are not significant at P = 0.05 level

a = N x cropping systems interaction is significant at P = 0.05 level

Appendix Table 26 - Effect of N rates and cropping systems on bean relative yields during different seasons at Kimutwa and Masii.

	Kimutwa				Masii			
Fertilizer	LR	SR	LR	SR	LR	SR	LR	SR
N kg/ha	1988	1988/89	1989	1989/90	1988	1988/89	1989	1989/90
0	0.80	0.78	0.75	0.67	1.15	1.02	0.71	1.05
25	0.60	0.71	0.66	0.57	0.79	1.10	0.78	1.40
50	0.68	0.75	0.67	0.64	1.35	0.90	0.79	0.71
100	0.67	0.80	0.79	0.66	0.77	0.94	0.79	0.85
Mean	0.70	0.76	0.72	0.63	1.02	0.99	0.74	1.01
F test	ns	ns	ns	ns	ns	ns	ns	ns
CV (%)	21	19	18	22	53	25	6	44
LSD 0.05	-	-	-	-	-	-	-	-
Cropping systems								
BSC	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BISNR	0.80	0.65	0.73	0.51	1.17	1.11	0.61	0.98
BISRR	0.66	0.88	0.75	0.58	0.89	1.05	0.83	1.09
BIANR	0.55	0.68	0.58	0.49	1.17	0.76	0.61	0.74
BIARR	0.50	0.60	0.52	0.59	0.85	1.02	0.67	1.22
Mean	0.70	0.76	0.72	0.63	1.02	0.99	0.74	1.01
F test	***	**	***	***	ns	ns	***	ns
CV (%)	29	34	17	33	95	31	16	66
Interaction	ns	ns	ns	ns	ns	ns	***	*
LSD 0.05	0.17	0.21	0.10	0.17	-	-	0.10	-

*, **, *** = Treatment differences are significant at P = 0.05, 0.01, 0.001 level
ns = Treatment differences are not significant at P = 0.05 level