MAIZE RESPONSE TO MUCUNA GREEN MANURE

by

SAMSON NYANG'AU MAOBE

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DECLARATION BY CANDIDATE

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

Signed.. Date 6/10/2008..............................

Samson Nyang'au Maobe, B.Sc (Agric), M.Sc (Agronomy)

DECLARATION BY UNIVERSITY SUPERVISORS

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

Signed.. Date 6/10/2008.......

Dr. Mary W. K. Mburu

Signed Date 6/10/2008..............

Professor Levi S. M. Akundabweni

Signed.. Date 6/10/2008.........

Dr. James Kamiri Ndufa

DEDICATION

To my dear wife Martha, children Sheila, Godfrey and Emmanuel.

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ABSTRACT

On-farm research and greenhouse experiments were carried out to determine effects of mucuna green manure application rate on maize growth, nitrogen uptake and grain yield. Mucuna rates evaluated were 0, 30, 60, 120, 240 and 480 kg N ha^{-1} corresponding to green manure quantities of 0, 1.5, 3, 6, 12 and 24 tons dry matter per hectare; and inorganic fertilizer, urea at levels of 0, 30, 60 and 120 kg N ha^{-1}. The effects of soil moisture content were: field capacity (-0.01 MPa), intermediate (-0.75 Mpa), and wilting point (-1.5 MPa). The experimental design was randomized complete block with four and three replications for field and greenhouse experiments, respectively. Field treatments were evaluated for 5 seasons. Residual N effects were evaluated for two seasons. Mucuna N only increased maize yield when applied at the rate of 120 kg N ha^{-1}. Maize grain yield was comparable at 30, 60 and 120 kg N ha^{-1} rates of mucuna and inorganic fertilizer N. There was no residual effect of N application irrespective of quantity or source. Mucuna decomposition was bi-phasic with an initial rapid phase with half-life of one week followed by a slower phase. Peak available N was at 2 weeks after application. Soil available N was significantly high at mucuna application rate of 240 kg N ha^{-1} but comparable at lower rates than 120 kg N ha^{-1}. The greenhouse experiment showed that soil water content significantly influenced the quantity of biomass decomposed; soil available N, plant N uptake and maize growth but biomass rates did not. The economic mucuna N application rate was 120 kg N ha^{-1} and 30 kg N ha^{-1} fertilizer N. Combination of low rates of mucuna green manure and inorganic fertilizer N may be applied judiciously to improve maize yield.

CHAPTER ONE

GENERAL INTRODUCTION

1.1 Background

Declining soil fertility is a constraint to food production in most of the developing world (Van Reuler and Prins, 1993). In Sub-Saharan Africa this arises mainly from net nutrient mining (Smaling, 1993). Increasing population has put pressure on land and subsequently led to rapid decline in soil fertility (Stahl, 1993). In Kenya, nitrogen, phosphorus and potassium depletion in maize production was reported as – 48.5 kg N, -5.0 kg P and – 35.2 kg K ha^{-1} yr^{-1} (FAO, 2004). The situation is worsened by inadequate or no use of inorganic fertilizers (Mose *et al.*, 1996), and losses through soil erosion (Gachene, 1997) and leaching. Gradual reduction in soil fertility, if allowed to continue, would result in food shortages.

Maize is the key food crop in Kenya, constituting 3% of Kenya's gross domestic product (GDP), 12% of the agricultural GDP and 21% of the total value of primary agricultural commodities (Republic of Kenya, 1995-2000). Maize is both subsistence and a commercial crop, grown on an estimated 1.4 million hectares (more than 30% of arable land) by large-scale farmers (25%) and smallholders (75%). The average annual production is at 2.4 million tons, for a population of 31 million, 79 kg/person and per capita consumption is 103 kg/person and Kenya is a net importer (De Groote, 2005).

The national maize yield is low, i.e. 1 and 2.9 t ha^{-1} in the semi-arid zone and highlands, respectively, primarily due to sub-optimal application of inorganic fertilizers (Hassan *et* *al.*, 1989). About one million more tonnes of maize grain could be added to current domestic production (33%) if improved seed and optimal levels of N and P were used (International Maize and Wheat Improvement Center (CIMMYT, 1998); Kenya Agricultural Research Institute (KARI, 1998). Fertilizer Use Recommendation Project (FURP), 1994) estimated 22, 53 and 44% increase in maize grain yield from 2500, 4000 and 4500 kg ha^{-1} in Kakamega, Kisii and Trans-Nzoia respectively, if farmers used the recommended fertilizer rates. High poverty levels and low returns to soil fertility management technologies account for sub-optimal fertilizer application (Oluoch-Kosura *et al.*, 2001). Morris *et al.* (2007) list unprofitability of maize as a major factor causing low fertilizer use in Africa.

Fertilizer consumption in Kenya has been increasing since 1980s and this is attributed to liberalized marketing (Morris *et al.*, 2007). In 2000-2003, consumption was at 325,000 tons per year, with 82% of smallholder farmers using the commodity (Crawford *et al.*, 2005; Ariga *et al.*, 2006a). But, the amount of fertilizer used is on the decline due to lack of cash and profitability (De Groote *et al.*, 2005; Morris *et al.*, 2007). Fertilizer use intensity of 25 to 31.8 kg ha^{-1} during 1996-2003 in Kenya though higher than 8 kg ha^{-1} for Africa, is far below 80 kg ha^{-1} in south Asia and 54 kg ha^{-1} in Latin America (Crawford *et al.*, 2005; Ariga *et al.*, 2006b). Oluoch-Kosura *et al.* (2001) observed that dependence on external inputs is inescapable but use will depend on the country's economy. Consequently, there is need to search for low-cost alternatives to supplement the costly inorganic fertilizer.

In the past, the problem of declining soil fertility was addressed through agronomic practices such as fallowing (Vlek, 1990) crop rotation, application of farmyard manure, composting and to some extent application of inorganic fertilizers. Smaling (1993) noted that the traditional organic inputs such as crop residues and animal manure and compost (Giller, 1997), often proposed as alternatives to inorganic fertilizers, cannot meet crop nutrient demand over large areas because of limited quantities available, low nutrient content, and high labour requirement for processing and application. Although some farmers resort to using combination of organic and inorganic fertilizers as alternative, the amount involved may be sub-optimal resulting in low crop yield (Palm *et al.*, 1997).

Techniques that optimize returns to the internally generated soil fertility enhancing resources available to farmers may find ready acceptance (Oluoch-Kosura *et al.*, 2001). Greater emphasis on alternative soil fertility maintenance measures such as agroforestry, novel intercropping systems, residue conservation, the use of manure, soil amendments and fertilizers are possible solutions (Vlek, 1990; Oluoch-Kosura *et al.*, 2001). Sanchez *et al.* (1997) recommended strategies that are mainly biological-based for N replenishment in Africa e.g. using leguminous tree fallows and cover crops, but with inorganic fertilizer supplementation.

Herbaceous legumes used as green manure and cover crops (GMCC) have been shown to have the potential to improve soil fertility in various parts of the world (Lathwell, 1990; Sarrantonio, 1991). The cover crops supply nitrogen (N) through biological N fixation (BNF) and organic matter in addition to providing ground cover that reduces soil erosion

(Lathwell, 1990). Research in Kenya by the Legume Research Network Project (LRNP) identified best-bet legume species suited to agro-ecological environments in Kenya (Maobe *et al.*, 1997a; Mureithi *et al.*, 1998). Amongst the species that have been ranked top in green manure production for high potential areas are: *Mucuna pruriens* (velvet bean), *Crotalaria ochreleuca* (sunnhemp), and *Canavalia ensiformis* (Jackbean). The legumes nodulate with indigenous bacteria in the soil (Mureithi *et al.*, 1998; Ojiem *et al*, 2000). On-farm studies to integrate GMCC in maize-based cropping systems have shown that the legumes improve maize grain yield (Wortmann *et al.*, 1994; Fischler, 1996; Dyck *et al.*, 1997). For that reason, it is important to articulate the extent to which GMCC legumes can substitute inorganic N fertilizer.

Nitrogen supply from GMCC species is dependent on biomass production which differs depending on: (a) agro-ecological environmental factors, such as soil moisture and temperature, (b) soil nutrient status due to land use history, (c) niche, (d) species type, and plant age at time when biomass is harvested and applied (Burle *et al.*, 1992). The variability in legume biomass quantities attainable in diverse production conditions is expected to influence N supply from the same. The knowledge gaps this study sets out to investigate in the use of legume cover crops are within the scope of research needs identified for the Eastern Africa region (AHI, 2000).

1.2 Statement of problem

Despite the variability in green manure productivity of GMCC species such as *Mucuna pruriens*, the amount of herbaceous legume green manure (above ground biomass) required to bring about noticeable improvement in growth, nitrogen availability and uptake and grain yield of maize is unknown (Burle *et al.*, 1992). It is important to identify the optimum amount of green manure for maize production. In the context of this research the optimum is considered to be the amount from given herbaceous legume species source that, meets plant N requirement maximizing crop yield. Abifarin (1984) defines the "optimum" as the most satisfactory condition for a plant's growth and development.

One of the reasons for inclusion of GMCC species in cropping systems is to promote sustainable agriculture through maintenance and amendment of soil productivity. For that to happen, added green manure biomass should have residual effect leading to a build up in fertility, and in particular through increase in soil organic matter (SOM) thereby reducing fertilizer requirements for crop production in subsequent seasons. From the available literature, it is not clear whether, optimal and various quantities of green manure applied have residual effect on soil fertility, maize yield and N losses in the soil profile.

The supply of N from inorganic source may not match crop demand for the nutrient depending on applied quantity, quality, timing, method of application both of which affect the rate of availability, thereby reducing fertilizer use efficiency. Unlike chemical fertilizer, the N in GMCC organic matter becomes available after decomposition and mineralization processes, which take time. Thus, the amount of N added, as green manure may need to be more than that supplied as inorganic fertilizer so as to achieve similar crop yields. The difference could be useful in the management of N to optimize fertilizer efficiency through combination of GMCC and inorganic fertilizer to synchronize crop demand and supply. As such, there is need to identify decomposition patterns of the various quantities of green manure that are produced in GMCC systems, and their effect on soil available N levels.

The literature available is scanty on the economics of applying legume biomass such as that of mucuna, as N source in maize production.

1.3 OBJECTIVES

1.3.1 Broad objective

To determine the effect of *mucuna pruriens* green manure on maize growth, nitrogen uptake and grain yield.

1.3.2 Specific objectives

To determine effects of mucuna green manure application rates on

1. Maize growth and N uptake in the season of application and the residual benefit
2. Mucuna decomposition pattern and soil available N levels in field conditions,
3. Mucuna decomposition pattern, soil available N and N uptake at varying soil moisture levels, under greenhouse conditions, and

To conduct economic analysis of mucuna nitrogen application on maize yield.

CHAPTER TWO

LITERATURE REVIEW

2.1 Maize growth and development

Maize has six developmental stages: seedling establishment (1week), early vegetative development (2-6 weeks), and late vegetative period in which occurs tassel and ear initiation (11 weeks) (Aldrich *et al.*, 1975). This is followed by silking (12 weeks), fertilization and kernel initiation. Kernel development and maturation occurs at 13-16 weeks and the last stage, maturity and drying, in 17-22 weeks (Pioneer, 2006). Seven days after emergence, maize seedling is established with 2 leaves, and a primary root system developed to the extent that it no longer depends on food supply from the kernel. Shortages of major nutrient elements become critical the moment roots take over in nourishment of the young plant (Aldrich *et al.*, 1975).

2.2 Maize nutrient and water requirements

Soil nutrient status influence maize growth in all the different stages of growth. Maize nutrient and water requirements vary throughout the growth period as summarized in Table 2.1. (Pioneer, 2006; O'Sullivan, 2006). Requirements are low during emergence and seedling establishment and are greatest when the plant is growing most rapidly and until grain filling is complete. Tasseling and ear initiation stage, pollen production, and formation of cobs and ear structures, create very high requirement for water and nutrients. Peak demand for N, P and water is at 11 to 12 weeks after emergence, which coincides with tasseling and ear initiation, and silking stages. The peak requirement for K occurs prior to tasseling, at 8-10 weeks (Table 2.1; O'Sullivan, 2006). Shortage of moisture, and nutrients reduce kernel fill, hence grain yield (Aldrich *et al.*, 1975).

Table 2.1.Percentage nutrient and water weekly requirement for maize phonological stages ♣

Phenological stage	Weeks after emergence (WAE)	Nutrient and water weekly requirements as percentage of total need			
		% N	% P	% K	% water
1. Seedling establishment stage	1	< 1	< 1	< 1	< 1
2. Vegetative phase					
(i) Early period					
Creation of root system and leaf structure	2-6	1-7	1-2	1-9	1-5
(ii) Late period					
Main growth to full size of stalk and leaves, rapid elongation of lower internodes	7-10	11-15	4-10	16-21	7-11
Reproduction phase					
3. Tassel and ear initiation stage	11	16	11	16	12
4. Silking stage	12	12	15	8	12
5. Kernel initiation	13	10	13	5	12
6. Kernel development and maturation stage	13-16	10-12	13-18	5-10	12-16
7. Maturity and drying stage	17-22	< 1	5 to < 1	- K	5 to< 1

♣Sources: Aldrich *et al.*, 1975; Pioneer, 2006; O'Sullivan, 2006.

Major nutrients required by maize are N, P, K, Mg and S. There might be variation with region and soil type, but levels requisite are 15, 3.3 and 4.2 kg N, P and K respectively per tonne of dry (14 %) grain produced. Also, 1.4 and 0.8 kg Mg and S in that order per tonne of grain (Pioneer, 2006). Whereas maize requires trace elements for normal growth and development, deficiency of micronutrients is uncommon (O'Sullivan, 2006).

Nitrogen uptake and shoot dry weight in cereals increase up to flowering stage (Fageria and Baligar, 2005). Nitrogen absorbed at vegetative stage contributes to growth in reproductive and grain filling stages via translocation. During ripening, about 70% of the N in the shoot will be translocated to the grain, and maintain N contents of the grain at certain percentages. At physiological maturity stage, N uptake as well as shoot dry weight decrease compared to flowering growth stage. At harvest, more N is accumulated in grain than in dry matter. Decrease in shoot dry weight at harvest is due to photosynthetic product translocation to grain during the interval from flowering to harvest (Fageria and Baligar, 2005).

2.3 Plant uptake of nitrogen

Amongst the essential plant nutrients, nitrogen is required in highest amounts. Nitrogen is absorbed as NH_4^+ and NO_3^- (Fageria and Baligar, 2005). Most of the soil-derived N enters the plant as NO_3^- (Olsen and Kurtz, 1982). Most common crops also readily absorb NH_4^+ and, if any preference exists it is usually in favour of NH_4^+ early and NO_3^- late in the season (Streeter and Barta, 1984). Most N movement occurs as NO_3^- in the flow of soil water to plant roots in response to transpiration. Since the attraction between NO_3^- and soil colloids is negligible, NO_3^- is mobile and is readily carried to plant roots by mass flow, hence there is a close relationship between plant N and water uptake. In contrast, attraction between NH_4^+ and soil colloids is substantial and its movement in and with soil water is much less. When potential uptake exceeds the supply from mass flow, the concentration of N species at the root surface is lowered and the process of diffusion commences (Olsen and Kurtz, 1982).

Nitrogen is a constituent of proteins, nucleic acids, amino acids, chlorophyll, and photosynthetic enzymes (Streeter and Barta, 1984). Nitrogen improves root and shoot growth. Its deficiency impairs metabolism in plants, causes chlorosis and, stunted growth and premature senescence starting with older leaves (Fageria and Baligar, 2005). Insufficient amount of N reduces leaf area index and duration, leading to lower radiation interception, lower radiation use efficiency, lower photosynthetic rates, reduced growth, dry matter and yield (Gregory *et al.*, 1997; Fageria and Baligar, 2005). Nitrogen is needed for metabolism to form protein, especially in young tissues. At flowering stage shortage of N causes kernels in the upper part of the ear to abort, and fail to develop even though fertilized (Streeter and Barta, 1984). Nitrogen plays vital role of establishing yield capacity and maintaining of photosynthetic activity during grain filling. Nitrogen concentration in leaf is associated with grain yield, as the N may later be translocated to grain. Also, slower N mobilization serves to maintain photosynthesis longer during grain filling (Fageria and Baligar, 2005). Biomass of maize is proportional to the amounts of radiation intercepted, water transpired and nutrients taken up.

2.4 Nitrogen source for plant growth

Nitrogen cycling in the soil-plant system, determines availability to crops. Nitrogen cycling involves N changes in amounts and transformation among different pools.

Nitrogen is added to the soil mainly through inorganic fertilizers. Other sources are biological fixation, precipitation, gases adsorption and organic manures (farmyard manure, green manures, and crop residues). Transformations of N in soil-plant systems include fixation, mineralization (ammonification), nitrification and immobilization. The utilization of NH_4^+ and NO_3^- by plants and microorganisms constitute assimilation and immobilization, respectively. Nitrogen loss occurs through leaching, runoff and volatilization.

Of the N in soil, 95% or more is present in the topsoil as an organic form, and the remainder is in mineral forms including some fixed as NH_4^+ (Streeter and Barta, 1988). The amount of N in form of soluble NH_4^+ and NO_3^- nitrogen is seldom more than 1 to 2 % of the total present, except where inorganic fertilizer has been applied. Some clay minerals (e.g. vermiculite and some smectite) have the ability to fix ammonium N between their clay units (Fageria and Baligar, 2005). About 8 % of total N in surface soils and 40 % of that in sub-soils may be in clay fixed form (Russell, 1973).

Mineralization is the conversion of organic forms of N to NH_4^+ and NO_3^- by microorganisms (Fageria and Baligar, 2005). It is controlled by soil microbial activity and varies from year to year with weather conditions. Nitrogen from organic matter becomes available very slowly because it is protected from rapid microbial release (Silgram and Shepherd, 1999). Only 2-3% of the N is mineralised to available forms in a year. About 50% of mineralised N is lost through various pathways that are part of N cycle: denitrification, leaching, volatilization, absorption and loss of N through plant canopy (Kumar and Goh, 2000). Some N is fixed on clay and organic matter (Silgram and Shepherd, 1999). Plant uptake of organic soil N depends on its mineralization rate and availability.

Crops in low input agricultural systems primarily depend on soil N derived from mineralization of soil organic matter. Crops take up externally added N in the soil and some is lost through leaching, denitrification, volatilization, surface runoff, and crop harvest. Some is assimilated in the bodies of microorganisms and fixed on clay and organic matter (Fageria and Baligar, 2005).

2.5 Benefit and potential of legumes as organic nitrogen sources

Legumes play an important role in low N input crop production systems because they fix atmospheric N biologically. Legume biological nitrogen fixation (BNF) is limited by available soil phosphorus. Acid soils are low in available P and this suppresses legume growth. Nitrogen concentration in legume pods and seed is higher than the rest of the plant (Lathwell, 1990). Grain weight is about 75% of pod weight. If mucuna seed is harvested the N in seed is not available to the soil The grain is normally exported off farm and trash may be burned or fed to animals leading to net loss from the farm (Hassan *et al.*, 1998). If legume biomass is incorporated in the soil it can provide extra N for food crops in addition to the nitrogen derived from the atmosphere. Large amounts of legume biomass may be required to meet crop N needs. The Legume Research Network Project

(LRNP) identified a number of legumes that produce substantial amounts of biomass (Mureithi *et al.*, 1998). Mucuna produces large aboveground biomass that if managed well can meet most if not the entire N requirement by maize (Lathwell, 1990). During 3 months growth period in eastern Uganda mucuna produced 2.6 to 7.9 t ha^{-1} of dry matter (DM), accumulating 80 to 200 kg N ha^{-1} in low and high potential agroecological zones of eastern Uganda (Kaizzi *et al.*, 2006). A significant fraction of the N, 34 to 108 kg N ha^{-1} (43 to 57%) was atmospheric biological fixed nitrogen (Kaizzi *et al.*, 2006). Lathwell (1990) estimates Ndfa to range from 60 to 80% and soil pH above 5 is required for optimum performance of mucuna.

Mucuna produces relatively little root biomass compared to aboveground biomass (Carsky *et al.* 2001). Roots weighed 0.4 t ha^{-1} and accounted for 5% of total biomass in the savanna of Nigeria. In acid soils of Nigeria, 93% of its roots were located in top 10 cm of soil. (Ibewiro *et al.*, 1998).

2.6 Effect of legume biomass on maize yield

Application of legume biomass as green manure has been shown to increase maize grain yield. However, responses differ depending on amounts applied, environment and management. In central Kenya, 1 to 2.7 t DM ha^{-1} of mucuna green manure (equivalent to 27 to 73 kg N ha^{-1}) raised maize grain yield by 80% (1.0 t ha^{-1} to 1.8 t ha^{-1}) (Mureithi *et al.*, 2002). In Kakamega, 4.6 and 5.1 t DM ha^{-1} of green manure (equivalent 134 and 139 kg N ha^{-1}) from mucuna and crotolaria, raised maize grain yield by 29 %.

In northwest Kenya, mucuna relay-cropped in maize produced 2.3 t ha^{-1} green manure biomass equivalent to 65 kg N ha^{-1} and increased following maize grain yield by 52 % over natural fallow control (Nyambati *et al.*, 2006). Onyango *et al.* (2003) showed that relay-cropping mucuna into maize after harvesting various food legumes (common bean, soyabean and cowpeas) and incorporation of its residue had potential to raise maize yield. After one year of residue application, maize grain yield under green manure was 44 % higher than of non-fertilized control, and was comparable to that which received inorganic 60 kg N ha^{-1} and 60 kg P_2O_2 ha^{-1}; the recommended level for maize production (Onyango *et al.*, 2003).

In Embu, eastern Kenya, incorporation of 8.1 and 6.3 t DM ha^{-1} of mucuna and crotolaria biomass (equivalent to 300 and 147 kg N ha^{-1} respectively) on a humic nitisol did not increase in maize yield significantly in long rains 1998 (Gitari *et al.*, 2002a). In the same experiment, incorporation of 2.3 and 1.4 t DM ha^{-1} of mucuna and crotolaria biomass supplying 85 and 33 kg N ha^{-1} respectively showed non-significant effect on maize grain yield, unlike the recommended inorganic fertilizer at 50 kg N ha^{-1}, during long rains 1999 (Gitari *et al.*, 2002 a). In eastern Kenya at Gachoka, incorporation of mucuna and crotolaria biomass at 9.2 and 6.3 t DM ha^{-1} equivalent to 133 and 91 kg N ha^{-1} respectively, on a nito-rhodic ferralsol, failed to give significant improvement on maize grain yield in long rains 1998 (Gitari *et al.*, 2002 b). However, mucuna and crotolaria applied at 10 and 7 t DM ha^{-1} of biomass equal to 116 and 82 kg N ha^{-1} respectively, on a humic nitisol, significantly increased maize grain yield by 38% over recommended inorganic fertilizer of 50 kg N ha^{-1} in the same season and region at Karurina (Gitari *et al.*, 2002 b). In a sandy soil at Mtwapa in coastal Kenya, mucuna and lablab relay-cropped with maize, and left to grow as sole crops after maize harvest prior to incorporation of biomass in following season, failed to make a significant effect on maize grain yield during long rains 1998 (Saha and Muli, 2002). Inorganic fertilizer at rate of 30 kg N ha^{-1} significantly increased maize grain yield by 27%, and its combination with legume proved to be of no advantage (Saha and Muli, 2002).

The variable effect of legume biomass application on maize grain yield in various locations and seasons as observed in this review was mainly attributed to variation in the quantities of material applied. Biomass may have been sufficient in some cases but less in others giving rise to uncertainty in the outcome, and erratic response. Biomass quality, edaphic and environmental factors may have contributed to variation also.

2.7 Organic matter decomposition and nutrient release

The main factors that control the organic matter transformation process are the quantity and quality of litter material components, the physical and chemical environment, and microorganisms. The soil microbial enzyme activity is affected by edaphic and climatic factors. Dehydrogenase activity is positively correlated with soil moisture and N concentrations (Rigobelo and Nahas, 2004). Of these factors, farmers most easily manage resource quality, and the best organic inputs are those that contain or release nutrients in ratios and rates required by crops (Palm *et al.*, 1997).

Nutrient release from organic material involves decomposition, which is mediated by soil microbes. Decomposition is enzymic digestion that produces energy, which may be appropriated by the microorganisms or liberated as heat, simple end products and humus. Besides the release of nutrients such as N, a slimy intermediate product of decay and humus that is the dark material that remains after the process, binds soil aggregates together thus enhancing stability (Brady, 1974).

Mineralization is the conversion of organic forms of N to NH_4^+ and NO_3^- by microorganisms. Since ammonia is the first form produced, the process has also been called ammonification. Fageria and Baligar (2005) describe ammonification as enzymatically catalysed microbial processes that hydrolyze organic and inorganic compounds to yield NH_4^+. The oxidation of NH_4^+ to NO_3^- is termed nitrification, and it takes place almost as rapidly as NH_4^+ is formed. The utilization of NH_4^+ and NO_3^- by plants and microorganisms constitutes assimilation and immobilization (Fageria and Baligar, 2005). Both processes occur simultaneously in soil, with the relative magnitudes determining whether the overall effect is net N mineralization or net N immobilization. Among the factors controlling net N mineralization of organic residues are: organic composition of the residue, soil temperature and water content, drying and rewetting events, soil characteristics (Cabrera *et al.*, 2005).

Organic residues added to the soil surface or incorporated into the soil undergo decomposition by the microbial biomass present (Cabrera *et al.*, 2005). Part of the carbon in the decomposing residues is evolved as CO_2 and part is assimilated by the microbial biomass involved in the decomposition process. If the amount of N present in the decomposing organic residue is larger than that required by the microbial biomass, there would be net N mineralization with release of inorganic N. If the amount of N in the residue is equal to the amount required there would be no net N mineralization. If the amount of N present in the residue is smaller than that required by the microbial biomass, additional inorganic N would need to be immobilized from the soil to complete the decomposition process. Therefore, amounts of C and N in residues and in decomposing microbial biomass control the occurrence of net N mineralization or net N immobilization. It has been shown that the C to N ratio of residues is related to the amount of N released and that the break-even point between net N mineralization and N immobilization occurs at C to N ratios of 15 and 40 (Cabrera *et al.*, 2005). Nitrogen concentration and the C-to-N ratio of the material still probably serve as the most robust indices when all plant materials are considered (Constantinides and Fawnes, 1994).

In addition to C:N ratio, polyphenols, proteins, soluble carbohydrates, and hemicellulose-like, cellulose-like, and lignin-like compounds, influence decomposition and N mineralization (Palm et al., 1997). The critical concentrations of N, lignin and polyphenol for transition from net immobilization to net mineralization have been established at >2.5 %, <15 %, and <4 %, respectively (Palm *et al.*, 2001). Nitrogen concentration in tissue ranging from 18 to 22 g kg^{-1} (1.8 to 2.2%) is the critical value for the transition from net immobilization to net mineralization. Not all organic materials with high N values, exhibit net mineralization. Lignin contents > 150 g kg^{-1} (15%) slows N release considerably, and polyphenol content > 30 to 40 g kg^{-1} (3 to 4%) can result in net immobilization of N (Palm, 1995). Lignin and polyphenols are particularly important modifiers of N release for the fresh, nonsenscent leaves of high-quality materials (Constantinides and Fownes, 1994). The immobilization resulting from polyphenolics, particularly condensed tannins, may be much longer than the temporary immobilization resulting from high C–to–N ratios in cereal residues (Constantinides and Fownes, 1994).

Materials with P content < 2.5 g kg^{-1} (0.25%) immobilize P. The phosphorus release patterns are not necessarily correlated to N release. Some materials showing net N mineralization can result in net P immobilization and vice versa, indicating the importance of looking at more than N in organic materials for release patterns of nutrients. Therefore, even if crop residues and other low-quality organic materials can be obtained in sufficient quantities, net N and probably P immobilization will occur, exacerbating the nutrient deficiencies, at least temporarily. The negative effects can be offset by combining with either inorganic N or high-quality organic materials with N content > 20 g kg^{-1} and P > 3 g kg^{-1} (> 0.3%). Nitrogen immobilization during decomposition tends to increase with increasing lignin and decreasing N content of plant tissue.

Polyphenol acts as bactericide, lowering the activity of microorganisms and enzymes, and ultimately slowing down decomposition and N release (Tian, 1992). In addition, the polyphenols bind mineralized N in the nitri and nitros–forms in soil humus, resulting in N fixation even at room temperatures. Similarly, high lignin acts as recalcitrant substance that is highly resistant to microbial decomposition hence slowing mineralization of lignin-bound N, resulting in immobilization (Tian, 1992).

Most herbaceous legumes screened and identified as promising for use in Kenya including mucuna, have N levels that are above the critical value range (>2.5% N). Similarly, the lignin and polyphenol concentrations of the legumes are below the critical value range for transition from net immobilization to net mineralization (Mureithi and Gitahi, 2004).

Other unique properties of legumes from some organic residues, such as pH, salinity, and heavy metal concentration, may affect activity and N mineralization, depending on the sensitivity of the microbial biomass present (Fageria and Balgar, 2005). Differences in amount of N released from the same residue in different soils have been observed (Cabrera *et al.*, 2005): The differences were attributed to adsorption of organic N by clays, increased aeration in sandier soils, different C to N ratios of microorganisms and microfauna and different populations of protozoa and nematodes present.

Soil water content and temperature interact in their effect on N mineralization (Cabrera *et al.*, 2005). In months with lower rainfall and air temperature the bacterial community numbers, respiratory and dehydrogenase activities decreased (Cabrera *et al.*, 2005).

During warmer and more moister months, bacterial number decreased followed by an increase in the microbial activities. Carbon dioxide evolution increased three to four fold from the driest to the most humid month, and was correlated with soil moisture content (Rigobelo and Nahas, 2004). Respirometer experiments by Birch (1958) showed that when dry soil is moistened a characteristic pattern of decomposition occurs in which all initial period of relatively rapid decomposition (stage 1) falls, during a few days, to a slow steady rate (stage 2). This pattern was repetitive with successive dryings and rewettings and was common to all soils studied, both in laboratory and field conditions with seasonal rainfall. The decline in rate of decomposition was attributed to a reduction in microbial activity, postulating that microorganisms active in the breakdown of substrate just after wetting had soon to compete with later developing less active ones (Birch, 1958).

2.8 Residual effect of green manure and fertilizers

Residual effect is the current increase in crop growth, yield or nutrient uptake caused by fertilizer applied in earlier seasons (Warren, 1992). Residual value is the proportion of fertilizer that remains in the soil and stays effective after the season of application. Residual effects were obtained after P application in the first year and continuing cropping for several seasons without further applications of fertilizer. To make allowance for the inevitable fluctuations in yields between years, results were expressed as the response to residues, either in kg ha^{-1} over a control or as a percentage of the crop yield. Warren (1992) cautioned that direct assessment of the residual value of organic manure along the lines of the experiments reviewed for soluble fertilizers, and suggested that it did not seem appropriate. The general practice is to apply organic manures on a continuous, annual basis to try to build up soil organic matter and fertility. Therefore, the concept of the residual effect of a single application might have limited usefulness.

Beckie and Brandt (1997) have adopted a different approach to assessment of residual influence of organic manure in various cropping systems: Nitrogen residual effect was computed as the amount of fertilizer N required for a non-legume crop grown on non-legume stubble to produce the same yield as that of the non-legume grown on legume stubble. The difference in net N mineralization between legume and non-legume stubble cropping systems was equated to the total N benefit (TNB) of the legume, and its residual effect. The major shortfall with the conventional method is that the N and the non-N benefits of the rotational systems are put together by assuming that the cereal yield improvement is primarily due to N fertilizer. This tends to overestimate the legume benefits in the system by ignoring rotational effects such as breaking cereal pest and disease cycles and enhanced nutrient cycling. As a possible remedy, Beckie and Brandt (1997) suggested use of legume broadleaf-cereal crop reference rotation instead of cereal-cereal reference rotation. In this case then, the benefit of the pulse crop to the succeeding crop is due to the N benefit provided by legume.

Sakala *et al.* (2004) evaluated residual effect of legumes grown and incorporated at early and late growth stages on maize yields on same plots in five sites in Malawi.

Incorporation of 6.7, 4.9 and 4.9 t DM ha^{-1} of green manure from mucuna, crotolaria and lablab, respectively in their early stages of growth significantly increased maize grain yield by 33 % compared to continuous maize cropping without fertilizer. Residual effect of legume material in Brazil was observed to be relatively small as measured either by yield increase or N uptake (Carsky *et al.*, 1999; 2001). In eastern Uganda application of 1.8 t DM ha^{-1} of biomass from tithonia failed to give significant residual effect on maize stover and yield, on sandy clay loam (Delve and Bashir, 2002).

Residual soil fertility has in some cases been referred to as the level of available plant nutrients, which a soil can provide without additional fertilization (Rowell, 1994). Residual soil fertility consists of "residual pools" of nutrients in the organic matter, exchangeable nutrients, slowly soluble chemical compounds, and nutrients in the soil mineral fraction (Brady, 1974). Plant availability of residual fertility is affected by many factors, including: the release of plant nutrients from the soil's mineral and organic fractions by dissolution and decomposition, past fertilization and cropping history. Residual effect of plant biomass application would depend on factors that determine its decomposition and persistence: residue physical and chemical quality; edaphic factors, soil and plant biomass management, and climate. Kumar and Goh (2000) reviewed effects of these factors on decomposition of plant residues.

2.9 Legume green manure residue management practices

Legume residue management influenced grain yield of maize reviewed on a nitisol at

Gatanga in central Kenya: Maize yield was higher where the residue was incorporated into the soil (2.1 t ha^{-1}) compared to leaving it on the surface as mulch (1.4 t ha^{-1}) (Mureithi *et al.*, 2005). On a sandy loam ferralsol at Kitale in North Rift Kenya, maize yield where legume biomass was incorporated was 13% higher than where the residue was left on soil surface as mulch (Kirungu *et al.*, 2000). Superior maize yields were attributed to higher accumulation of nitrate in the soil profile with incorporation but greater N loss via volatilization with surface mulching (Kirungu *et al.*, 2000). Costa *et al.* (1990) found that incorporated mucuna had a net inorganic N accumulation 60 % greater than that placed as surface mulch, and that 45 % of the N in the surface application treatment was unaccounted for, and probably lost to volatilization. Surface mulch based systems might have potential for improved soil moisture conservation, especially in water deficient environments (Gachene *et al.*, 2002).

2.10 Nitrogen use efficiency

Nitrogen use efficiency (NUE) can be described as the maximum economic yield produced per unit of N applied, absorbed, or utilized by the plant to produce grain and straw, and reflects the ability of the plant to convert inputs into outputs (Fageria and Baligar, 2005). Nitrogen use efficiency is used to evaluate the fate of applied chemical fertilizers and their role in improving crop yields. It can be classified as agronomic, physiological, agro-physiological, apparent and utilization efficiencies, depending on which attribute is used in evaluating destiny of applied N. Fageria and Baligar (2005) described apparent N recovery (ANR) as the percentage of applied N that is taken up. On average, NUEs were higher at lower than at higher application rates because plant absorption mechanisms might have been saturated, and N loss exceeded the rate of plant uptake. Nitrogen efficiencies can differ with source of N and environment particularly soil moisture (Streeter and Barta, 1984) and other factors e.g crop genotype and N management.

On sandy, sandy clay and clay soils in Zimbabwe, apparent N recovery (ANR) was 25 to 53 % indicating that there was a lot of N not utilized by maize from application of 4.7 to 11.2 t DM ha^{-1} of biomass from mucuna (Whitbread *et al.*, 2004). The loss of 73 kg N ha^{-1} as nitrate-N from the soil profile (0-20 cm) early in the wet season, and prior to maize N demand was proposed as the reason for low N recovery. In the Guinea savannah of Ghana, ANR in mucuna, crotolaria, and calopo (*Calopogonium mucunoides*), was found to be 22 % while that of inorganic N fertilizer used at 50 kg N ha^{-1} was 57 % on a ferric lixisol (Fosu *et al.*, 2003). Apparent recovery by maize in the same study was significantly more in high quality green manure (low lignin/N ratio) than in low quality (high lignin/N ratio) material. Lower N recoveries from green manure compared with inorganic N fertilizer emphasized the need to apply larger quantities of organic residue-N to match fertilizer response. Also, it is underscored that N supply from green manures alone could not be used to explain the increased cereal yields that may be observed with the use of cover crops, suggesting involvement of a large non-N effect (Fosu *et al.*, 2003).

2.11 Effects of rainfall on maize yield

Nutrient and water availability are the basic soil fertility factors that determine yield of crops (Rowell, 1994). Rainfall plays an important role in replenishing soil moisture. Also, nutrients are taken up in solution, so precipitation remains an important element of yield (Onyango and Muriuki, 1999). Simango (1976) studied the relationship between maize yield to rainfall during sowing to tasseling, tasseling to flowering, and flowering to maturity, at Katumani, Embu and Kitale in Kenya. Regression analysis showed that rainfall totals in the periods between sowing and tasseling, tasseling and flowering, had the highest significance, and therefore very important to the maize. Rainfall in the flowering to maturity period was the least significant.

Fertilizer use and recommendation project (FURP) investigated the influence of rainfall and temperature on maize yield in 71 sites in Kenya. Soil chemical properties, rainfall and temperature influenced maize response to fertilizer application (Onyango and Muriuki, 1997). Precipitation effects were better demonstrated in delayed planting of maize, which was a factor of onset of rainfall. In western Kenya, the study on rainfall regimes showed that 4-week delay accounted for yield losses of 2654 kg ha^{-1} in first season, and 1450 kg ha^{-1} in the second season (i.e 36-167%) in the long rains depending site (Onyango and Chege, 2000). Further, the study demonstrated that fertilizer response was not related to annual rainfall amounts, but rather on its distribution throughout the season. An investigation of seasonal rainfall received during six phenological phases of maize: planting-emergence, emergence–9^{th} leaf stage, 9^{th} leaf stage-tasseling, tasseling-silking and silking-full ripeness, showed that amount received in the later stage was the most significant in yield determination. Early planting of maize would ensure that water requirement climax, at silk–full ripeness stage, will coincide with peak rainfall (Onyango and Muriuki, 1997).

Temperature affects maize yield. Okoth and Wamae (1999) using FURP data established that elevation of site influenced maize yields in Kenya. High temperatures are usually associated with low rainfall, and tend to reduce the influence of rainfall through evaporation. FURP results also showed that maize yields decreased with increasing temperatures that had opposite effect with that of rainfall. In coastal Kenya, there was a clear relationship between response to N and rainfall received between silking and full ripening stage (Onyango and Muriuki, 1997). Using FURP data, Onyango and Chege (2000) found that the causes of low yields in late planting are inadequate initial soil moisture and poor rainfall distribution. Also, interaction between temperature and soil moisture. Rainfall onset effect was only significant if available moisture reached field capacity. Cavelier *et al.* (2000) showed that soil N mineralization and nitrification increased more with changes in soil water content than with changes in soil temperature.

2.12 Effects of inorganic fertilizer on maize yield

Okoth and Wamae (1999) studied fertilizer use recommendation project (FURP) zones of Kisii region using geographical information system (GIS), maize database project (MDP) climatic statistics, and Kenya Soil Survey (KSS) data. It was found that 38,225 ha of

Kisii districts' soil mapping units require application of 0 kg N ha^{-1} while 94,030 ha need 75 kg N ha^{-1}, during long rains season. Further, they observed that relationship between maize yield obtained and soil chemical properties was not clear with the exception of % organic carbon in which responses to N application appeared related to low (< 2 % C) levels in the soil. From the results a decision rule whereby 3 % organic carbon was defined to be the boundary between application of 0 and 75 kg N ha^{-1} was developed (Onyango and Muriuki, 1997). Phosphorus requirement for the same soil units was found to be 0 kg P_2O_5 ha^{-1} for some, while 25 kg P_2O_5 ha^{-1} and 50 kg P_2O_5 ha^{-1} was needed for others (Okoth and Wamae, 1999).

The Fertilizer Extension Project (FEP) results confirmed those of Fertilizer Use Recommendation Project (FURP), 75+0+0, from Otamba trial site. In higher areas of Upper Midlands, one (UM_1 represented by Kegati in Keumbu division, results showed that use of 75+50+0 was the best treatment. According to Schnier *et al* (1996) response to N or P was obtained for major food crops in most of the 70 FURP sites selected on account of soils and climate in various agroecological units of Kenya. Significant interaction between N and P was almost non-existent. The critical soil P levels for maize were 13 ppm P using modified Olsen extract and 32 ppm P for Mehlich I extract (Schnier *et al*., 1996).

2.13 Economics of fertilizer use in maize production

Mugunieri *et al*. (1997) performed economic analysis of fertilizer use in Kisii district, Kenya using farm and experimented production response functions. The optimal fertilizer levels in smallholder maize farms based on experimental response were 29 kg N ha^{-1} and 46 kg P ha^{-1}. On average smallholder farmers were applying at 11 kg N ha^{-1} and 19 kg P ha^{-1} that is less than 50% of optimum levels. The levels from farm response were 13 kg N ha^{-1} and 14 kg P ha^{-1}, and not very different from those used by the farmers. The findings indicated that economically optimal fertilizer rates from experimental response were much higher than those obtained under farm conditions.

Other findings from the study were that: on average, most farmers are using fertilizer close to on-farm response functions. Farmers stood to lose if they use optimum fertilizer levels from experimental response functions unless they improve their field management practices (Mugunieri *et al.* (1997). Shiluli *et al.*, (2003) studied agronomic and economic benefits of applying N and P to maize in 1994-96 in western Kenya. Nitrogen consistently increased maize grain yield significantly in all locations. This was unlike phosphorus application that improved maize grain yield only in some of the experimental locations covered. Partial budget analysis to determine rates of N: P that would give acceptable returns at low risk to farmers showed that two N: P combinations (i.e. 30:0 and 60:40 kg ha^{-1}) were economically best and stable within a price variability range of 20% (Shiluli *et al.*, 2003).

2.14 Knowledge gaps

Literature available is scanty on effects of legume biomass application rates on maize growth and yield, nitrogen uptake, and residual effect.

Maize yield responses obtained are as variable as the different amounts of biomass attained and applied. It is unclear at what rate of mucuna application that the N supply should be supplemented by combining with inorganic fertilizer.

Generally it has been assumed that involvement of legume would increase maize yield with little attention on the biomass productivity of the maize-legume system.

The economic aspects legume green manure-based N sources in maize are scarcely explored. As with inorganic fertilizer, different amounts of the legume N applied have varied maize yield response, and production cost.

So, this research sought to articulate the potential role of mucuna green manure biomass on N supply to maize.

CHAPTER THREE

NITROGEN EFFECTS, MAIZE GROWTH, NITROGEN UPTAKE, AND GRAIN YIELD

3.1 Introduction

Maize yield in Kenya is limited by inadequate soil nutrients among them nitrogen. Mucuna has shown potential as a cheap on-farm source of N for maize (Mureithi and Gitahi, 2004). But the legume has the problem of low and variable biomass output in different agro-ecological zones and yield practices. Kaizzi *et al.* (2006) demonstrated variability in mucuna biomass yield and N accumulation, with agro-ecological zones in eastern Uganda. This may affect mucuna capability to meet maize N requirement for maize. Therefore, there is need to evaluate various quantities of mucuna green manure that are attainable in various farming situations, on maize growth and yield. Mucuna accumulates substantial N, which has potential to meet most if not all the N needs of maize, when incorporated into the soil. Part of N in mucuna, accumulated in the biomass, is taken up from soil, while some is derived from the atmosphere (ndfa). Mucuna Ndfa ranges from 43% to 80% of accumulated N (Carsky *et al.*, 2001; Kaizzi *et al.*, 2006). In eastern Uganda, during 22 weeks, mucuna produced 2.6 to 7.9 t ha^{-1} of dry matter, accumulating 80 –200 kg N ha^{-1}, and derived approximately 34–108 kg N ha^{-1} from the atmosphere (Kaizzi *et al.*, 2006).

Beneficial residual effect from mucuna during subsequent cropping season of maize, hence fertilizer saving, has been documented (Sakala *et al.*, 2004). It is important to determine the application rate of mucuna biomass, required to make substantial residual effect on maize growth, N uptake and yield. The objective of this Chapter was to evaluate effect of different application rates of mucuna green manure: (i) on maize dry matter, nitrogen uptake and grain yield during application season and, (ii). Mucuna N residual effects on maize growth, nitrogen uptake and grain yield.

3.2 Materials and Methods

3.2.1 Site climatic characteristics

Field experiments were carried out on-farm at Mosocho, Kisii district, southwest Kenya. Table 3.1 shows the seasons during which the experiments were carried out and planting dates. Figure 3.1 shows that rain is bi-modally distributed from February to August (long rains) and from September to February (short rain season). The two seasons have rainfall ranging from 800 to 1000 mm, and 450 to 700 mm, respectively. Mean annual temperatures range from 18°C to 21°C and average minimum temperatures vary from 11°C to 14°C (FURP, 1987). The experimental site area at Bokeabu village is in lower midlands zone one to two (LM_1-$_2$), and has characteristics as described in FURP (1987). Variability in the total decadal rainfall amongst planting seasons and with regard to on-set, planting date, distribution and plant phenology is illustrated in Figure 3.1.

Table 3.1 Field maize experiment planting dates and phenology.

	Date of sowing	Days to 50 % tasselling	Days to 75% maturity	Days to harvesting	Total rainfall (mm)
Nitrogen response experiments					
1 Short rains, 2002	20-9-02	77-84	91-112	154	638
2 Long rains, 2003	21-3-03	77-84	91-112	172	1654
3 Short rains, 2003	15-9-03	77-84	91-112	154	850
4 Long rains, 2004	18-3-04	77-84	91-112	172	999
5 Short rains, 2004	18-9-04	77-84	91-112	154	884
Nitrogen residual effect					
a. First depletion season					
1 Long rains 2003	21-3-03	77-84	91-112	172	1654
2 Short rains 2003	15-9-03	77-84	91-112	154	850
3 Long rains 2004	18-3-04	77-84	91-112	172	999
4 Short rains 2004	18-9-04	77-84	91-112	154	884
b. Second depletion season					
1 Short rains 2003	15-9-03	77-84	91-112	154	850
2 Long rains 2004	18-3-04	77-84	91-112	172	999

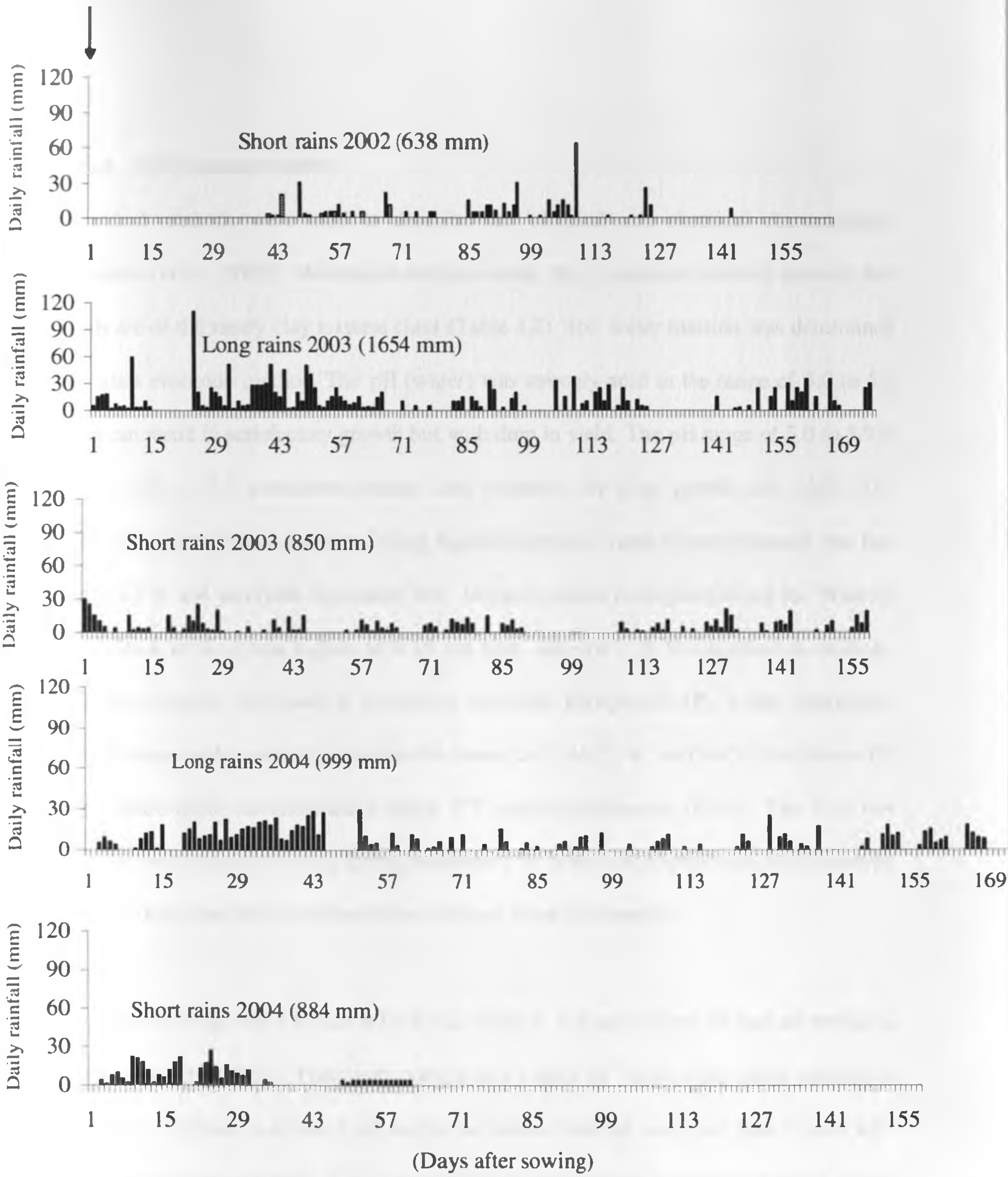


Figure 3.1 Variability of daily rainfall during planting seasons at Bokeabu village, Mosocho, Kisii, southwest Kenya. Long rains season (LR) = March to September; Short rains season (SR) = September to March. (Phenological stages: vegetative development = 1 to 77 days, reproductive = 77 to 84 days, kernel development and maturation =91 to 112 days, maturation and drying = 119 to 154 days in SR or 172 in LR.). Down arrow shows planting date. Data at start of SR 2002 and end of LR 2004 are missing.

3.2.2 Site characterization

Standard methods were used to describe soil physical and chemical characteristics (Okalebo *et al.*, 2002). Mechanical analysis using the hydrometer method showed that soils are of the sandy clay textural class (Table 3.2). Soil water reaction was determined by glass electrode method. The pH (water) was strongly acid in the range of 5.0 to 5.9 that can result in satisfactory growth but with drop in yield. The pH range of 5.0 to 5.9 is below 6.6 to 7.3 considered neutral and optimum for crop growth and yield. The percentage total N was measured using Kjeldahl method. Total N level obtained was less than 0.2 % and therefore considered low. Organic carbon determined using the Walkley and Black method was highest in 0-15 cm with value of 2.18 % classified as medium. Mehlich method was used in extracting available phosphorus (P), while ammonium acetate was used to extract exchangeable bases (Ca^{2+}, Mg^{2+}, K^+ and Na^+). Phosphorus (P) was determined calorimetrically using UV spectrophotometer (UVS). The first two cations were measured using flame photometry by atomic absorption spectrophotometer (AAS). The other two were determined using a flame photometer.

Phosphorus level was 8.5 ppm at 0-15 cm, which is low as it is less 20 ppm according to Mehlich (FURP, 1987). Potassium amount was 1 cmol kg^{-1} at 0-15 cm that is considered adequate. Calcium was low at all depths, as values obtained were less than 2 cmol kg^{-1}. Cation exchange capacity (CEC) determined by ammonium saturation method ranged from 10.4 cmol kg^{-1} at 0-15 cm depth to 11.4 cmol kg^{-1} at 15-30 cm which indicates low nutrient availability as values range between 6 to 12 cmol kg^{-1}. Low CEC values result in a small capacity for soil to hold nutrient cations that together with leaching caused by high rainfall may lead to deficiencies. Soil type is nito-humic ferralsol (FURP, 1989), and is of low to medium inherent fertility, as its CEC value is less than 15 cmol kg^{-1} and base saturation 57 to 60 % (Table 3.1) (FURP, 1989).

Table 3.2. Physical and chemical properties of soil in field experimental site at Mosocho, southwest Kenya [1]

Parameter Measured	Units	Soil depth (cm) 0-15	15-30	30-50	50-100	[2] Critical values, and classification.
Particle size						
- Sand	%	46	40	46	40	
- Silt	%	8	10	8	8	Sandy clay soil
- Clay	%	46	50	46	52	
Bulk density	g cm^{-3}	1.0	1.1	1.1	1.1	
pH (ratio 1:2.5)						
H_2O		5.1	5.9	5.2	5.6	(5.0-5.9)
1 N KCl						Strongly acid
		4.2	4.6	4.5	4.9	
Organic matter (O.M)	%	3.8	2.8	2.3	1.7	(2.1-4.2) Medium
Organic carbon (O.C)	%	2.2	1.6	1.3	1.0	(1.6-2.0) Medium
Total nitrogen (N)	%	0.18	0.14	0.07	0.05	(< 0.2) Low
C: N ratio		12	12	19	19	(< 20) Low
Avail. Phosphorus (Mehlich method)	ppm	8.5	1.5	0.25	0.22	(<20) Low
Avail. Potassium (K)	Cmol kg^{-1}	1.00	0.95	0.20	0.15	(0.2-1.5) Adequate
Calcium (Ca)	Cmol kg^{-1}	0.55	0.45	0.23	0.30	(< 2.0) Low
Magnesium (Mg)	Cmol kg^{-1}	4.7	5.15	5.15	3.35	(>3.0) Excessive
Sodium	Cmol kg^{-1}	0.01	0.01	0.01	0.01	(< 2.0) Adequate
Base saturation (Ca^{2+}, Mg^{2+}, K^+ and Na)	%	60	58	47	30	(40-85) Medium (FURP, 1987)
CEC	Cmol kg^{-1}	10.4	11.4	11.8	12.6	(6-12) Low
Overall						Low to medium inherent fertility soil

[1] To convert Cmol kg^{-1} to ppm (mg l^{-1}): Multiply by 1000 x atomic weight (Okalebo *et al.*, 2002). To convert % to ppm (mg l^{-1}): divide by 10,000.

[2] Landon, J. R. 1984. Booker tropical soil manual: A handbook for soil survey and agricultural land evaluation in the tropics and sub-tropics. Longman Inc, New York, U.S.A. 450p.

3.2.2.1 Mucuna green manure biomass

Mucuna green manure characterization was done on composite sample. It was assumed that mucuna biomass would be applied as produced, irrespective of its plant part composition. The nutrient concentration in the composite sample was 46% C, 1.6% N, 0.36% Ca, 0.16 Mg and C:N ratio 21.

3.2.3 Experimental design

3.2.3.1 Effect of mucuna on maize growth and tissue N.

Mucuna green manure was applied at 0, 30, 60, 120, 240 and 480 kg N ha^{-1}; and urea at 30, 60 and 120 kg N ha^{-1}. The mean tissue N concentration in mucuna was 1.6 % hence mucuna dry matter (DM) was 0, 1.5, 3, 6, 12 and 24 t DM ha^{-1}, respectively. These corresponded to 0, 19, 38, 76, 152 and 305 kg fresh weight of the biomass per 21 m^2 plot, in that order. The experiment was laid out, as randomised complete block design replicated four times (Mead *et al.*, 1983). Maize H614 was planted at 75 cm x 30 cm, one plant/hill. Data were collected on maize height, dry matter yield (TDM), grain yield and tissue N. The treatments were evaluated for five seasons when N was applied, and two seasons to assess maize response to residual N (Table 3.1). Plant N was determined in selected seasons to minimize cost of analysis. These were short rains 2002 and 2003, and long rain 2004, and long rain 2003 in the residual N effect trial. Table 3.3 shows the seasonal schedule of the experiments.

3.2.3.2 Effect of mucuna residual N on maize growth in subsequent seasons

Applied treatments in short rain 2002 as described in section 3.2.3.1 were evaluated for residual effect on maize planted in long and short rains 2003, within the previous experimental design (Table 3.3) and plots. Treatments applied in long rain 2003 were assessed for their residual effect on maize dry matter yield and total N in first and second subsequent planting seasons in short rain 2003 and long rain 2004, respectively (Table 3.3). Those applied in short rain 2003 were evaluated for residual effect in long rain 2004; while those applied in long rain 2004 were assessed for the effect in short rain 2004 (Table 3.3).

Table 3.3 Field planted maize seasonal schedule

	EXPERIMENT: **APPLICATION SEASON**			EXPERIMENT: **SUBSEQUENT SEASONS**					
		DATES		**FIRST DEPLETION**	**DATES**		**SECOND DEPLETION**	**DATES**	
		Planting	Harvest		Planting	Harvest		Planting	Harvest
1	Short rain 2002 (**S1**)	20-9-02	3-3-03	-			-		
2	Long rain 2003 (**S2**)	21-3-03	11-9-03	Long rain 2003 (**S1R1**)	21-3-03	11-9-03	-		
3	Short rain 2003 (**S3**)	15-9-03	19-2-04	Short rain 2003 (**S2R1**)	15-9-03	19-2-04	Short rain 2003 (**S1R2**)	15-9-03	19-2-04
4	Long rain 2004 (**S4**)	18-3-04	8-9-04	Long rain 2004 (**S3R1**)	18-3-04	8-9-04	Long rain 2004 (**S2R2**)	18-3-04	8-9-04
5	Short rain 2004 (**S5**)	18-9-04	16-2-05	Short rain 2004 (**S4R1**)	18-9-04	16-2-05	-		

<u>KEY</u>

S1 = Short rain 2002, **S2** = Long rain 2003, **S3**=Short rain 2003, **S4** = Long rain 2004, **S5** =Short rain 2004
S1R1 =Long rain 2003, first subsequent season, **S1R2** = Short rains 2003, second subsequent season.
S2R1 = Short rain 2003, first subsequent season; **S2R2** =Long rain 2004, second subsequent season.
S3R1=Long rain 2004, first subsequent season
S4R1 = Short rain 2004, first subsequent season

3.2.4 Crop management

Mucuna green manure grown on a nearby plot was harvested, chopped into small pieces of about 2 cm and incorporated into the soil according to treatments prior to planting of maize on the same day. Phosphorus (P) and potassium (K) were applied as triple super phosphate, and muriate of potash, respectively. All plots were supplied basally with 50 kg ha^{-1} P and K to ensure nutrients were not limiting, except for N. Nitrogen was applied as mucuna green manure; and inorganic fertilizer-urea in two splits: First half at one week after emergence (WAE), and second one in 3 to 4 WAE, after first weeding. The purpose of splitting was so as to minimize losses through leaching, denitrification, run off and volatilisation.

The experimental plots managed as described above but no fresh application of mucuna, inorganic fertilizer-urea, P or K was applied in the residual plots.

3.2.5 Data collection

3.2.5.1 Plant height

Maize height was measured at 8, 12 and 16 weeks after emergence (WAE) using a meter rule. The first two observation dates corresponded to vegetative and tasseling stages and 16 WAE was at harvest. Height was measured as distance from ground level to the upper-most tip of maize. At tasseling, the upper-most tip of the flag leaf was used. Prediction functions were generated for other maize variables (Table 3.4) that are relatively difficult to measure, from plant height, using linear relationships (Mead *et al.*, 1993).

3.2.5.2 Dry matter

Maize dry matter yield was determined at 8, 12 and 16 weeks after emergence (WAE). Four plants selected randomly in each plot were cut at the ground level, and chopped into small pieces, which were oven-dried at 105°C for 72 hours to constant mass and weighed.

3.2.5.3 Maize grain yield

Grain yield was determined from the harvest of 5.2 m^2 area in the centre of the plot. The grain was oven-dried at 105°C for 72 hours to obtain grain yield dry matter weight. Maize grain to be used in plant total N analysis was dried at 65 ^{0}C for 72 hours to constant mass.

3.2.5.4 Harvest index

This was calculated as the ratio of maize grain dry weight to whole plant dry weight. The latter was made up of dry grain weight and dry weight of other plant parts at harvest.

3.2.5.5 Plant total nitrogen

Maize N uptake was measured from above ground mass samples collected at harvest. The samples were chopped into small pieces, which were oven-dried at 65°C for 72 hours to constant mass. The total N percentage in stover or grain was measured by Kjeldahl and colorimetric procedures (Okalebo *et al.*, 2002).

3.2.6 Data analysis

Genstat was used in performing data analysis and significant treatment effects determined using analysis of variance at F-probability of 0.05. Treatment means found to be significant were separated using Fishers' protected least significant difference (LSD) test (Mead *et al.*, 1983).

3.3 Results and Discussion

3.3.1 Relationship between plant height and dry matter accumulation

Crop growth may be assessed using direct dry matter accumulation methods or indirect methods (Tittonell *et al.*, 2005). The latter approaches though not commonly used have the advantage of being non-destructive, quicker, and therefore may be used for early yield estimations in farmers' fields. If validated to accuracy the approaches, such as in the use of plant height, might be fast, cheap and simple (Tittonell *et al.*, 2005). An attempt was made to relate maize plant height to the accumulated dry matter.

Maize plant height and dry matter yield increased over time in all the treatments and seasons. (Figure 3.2). Simple linear regression relationships indicated that plant height; total dry matter (TDM) and grain yield were positively related (Table 3.4). The N sources did not influence plant height significantly, but the seasons did. In most of the seasons, variation in plant height explained less that 50% and 40% of the total biomass and grain yield, respectively (Table 3.4). Averaged between N sources, regression coefficients (R^2) were lowest and highest in the short rains 2002 and long rains 2003, respectively (Table 3.4). Generally, variation in plant height accounted for 63% and 44% of variation in TDM and grain yield, respectively in the long rain season compared to 44% and 35% in the short rain season.

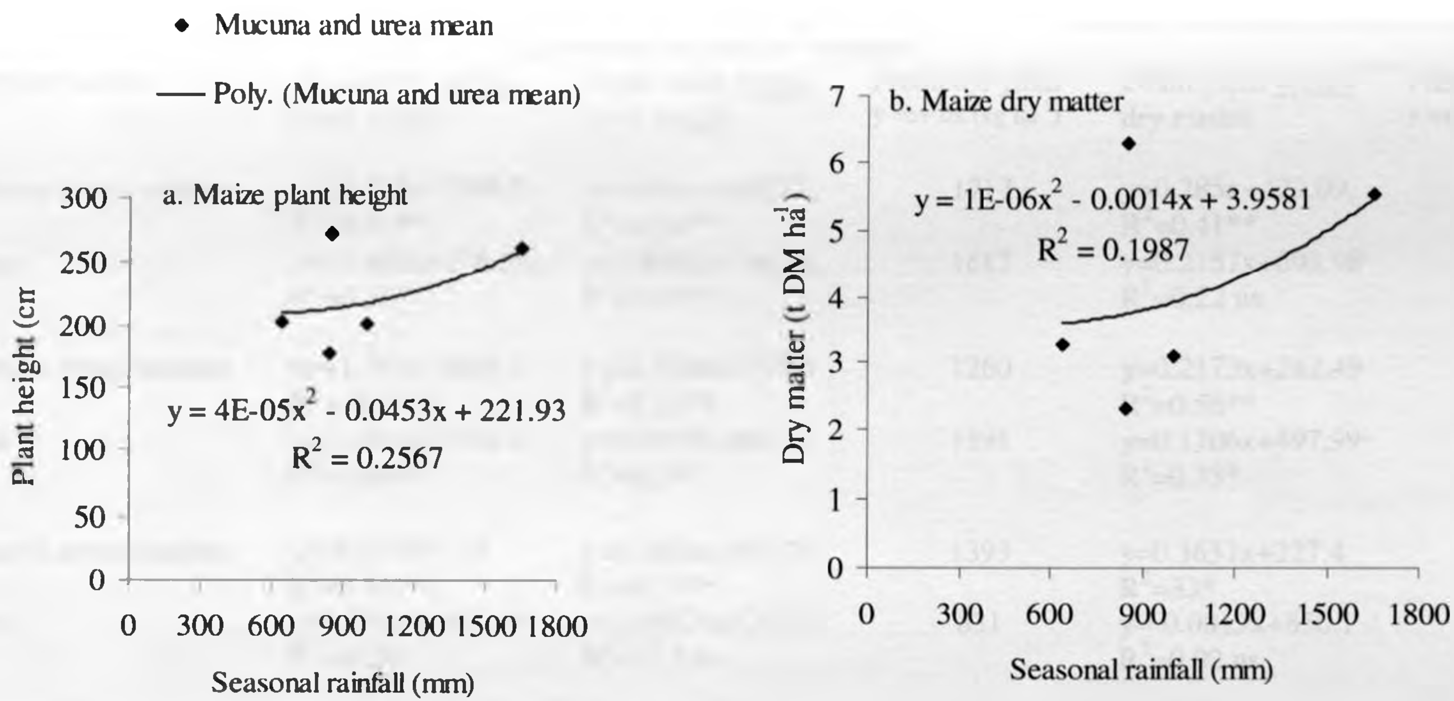


Figure 3.2 Maize plant height and dry matter response to seasonal rainfall at Mosocho, Kisii, southwest Kenya (2002-04).

Table 3.4 Regression of maize variables against its height

		Regressions on maize variables				
Planting season	Nitrogen source	Dry matter versus plant height	Grain yield versus plant height	Predicted yield y =a+ bx (kg ha^{-1})	Grain yield versus dry matter	Predicted yield y =a+ bx (kg ha^{-1})
Short rain 2002	Mucuna green manure	y=22.365x-1096.5, R^2=0.41**	y=8.981x-4.02.27, R^2=0.34**	1717	y=0.285x+423.09, R^2=0.41**	1987
	Urea	y=13.605x+288.69, R^2=0.31*	y=7.6402x-196.51, R^2=0.47**	1617	y=0.2157x+693.98 R^2=0.22 ns	1816
Short rain 2003	Mucuna green manure	y=41.787x-5001.3 R^2 = 0.51**	y=12.338x-1735.6 R^2=0.53**	1260	y=0.2173x+242.49 R^2=0.56**	2195
	Urea	y=35.541x-3744.2 R^2 = 0.40**	y=8.6495x-804.58 R^2=0.26*	1191	y=0.1706x+497.99 R^2=0.33*	1938
Short rain 2004	Mucuna green manure	y=16.2x-497.55 R^2=0.54**	y=8.5866x-441.25 R^2=0.38**	1393	y=0.3637x+227.4 R^2=33*	1401
	Urea	y=8.891x + 603.49 R^2 =0.28*	y=3.4682x+137.22 R^2=0.12 ns	831	y=-0.0819x+850.1 R^2=0.02 ns	850
Long rain 2003	Mucuna green manure	y=43.687x-5927.7 R^2=0.83**	y=18.485x-1708.7 R^2=0.73**	3497	y=0.3798x + 1028 R^2=0.71**	3936
	Urea	y=31.541x-2821.9 R^2=0.66**	y=13.522x-470.9 R^2 =0.42**	3387	y=0.3562x +1110 R^2=0.44**	3936
Long rain 2004	Mucuna green manure	y=29.929x-3180.1 R^2=0.37**	y=34.283x-4100.4, R^2=0.43**	2585	y=0.5669x+1135.4 R^2=0.28 ns	1139
	Urea	y=31.728x-3011.9 R^2=0.65**	y=10.179x-29.466 R^2=0.29*	1979	y=0.3341x+894.48 R^2=0.48**	3258

** = R^2 is highly significant; *= R^2 is significant, ns=R^2 is not significant.

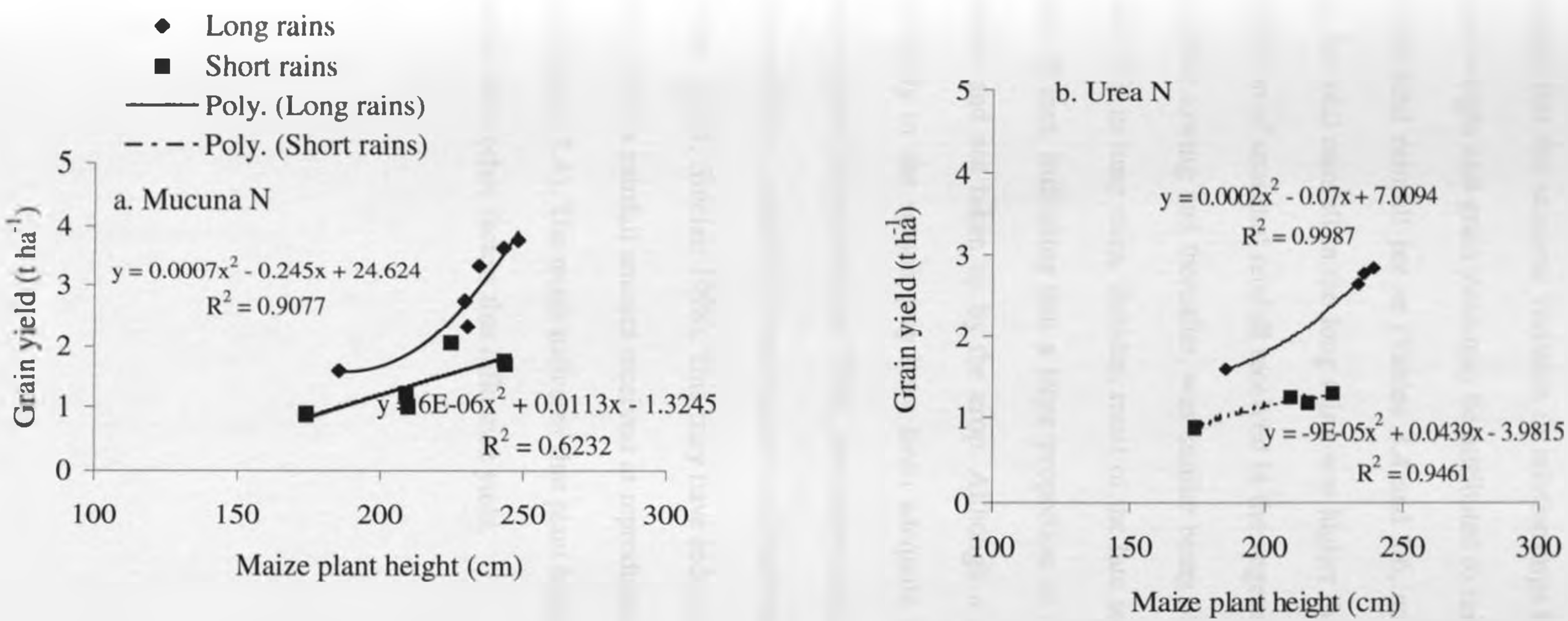


Figure 3.3 Maize plant height relationships with grain yield at Mosocho, Kisii, southwest Kenya (2002-04)

It is notable that the seasonal variation in relationships between maize plant height with dry matter weight and grain yield may be attributed to rainfall distribution within a period rather than total rainfall per se (Tables 3.4 and 3.6, and Figure 3.4). Nevertheless, on average the total rainfall in the long rains was higher that in the short rains. Generally, the proportion of seasonal rainfall received in the vegetative and reproductive phases i.e. 80 days after sowing and thereafter, was similar being 63% and 37% for short rains and, 64% and 37% in long rains Besides, most of the late season daily rainfall was low, i.e. less than 30 mm, indicating that a large proportion of it might have been lost through evaporation and not taken up by the crop. Although a larger proportion of the rainfall received early in the season may have been adequate for vegetative maize growth as indicated by plant height and total TDM, late season drought may have hampered process of photosynthesis, assimilate translocation and nutrient uptake (Eastin and Sullivan, 1984; Moss, 1984; Sinclair 1998). This may have reduced the correlation between height and grain yield as rainfall amount received at reproductive phase was found to influence the latter (Figure 3.4). The result indicates that plant height should be used judiciously, in conjunction with other factors that influence yield.

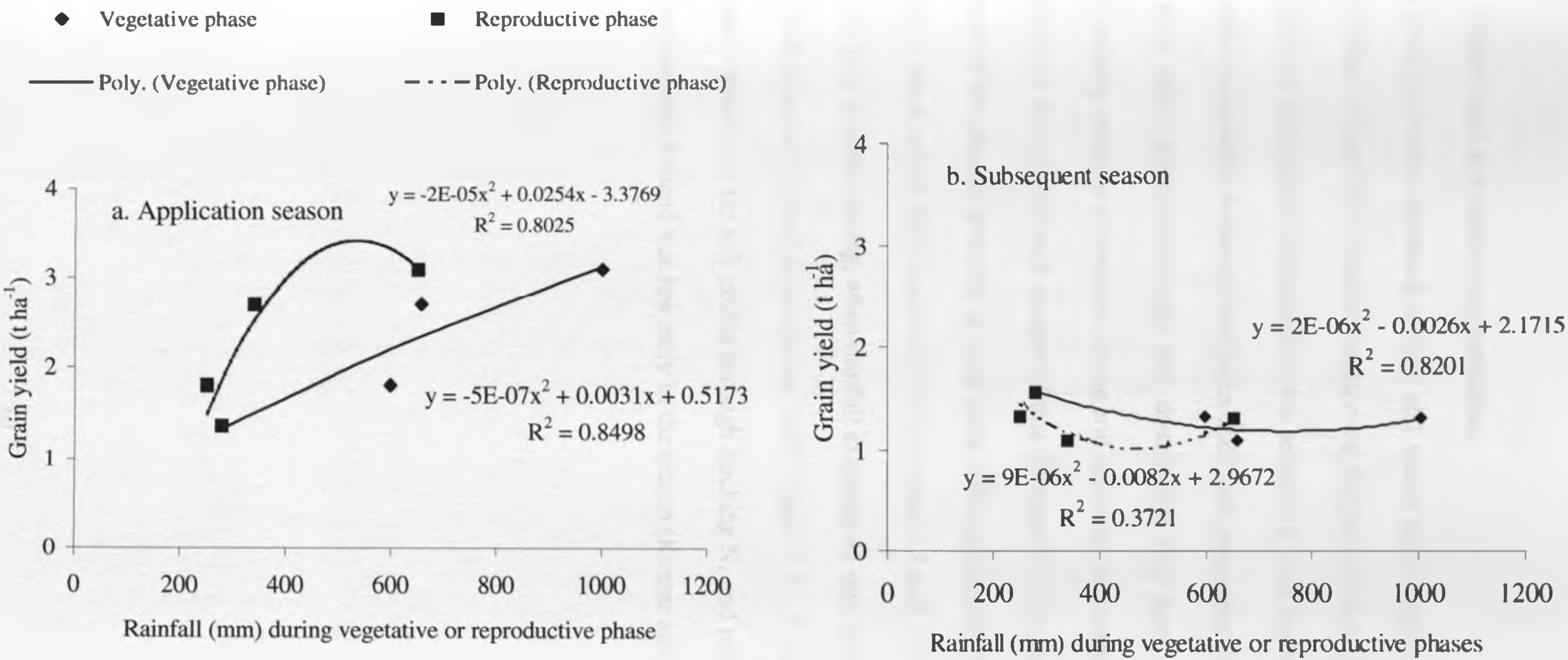


Figure 3.4 Effect of rainfall amount received during vegetative or reproductive phase of maize on grain yield during application and subsequent planting seasons at Mosocho, Kisii, southwest Kenya (2002-04) (Reproductive phase is the period 80 days after sowing.).

3.3.2 Maize total dry matter accumulation

Maize total dry matter increased in time and varied significantly among seasons by 16 WAP (Tables 3.5 and 3.6). Total dry matter was highest in the long rains 2003 and short rains 2003 but comparable between the two seasons. It was lowest in the in short rains 2004 while comparable between short rains 2002 and long rains 2004, but higher than in short rains 2004. Rainfall amounts and distribution may have influenced the maize growth patterns because of variation in the soil moisture. Although rainfall in short rains 2003 was only 51% of the total amount of that received in long rains 2003, it is probable that some of the rainfall received in long rains 2003 might have been stored in the soil profile and taken up by short rains 2003 crop (Tables 3.5 and 3.6). There were six days out of the first 50 after sowing, when rainfall exceeded 45 mm day^{-1} (totaling 321 mm or 50% of the seasonal rainfall) in long rains 2003 (Figure 3.1). It is probable that some of this water drained into the soil profile through leaching N, and run-off, because the crop water and nutrient demand was low early in the season (Kumar and Goh, 2000).

Table 3.5 Maize total dry matter response to N fertilizer at 8, 12 and 16 weeks after emergence, during application season, at Mosocho, Kisii, southwest Kenya (2002-04).

		Maize dry matter (t ha^{-1})																	
		Short rain 2002			Long rain 2003			Short rain 2003			Long rain 2004			Short rain 2004			**Season and interactions**		
Treatment		Weeks after emergence (WAE)															WAE		
Nitrogen (kg N/ha)		8	12	16	8	12	16	8	12	16	8	12	16	8	12	16	8	12	16
	0	0.65	2.60	3.37	0.96	3.28	5.17	1.34	3.33	5.15	1.12	1.57	4.95	0.88	1.59	3.08			
Mucuna	30	0.56	2.51	5.12	1.52	5.50	7.47	1.46	6.24	6.95	1.50	2.28	4.54	1.06	1.82	3.21			
green	60	0.89	3.11	5.13	1.80	5.86	7.19	1.28	5.05	7.41	1.38	2.37	5.49	1.32	2.28	3.12			
manure	120	0.81	4.19	5.53	1.90	6.71	8.68	1.94	7.85	9.04	2.12	3.25	5.83	1.98	2.44	4.38			
	240	0.83	4.11	6.49	1.52	5.50	7.47	2.55	7.96	10.57	1.96	3.04	8.01	1.69	3.45	4.80			
	480	0.81	3.26	5.16	1.52	5.50	7.47	2.95	8.12	10.96	2.45	4.02	6.63	1.59	3.03	3.83			
Inorganic	30	0.85	2.75	5.31	1.55	5.12	8.17	2.01	5.63	9.53	1.93	3.26	5.46	1.08	2.14	3.77			
fertilizer-	60	0.93	3.63	5.05	1.24	5.42	7.82	2.47	6.67	7.34	2.73	4.34	5.40	1.71	1.94	3.69			
urea	120	0.96	3.21	5.25	1.65	6.62	7.81	1.79	5.89	8.46	2.53	3.61	10.36	1.52	2.38	3.71			
Mean		0.81	3.26	5.16	1.52	5.50	7.47	1.98	6.31	8.38	1.97	3.08	6.30	1.42	2.34	3.73			
Season (S) F test																	*	*	*
LSD season																	0.28	0.61	0.93
N Source F test		*	ns	ns	*	ns	ns	ns	ns	ns	*	ns	ns	ns	ns	ns			
LSD N source (NS)		0.12	0.64	0.74	0.32	1.05	1.68	0.28	1.31	2.09	0.63	0.81	0.75	0.43	0.31	0.99			
LSD N source rates		0.13			0.57						1.08								
N source x S F test																	ns	ns	ns
LSD NS x season																	0.25	0.82	1.46
N rate F test		*	*	*	*	*	ns	*	*	*	*	*	*	*	*	ns			
LSD N rate		0.14	0.71	1.27	0.58	1.73	2.84	0.91	1.80	3.21	0.97	1.49	2.47	0.52	0.60	1.72			
N rate x S F test																	*	*	ns
LSD N rate x S																	0.67	1.31	2.34
% C.V Treatment		11.9	14.8	16.8	25.3	20.9	25.2	31.3	19.6	26.3	33.8	33.1	26.8	24.9	17.4	31.6			

F=Fisher test; * =Differences significant, ns=non-significant; LSD=Least significant difference; N source rates=30, 60,120 kg Nha^{-1}

Table 3.6 Seasonal rainfall distribution during maize vegetative and reproductive phases at Mosocho, Kisii, southwest Kenya (2002-04)*

	Rainfall (mm)			
Planting season	Vegetative phase	% of seasonal total	Reproductive phase	% of seasonal total
Short rains 2002	359	56	279	44
Long rains 2003	1002	61	652	39
Short rains 2003	599	70	251	30
Long rains 2004	658	67	341	34

* Reproductive phase was the period 80 days after sowing.

Although the total rainfall in long and short rains 2003 and short rains 2004 was comparable (a difference of only 34 mm), most of it in the short rains 2004 fell in the first month and no rain fell in the late vegetative and reproductive stages when both water and nutrient demand is highest (Figure 3.1 and Table 3.6). This explains the low total dry matter produced because the growing season in short rains 2004 was shortened by the late season drought compared to the other seasons. The thought on effects of water stress in late season are in accordance with Sinclair (1998), O'Neil *et al.* (2004), Eastin and Sullivan (1984). On the contrary the short rains 2002 experienced early season drought. Although the total seasonal rainfall was low in short rains 2003, the percentage distribution between the vegetative and reproductive phase at 63% and 37% for short rains, and 64% and 37% in long rains was comparable (Table 3.6). In contrast, rainfall distribution in long rains 2004 which had 36% more rainfall than short rains 2004 had most of the rain fell early in the season (vegetative phase) in the former and most of the rain that fell in the reproductive phase was less than 10 mm/day and therefore might have been lost through evaporation. These rainfall trends are expected to have influenced total dry matter production trends in the residual effect experiments as well (Section 3.3.4).

Seasonal rainfall has the role of replenishing soil moisture. The strong interaction between water and availability of nutrients to crops arises from effects of soil moisture on, (i) the release of nutrients unavailable to available forms; (ii) the transport nutrients to plant roots; and (iii) loss processes (Gregory *et al.*, 1997). Also, biomass production of annual crops as maize is often directly proportional to not only the amounts of radiation intercepted but, water transpired and nutrients taken up (Gregory *et al.*, 1997). There was unclear relationship between amount of rainfall received and level of dry matter produced. This was attributed to differences in start of rainfall after season on-set, distribution within season, and planting date (Figures 3.1 and 3.2). Mburu and Gitari (2006) observed that despite the rainfall accounting for 74 % of the variation in grain yield at Kabete and Embu in Kenya, the relationship between total seasonal rainfall and maize stover yield was indistinct. They explained the complexity of rainfall distribution effects on stover yield by variability within the season, and crop sensitivity to length and intensity of water stress in dry spell, despite similar quantities of rain. Thus, climatic factors should be taken into account when planning management measures because depletion of soil water is commonplace as rainfall in most rapid crop growth period is less than potential rate of evaporation in most of the world (Gregory *et al.*, 1997; (Dahlin *et al.*, 2005).

3.3.3 N source and rate effects

The nitrogen source effect on total dry matter was non-significant except at 8 weeks after planting (WAP) in the short rains 2002, long rains 2003 and long rains 2004. However, the trend did not persist to the end of the season (Table 3.5). In short rains 2002 and long rains 2004, total dry matter was significantly higher in maize where urea was applied but TDM was higher in maize that had mucuna as the source of N. It is probable that the unusually low TDM obtained at an application rate of 60 kg ha^{-1} urea was an artifact rather that a real fertilizer type effect. The 8^{th} week corresponded to a rapid growth stage in the vegetative phase (Tesser, 1984). There was no significant interaction between N source and season.

Lack of advantage in the application of mucuna green manure over urea fertilizer in the range of N rates evaluated was contrary to expectation. Mucuna was expected to have other benefits like the addition of organic matter and non-N nutrients (Hesterman, 1988; Frye *et al.*, 1988). The outcome was probably because the expected advantage of organic N source might be occurring at rates higher than those applied and, possibly after cumulative effect to build the soil organic matter content has taken place. It is also probable that that composition of the organic matter may have played an important role due to N release pattern in relation to crop N demand. The mucuna green manure applied had N concentration of 1.6% that is within range of 1.4 to 1.8% considered threshold (Kumar and Goh, 2000) for net mineralization. Consequently, it may have decomposed rapidly and possibly supplied available N comparable to urea, at the similar application rates.

Maize dry matter accumulation varied significantly at different nitrogen application rates and there was also a significant interaction between N rate and season at 8 and 12 WAP (Table 3.5). Maize fertilized with urea at application rates of 30, 60 and 120 kg N ha^{-1} had comparable and significantly higher dry matter yield than that in the control at 8 or 12 and 16 weeks after emergence. There was significant interaction between N application rate and planting season on maize dry matter weight. Maize supplied with mucuna and urea fertilizer at 30, 60 and 120 kg N ha^{-1} had significantly higher dry matter yield in long and short rains 2003 compared to that in other seasons (Table 3.5). This showed that maize response to N application rate varied across planting seasons probably due to changes in total rainfall as well as distribution within the season. Comparatively, maize in high application rates of mucuna at 120, 240 and 480 kg N ha^{-1} though with similar trend, had significantly more dry matter weight even in short rain 2002 season which had the lowest total rainfall (Table 3.5). Therefore high rates of N are required in order to get good response in seasons of less rainfall, because N uptake is less (Fageria and Baligar, 2005).

The lack of significant increase in TDM in maize supplied with mucuna green manure at the rate of 30 kg N ha^{-1} was perhaps because the amount was too small to trigger co-metabolism (Kuzyakova *et al.*, 2000; Hammer and Maschner, 2004). Mureithi *et al.* (2002) found that 1.0 t DM ha^{-1} of mucuna green manure equivalent to 27 kg N ha^{-1} applied to a nitisol at Gatanga, central Kenya in 1999 long rains did not have significant improvement in maize grain yield.

In this study, maize supplied with 60 kg N ha^{-1} or more had significantly higher TDM at 8 and 12 or 16 weeks after emergence (WAE) compared with that depended solely on soil N (control) (Table 3.5). This indicated that fertilizer applied at 60 kg N ha^{-1} and above supplied significantly higher N to the maize compared to 30 kg N ha^{-1} (Table 3.5). Maize receiving mucuna N at rates of 120, 240 and 480 kg ha^{-1} had higher dry matter weight at 8, 12 and 16 WAE than that in the control indicating that the treatments were superior (Table 3.5).

The explanation to the above observation could be two–fold: It may be that N applied at 30 kg N ha^{-1} of inorganic fertilizer N sufficed maize requirement at the site or fertilizer-N in excess of 30 kg N ha^{-1} was lost in leaching; run-off, volatilization or denitrification, hence was not available for uptake and maize growth. In either case, the outcome shows that there may be no advantage in maize growth in application of urea fertilizer level greater than 30 kg N ha^{-1} at the site. The finding corroborate with the FURP (1994) recommendation of 30 kg N ha^{-1} as the economical application rate of N to use in the experimental region for maize.

The failure of high N fertilizer application such as 120 kg N ha^{-1} to increase dry matter production compared to lower rates has been demonstrated. In Swaziland, maize dry matter response to N at 0, 50, 100 and 150 kg N ha^{-1} was 9.2, 10.2, 11, and 10.6 t ha^{-1}, respectively. This indicated initial TDM response to increasing N up to 100 kg N ha^{-1} and then declined (Mkhabela *et al.*, 2001). In the current study, there was no significant increase in TDM in maize supplied with 120 kg N ha^{-1} or more. This possibly indicated that there were luxury uptake (Muriuki and Qureshi, 2001) or the excess N was lost through leaching, volatilization, run-off or denitrification (Fageria and Baligar, 2005).

3.3.4 Fertilizer N residual effects on maize dry matter yield

3.3.4.1 Effect of planting season

Maize dry matter yield varied significantly among planting seasons and it was highest in short rain 2003 and lowest in short rain 2004 (Figure 3.5; Tables 3.7 and 3.8). The nitrogen source or amount applied in the previous season did not have a significant effect on dry matter in the following season. The seasonal variation in the dry matter may have been as a result of the variation in rainfall amount and distribution and not previous N treatments. Nitrogen especially the nitrate N is labile in soil and if not taken up by crops, it is easily leached beyond the crop rooting zone or transformed. While ammonium N may be adsorbed on soil colloids but it is also transformed into nitrate forms that are easily lost. Similar observations of mucuna green manure non residual N advantage have been reported (Carsky 1989, Ssali, 1990, Delve and Bashir, 2002). It is notable that although applied N stimulated significant maize growth in all the seasons, the maize TDM in seasons when no N was added was lower compared to the plots where there was continuous maize growth without fertilizer application. The reduction in TDM was 35%, 9% and 23% in long rains 2003; short rains 2003 and long rains 2004, respectively. The maize dry matter yield in the residual plots was 12% higher compared to the control treatment. Averaged among all the seasons, the TDM reduction in the fertilizer-applied treatments was 12%. The reduction in crop growth in fields previously supplied with fertilizer explains the notion of smallholder farmers who do not add fertilizer to their farms that "fertilizer impoverishes soil". The explanation is that added fertilizer N possibly stimulates root growth that leads to more N uptake more from soil N pool compared to the control treatment. Roots grow and extend within those volumes of soil where soil moisture and nutrients are available (Fageria and Baligar, 2005; Eastin and Sullivan, 1984; Streeter and Barta, 1984).

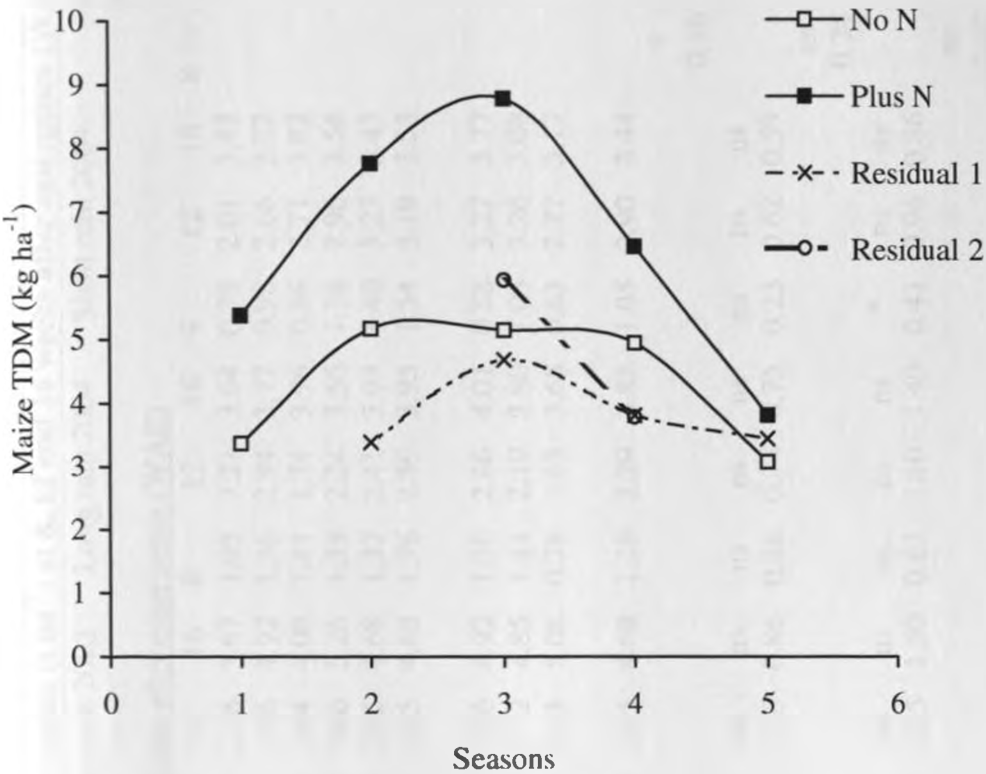


Figure 3.5. Summary of maize total dry matter TDM) response (16 weeks after emergence) to fertilizer application and residual affects in five seasons, at Mosocho, Kisii. The five seasons are 1 - SR 2002; 2 - LR 2003; 3 – SR 2003; 4 - LR 2004; 5 - SR 2004. LR and SR mean long and short rains, respectively.

Table 3.7 Residual N fertilizer effect on maize dry matter accumulation one season after application, at Mosocho, Kisii, southwest Kenya (2003-04)

		Maize dry matter (t ha^{-1}) at 8, 12 and 16 weeks after emergence (WAE)														
		Long rain 2003			Short rain 2003			Long rain 2004			Short rain 2004			**Season and interactions**		
Treatment		Weeks after emergence (WAE)												WAE		
Nitrogen (kg N/ha)		8	12	16	8	12	16	8	12	16	8	12	16	8	12	16
	0	0.55	2.06	2..35	0.74	2.36	3.67	1.05	2.21	3.64	0.76	2.01	3.42			
Mucuna green	30	0.73	2.90	3.33	0.81	2.86	4.92	1.36	2.94	3.77	0.98	2.66	3.22			
Manure	60	0.62	2.62	2.63	0.78	2.64	4.08	1.11	1.74	3.96	0.86	2.71	3.82			
	120	0.85	2.75	4.74	0.76	2.86	5.26	1.39	2.24	3.56	1.16	2.96	3.56			
	240	0.97	3.03	3.65	0.75	2.85	4.68	1.37	2.41	3.93	1.40	3.27	3.43			
	480	0.77	2.64	3.27	0.75	2.85	4.68	1.96	2.59	3.95	1.54	3.19	3.53			
Inorganic fertilizer-	30	0.73	2.80	2.97	0.81	2.86	4.92	1.36	2.66	4.01	0.88	3.27	3.77			
Urea	60	1.07	2.94	4.06	0.65	3.32	4.85	1.11	2.19	3.80	1.03	3.26	3.08			
	120	0.67	2.08	2.43	0.70	3.03	5.08	0.78	1.63	3.68	0.83	2.77	3.17			
Mean		0.77	2.64	3.27	0.75	2.85	4.68	1.29	2.29	3.81	1.05	2.90	3.44			
Season (S) F test														*	*	*
LSD season														0.16	0.37	0.46
N Source (NS) F test		ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns			
LSD N Source		0.19	0.57	0.78	0.16	0.56	0.86	0.36	0.74	0.75	0.23	0.62	0.59			
N source x season F test														ns	ns	ns
LSD N source x season														0.24	0.65	0.78
N rate (NR) F test		ns	ns	*	ns	ns	ns	ns	ns	ns	*	ns	ns			
LSD N rate		0.33	1.10	1.11	0.31	1.05	1.50	0.63	1.10	1.49	0.41	0.96	0.86			
N rate x season F test														ns	ns	ns
LSD N rate x season														0.45	1.07	1.27
% C.V Treatment		29.4	28.2	23	27.5	24.9	21.5	33.7	32.8	26.7	26.7	22.6	17.1			

F=Fisher test; * =Differences significant, ns= non-significant; LSD=Least significant difference; N source rates=30, 60, 120 kg N ha^{-1}

Table 3.8 Maize dry matter accumulation two seasons after N fertilizer application at Mosocho, Kisii, southwest Kenya (2003-04).

		Maize dry matter ($t\ ha^{-1}$) at 8, 12 and 16 weeks after emergence (WAE)								
		Short rain 2003			Long rain 2004			**Season and interactions**		
Treatment		Weeks after emergence (WAE)						WAE		
Nitrogen (kg N/ha)		8	12	16	8	12	16	8	12	16
	0	1.34	3.33	5.08	1.23	2.74	3.35			
Mucuna green	30	1.40	4.16	5.85	1.14	2.60	3.78			
Manure	60	1.37	4.02	5.87	1.22	2.62	3.94			
	120	1.67	4.45	6.41	1.14	2.60	3.78			
	240	1.90	6.01	7.78	1.14	2.60	3.78			
	480	1.49	4.28	5.93	1.14	2.60	3.78			
Inorganic	30	1.46	3.99	6.77	1.15	2.65	3.77			
fertilizer-Urea	60	1.30	4.15	3.96	0.89	2.70	3.57			
	120	1.48	4.16	5.75	1.21	2.29	4.30			
Mean		1.49	4.28	5.93	1.14	2.60	3.78			
Season (S) F test								*	*	*
LSD season								0.25	0.51	0.70
N Source (NS) F test		ns	ns	ns	ns	ns	ns			
LSD N Source		0.76	0.81	0.44	0.59	0.78	0.90			
N source x season F test								ns	ns	ns
LSD NS x S								0.48	0.77	1.21
N rate (NR) F test		ns	ns	ns	ns	ns	ns			
LSD N rate		0.70	1.74	2.22	0.84	1.10	1.58			
N rate x season F test								ns	ns	ns
LSD N rate x S								0.45	1.07	1.27
% **C.V** Treatment		32	27.5	25.5	47.6	27.4	27.1			

F=Fisher test; * =Differences significant, ns= non-significant; LSD=Least significant difference; N source rates=30, 60, 120 kg N ha^{-1}

3.3.5 Nitrogen application effects on maize grain yield

3.3.5.1 Grain yield response to N in the season of applied

Maize grain yield varied significantly among seasons and it was highest in the long rains 2003 and lowest in short rains 2004 (Figure 3.6 and Table 3.9). On average, yield was 2.1 times higher in the long rains compared to short rain seasons. Yield was comparable in short rain 2002 and short rain 2004 but was significantly higher in short rain 2003. This may be attributed to variation in seasonal rainfall whereby there was more in long than short rains (Figure 3.1). However, lack of clear relationship between seasonal amount of rainfall received and maize grain yield showed that quantity alone could not account fully for the variation. It is probable rainfall distribution within the season played a more important role than total rainfall for example late season drought significantly reduces grain yield (Figure 3.4 and Table 3.6). It is likely that inter-seasonal rainfall and temperature variation may have also influenced soil microbial activities that influence N availability (Rigobelo and Nahas, 2004).

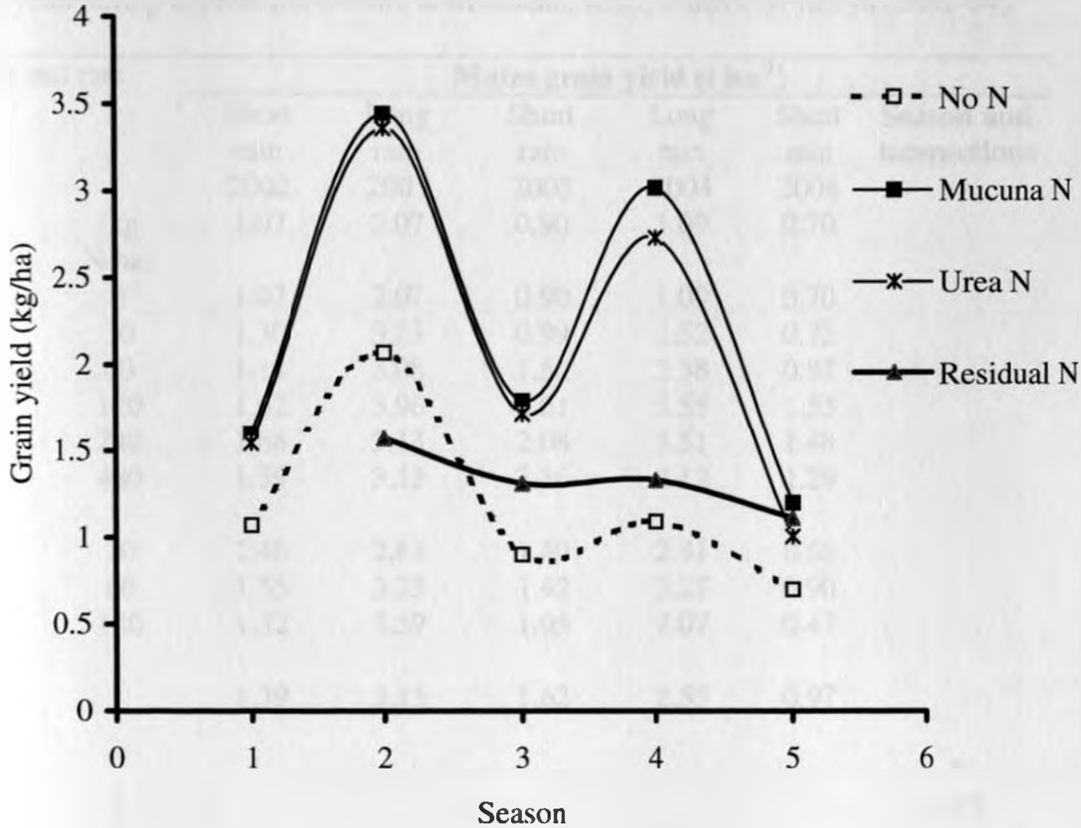


Figure 3.6 Seasonal maize grain yields variation in five seasons at Mosocho, Kisii. Numbers 1 to 5 corresponds to Short rains 2002, Long rains 2003, Short rain 2003, Long rains 2004 and Short rains 2004, respectively.

Table 3.9 Effect of mucuna green manure and inorganic fertilizer-urea application rate on maize grain yield during application season, at Mosocho, Kisii, southwest Kenya (2002-04).

N source and rate		Maize grain yield (t ha^{-1})					
		Short rain 2002	Long rain 2003	Short rain 2003	Long rain 2004	Short rain 2004	**Season and interactions**
N Source	(kg N/ha)	1.07	2.07	0.90	1.09	0.70	
Mucuna	0	1.07	2.07	0.90	1.09	0.70	
	30	1.30	3.13	0.99	1.52	0.72	
	60	1.14	3.08	1.52	2.38	0.97	
	120	1.62	3.96	3.01	3.55	1.53	
	240	1.68	3.13	2.08	3.51	1.48	
	480	1.39	3.13	2.36	4.12	1.29	
Urea	30	1.46	2.83	1.40	2.41	0.68	
	60	1.55	3.23	1.42	2.27	0.90	
	120	1.32	3.59	1.95	2.07	0.47	
Mean		1.39	3.13	1.62	2.55	0.97	
Season (S)							*
LSD season							0.33
N Source		ns	Ns	Ns	ns	*	
LSD N source		0.20	0.45	0.43	0.70	0.36	
LSD N source rates						0.50	
N source x season							ns
LSD N source x season							0.44
N rate F test		*	*	*	*	*	
LSD N rate		0.35	0.56	0.53	1.01	0.47	
N rate x season							*
LSD N rate x season							0.63
% C.V Treatment		17.3	11.8	22.6	27.2	33.3	

F=Fisher test; * =Differences significant, ns=Differences non-significant; LSD=Least significant difference.

At any given rate, nitrogen source (either mucuna or urea) did not influence grain yield. Grain yield increased with increasing N rate. Yield was comparable at 0 and 30 kg N ha^{-1} in all the seasons where mucuna N was applied but was significantly higher in the long seasons but not in the short rain seasons. The highest maize yield was obtained where mucuna green manure was applied at 120 kg N ha^{-1} with insignificant increase at 240 and 480 kg N ha^{-1}. Maize yield was comparable where urea was applied at 30 and 60 kg N ha^{-1} though higher than where no N was applied. Urea was split applied while mucuna was applied only once and this may have resulted in better response at low rates compared to mucuna. There was no further increase in yield where urea was applied at 120 kg ha^{-1}.

3.3.5.2 Grain yield response to residual N fertilizer

Maize grain yield varied significantly among seasons but response to previously applied N was non significant irrespective of N source and rate in all the seasons (Table 3.10). The yield after one or two seasons after N application was comparable.

Table 3.10. Residual fertilizer N effect on maize grain yield during at Mosocho, Kisii, southwest Kenya (2003-04).

Nitrogen fertilizer treatments		Maize grain yield (kg/ha)				Season and interactions	Maize grain yield (kg/ha)		Season and interactions
		One season after N application					Two seasons after N application		
N Source	N (kg/ha)	Long rain 2003	Short rain 2003	Long rain 2004	Short rain 2004		Short rain 2003	Long rain 2004	
Mucuna N	0	1.13	1.07	1.52	0.94		1.11	1.5	
	30	1.47	1.31	1.40	1.08		1.67	1.64	
	60	1.35	1.26	1.14	1.22		1.52	1.71	
	120	2.44	1.40	2.04	1.17		1.41	1.99	
	240	1.91	1.31	0.98	1.02		1.87	1.64	
	480	1.54	1.31	0.94	1.12		1.52	1.64	
Urea N	30	1.21	1.47	1.36	1.40		1.54	1.3	
	60	2.18	1.63	1.67	0.91		1.41	1.51	
	120	0.95	1.06	0.93	1.12		1.67	1.84	
Mean		1.57	1.31	1.33	1.11		1.52	1.64	ns
Season						*			0.27
LSD season						0.26			
N Source		ns	ns	ns	ns		ns	ns	
LSD N source		0.58	0.36	0.57	0.32		0.32	0.44	Ns
N source x season						ns			0.32
LSD N source x season						0.46			
N rate		*	ns	ns	ns		ns	ns	
LSD N rate		0.76	0.54	0.76	0.50		0.7	0.79	Ns
N rate x season						ns			0.70
LSD N rate x season						0.69			Ns
% C.V Treatment		33.2	27.2	39.1	30.8		31.4	31.8	0.27

F=Fisher test; * =Differences significant, ns=Differences non-signifcant; LSD=Least significant difference.

3.3.6. Maize harvest Index

Harvest index (HI) is an indicator of plant biomass allocation between biological (TDM) and economic yields i.e. grain in maize. The effect of N source and rate was evaluated. Harvest index varied significantly among seasons and was highest in the long rain seasons but low in the short rain season (Table 3.11). Season and N rate interaction influenced HI significantly. The interactions occurred in long rains 2003, short rains 2003, long rains 2004 and short rain 2004 both in the season N was applied and one season after N application (Tables 3.11, 3.12 and 3.13); on the whole mucuna N increased HI in long rains 2004 and short rains 2004. Nitrogen fertilizer type did not influence HI significantly in most of the seasons but with the exception of short rains 2004; where HI was approximately 61% lower in maize supplied with urea N compared to that supplied with mucuna N.

Table 3.11 Effect of mucuna green manure and urea fertilizer application rate on maize harvest index during application season, at Mosocho, Kisii, southwest Kenya (2002-04).

		Maize harvest index (HI)					
		Short rain 2002	Long rain 2003	Short rain 2003	Long rain 2004	Short rain 2004	**Season and interactions**
Rainfall (mm)		638	1654	850	999	844	
Treatment							
Nitrogen (kg N/ha)	0	0.34	0.40	0.15	0.23	0.22	
Mucuna green manure	30	0.26	0.43	0.31	0.32	0.22	
	60	0.24	0.43	0.19	0.47	0.31	
	120	0.30	0.47	0.27	0.61	0.36	
	240	0.26	0.43	0.25	0.45	0.33	
	480	0.28	0.43	0.30	0.66	0.34	
Inorganic fertilizer-Urea	30	0.29	0.34	0.22	0.45	0.18	
	60	0.32	0.42	0.25	0.46	0.24	
	120	0.25	0.53	0.32	0.21	0.12	
Mean		0.28	0.43	0.25	0.43	0.26	
Season (S) F test							*
LSD season							0.06
N Source F test		ns	ns	ns	ns	*	
LSD N source (NS)		0.06	0.10	0.12	0.15	0.07	
N source rates F test						ns	
LSD N source rates						0.11	
N source x season F test							ns
LSD N source x season							0.10
N rate (NR) F test		ns	ns	ns	*	*	
LSD N rate		0.11	0.13	0.18	0.18	0.10	
N rate x season F test							*
LSD N rate x season							0.15
% C.V Treatment		27.9	20.5	48.5	29.5	26.8	

F=Fischer test; * =Differences significant, ns=Differences non-significant; LSD=Least significant difference; N source rates=30, 60 and 120 kg N ha^{-1}.
S and I = Season and interactions.

Table 3.12 Effect of mucuna green manure and urea fertilizer application rate on maize harvest index during first subsequent season, at Mosocho, Kisii, southwest Kenya (2003-04).

		Maize harvest index (HI)				
		Long rain 2003	Short rain 2003	Long rain 2004	Short rain 2004	**Season and interactions**
Rainfall (mm)		1654	850	999	844	
Treatment						
Nitrogen (kg N/ha)						
	0	0.47	0.30	0.42	0.28	
Mucuna green manure	30	0.44	0.30	0.36	0.33	
	60	0.49	0.31	0.29	0.32	
	120	0.52	0.27	0.56	0.34	
	240	0.51	0.29	0.24	0.30	
	480	0.47	0.29	0.25	0.32	
Inorganic fertilizer-Urea	30	0.41	0.30	0.34	0.37	
	60	0.55	0.34	0.42	0.29	
	120	0.38	0.21	0.27	0.35	
Mean		0.47	0.29	0.35	0.31	
Season (S) F test						*
LSD season						0.05
N Source F test		ns	ns	ns	ns	
LSD N source (NS)		0.09	0.07	0.20	0.12	
N source x season F test						ns
LSD N source x season						0.08
N rate (NR) F test		ns	ns	ns	ns	
LSD N rate		0.14	0.10	0.20	0.11	
N rate x season F test						*
LSD N rate x season						0.14
% **C.V** Treatment		19.9	23.7	33.7	23.1	

Table 3.13 Effect of mucuna and urea fertilizer nitrogen application rate on maize harvest index in second subsequent season at Mosocho, Kisii, southwest Kenya (2003-04).

		Maize harvest index (HI)		
		Short rain 2003	Long rain 2004	**Season and interactions**
Rainfall (mm)		850	999	
Treatment				
Nitrogen (kg N/ha)				
	0	0.22	0.44	
Mucuna	30	0.28	0.41	
green	60	0.27	0.44	
manure	120	0.23	0.41	
	240	0.24	0.41	
	480	0.27	0.41	
Inorganic	30	0.24	0.34	
fertilizer-	60	0.35	0.41	
Urea	120	0.30	0.44	
Mean		0.27	0.41	
Season (S) F test				*
LSD season				0.04
N Source F test		ns	ns	
LSD N source (NS)		0.06	0.10	
N source x season F test				ns
LSD N source x season				0.06
N rate (NR) F test		ns	ns	
LSD N rate		0.11	0.13	
N rate x season F test				ns
LSD N rate x season				0.33
% C.V Treatment		29.4	19.7	

3.3.7 Plant total nitrogen

The source of nitrogen applied had non-significant effect on maize total N at all rates and seasons. Total N uptake increased with increasing N rate in all the seasons (Figure 3.7 and Table 3.14) and was comparable in short rain 2003 and long rain 2004 but lower in SR 2003. It was lowest in the residual N experiment where there was depletion for one season. Maize N uptake at 0 and 60 kg N ha^{-1} fertilizer rated was comparable but significantly lower than that at 120, 240 and 480 kg N ha^{-1}. However, uptake was comparable at the latter three rates. Maize stover and grain N concentration failed to show significant response to N, irrespective of N source and application rate.

Plant nutrient uptake is a function growth and therefore it is not surprising that N uptake increased at increasing N application rates and therefore environmental conditions that enhance growth also enhance N uptake (Ma and Dwyer, 1998).

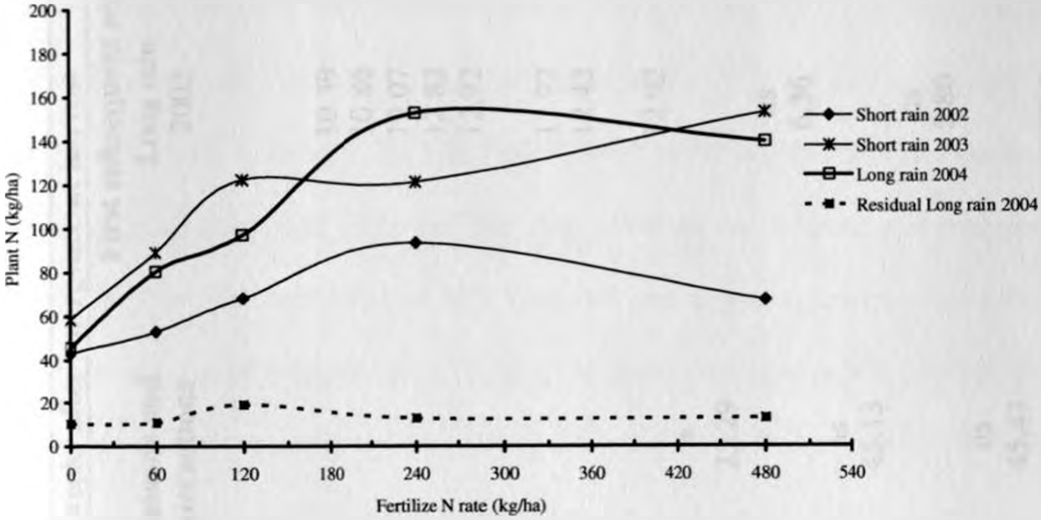


Figure 3.7. Maize total N response to mucuna green manure and fertilizer N rate during application season at Mosocho, Kisii, southwest Kenya (2002-04).

Table 3.14 Effect of mucuna green manure and inorganic fertilizer-urea application rate on maize total nitrogen during application, and first subsequent planting seasons at Mosocho, Kisii, southwest Kenya (2002-04).

		Maize total N (kg N ha^{-1}) in 16 weeks after emergence-at harvest				
		Application season				First subsequent season
		Short rain 2002	Short rain 2003	Long rain 2004	**Seasons and interactions**	Long rain 2003
Treatment						
Nitrogen (kg N ha^{-1})						
	0	43	58.5	45.6		10.39
Mucuna green	60	53	89.1	80.5		10.86
manure	120	68.2	122.3	97.1		19.07
	240	93.5	121.3	152.8		12.83
	480	67.5	153.3	140		12.92
Inorganic	60	74.9	71.0	80.2		11.92
fertilizer-urea	120	72.2	140.6	165.4		12.43
Mean		67.5	108	108.7		12.92
Season (S) F test					*	
LSD season					25.29	
N Source (NS) F test		ns	ns	ns		ns
LSD N Source		22.17	65.8	60.6		6.36
N source x season F test					ns	
LSD NS x S					45.13	
N rate F test		*	*	*		ns
LSD N rate		27.54	62.27	44.99		5.80
N rate x season F test					ns	
LSD N rate x S					45.47	
% C.V Treatment		22.40	32.4	23.3		24.7

F=Fisher test; * =Differences significant, ns= non-significant; LSD=Least significant difference; N source rates= 60 and 120 kg N ha^{-1}

3.3.8 Nitrogen apparent recovery

Nitrogen recovery efficiency (NRE) in maize varied significantly with planting season. It was higher in short rains 2003 but comparable in short rains 2002 and long rain season 2004 (Table 3.15 and Figure 3.8). Recovery increased with N application rate up to 240 kg N ha^{-1} beyond it decreased (i.e. short rains 2002) or did not change. The variability in N fertilizer application rate accounted for 69 to 100% of the variability in recovery. The recovery efficiency ranged between 18% and 65% and was comparable irrespective of N source and amount of N added (Table 3.10). The maize N recovery of applied fertilizer is comparable to those reported by Ssali, 1990 (35% to 55%) and Jarvis *et al.* 1996 (34% to 43%). Lack of residual N response may indicate that the N not taken up by maize was possibly lost through leaching or volatilization (Sutton *et al.*, 1993).

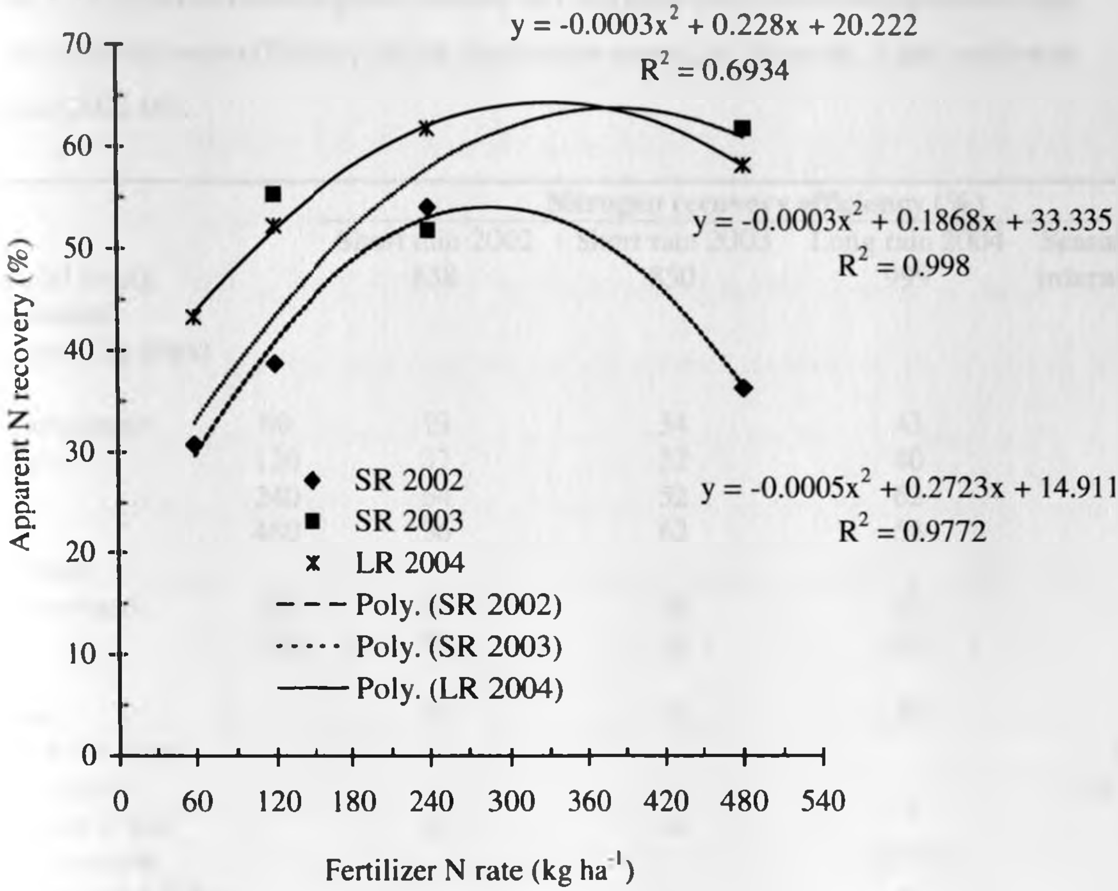


Figure 3.8 Maize apparent nitrogen recoveries at Mosocho, Kisii, southwest Kenya (2002-04).

Table 3.15 Effect of mucuna green manure and inorganic fertilizer-urea application rate on nitrogen recovery efficiency during application season, at Mosocho, Kisii, southwest Kenya (2002-04).

		Nitrogen recovery efficiency (%)			
		Short rain 2002	Short rain 2003	Long rain 2004	**Season and interactions**
Rainfall (mm)		638	850	999	
Treatment					
Nitrogen (kg N/ha)					
Mucuna green manure	60	19	34	43	
	120	37	52	40	
	240	54	52	62	
	480	36	62	58	
Inorganic fertilizer-urea	60	43	18	43	
	120	40	58	65	
Mean		38	46	52	
Season (S) F test					*
LSD season					22.56
N Source F test		ns	ns	*	
LSD N source				39.72	
N source rates F test				ns	
LSD N source rates				48.4	
N source x season F test					ns
LSD N source x season					22.78
N rate F test		ns	ns	*	
LSD N rate		38.07	61.09	37.43	
N rate x season F test					ns
LSD N rate x season					18.89
% C.V Treatment		74.3	58.6	49	

F=Fisher test; * =Differences significant, ns=Differences non-signifcant; LSD=Least significant difference; N source rates= 60 and 120 kg N ha^{-1}

3.3.9 Tissue Nitrogen in maize

The percentage of nitrogen in maize stover and grain was not significantly influenced by planting season, N source and rate of application (Table 3.16). The significant treatment effects on stover and grain in short rain 2003 and long rain 2004 were attributed to sampling error. The significant result in maize stover during short rains 2003 was attributed to the extremely low percentage of N in mucuna application rate of 240 kg N ha^{-1} that was unexpected (Table 3.16). The low concentration of N in maize grain on mucuna application rate of 120 kg N ha^{-1} was similarly sudden. This possibly is the reason for significant response to N application rate during short rains 2003 (Table 3.16). It would appear that under the experimental conditions tissue N concentration of maize grain is probably stable attribute that did not change with supply level of the nutrient. Nutrient uptake in plant is considered an integration of all factors affecting nutrient availability. Concentrations of most nutrients in plant tissues are restricted to fairly narrow ranges. This is because plants have a remarkable ability to regulate nutrient uptake according to their growth demands (Fageria and Baligar, 2005). Although nutrient concentrations are influenced by soils, plant and climatic factors, plant tissue concentrations are still relatively more stable and useful parameters compared with soil analysis for identifying nutritional status of crop plants (Fageria and Baligar, 2005).

Table 3.16 Effect of mucuna green manure and inorganic fertilizer-urea application rate on nitrogen concentration of maize stover and grain at Mosocho, Kisii, southwest Kenya (2002-04).

		Application season					
		Tissue nitrogen concentration in maize stover and grain (%)					
		Short rain 2002		Short rains 2003		Long rain 2004	
Treatment		Stover	Grain	Stover	Grain	Stover	Grain
Nitrogen (kg N ha^{-1})							
Control	0	0.90	1.94	1.01	0.98	0.89	1.62
Mucuna green manure	60	0.94	1.46	0.91	2.35	0.96	1.60
	120	1.07	1.54	1.08	2.06	1.07	2.04
	240	1.24	1.85	0.85	2.63	1.08	1.78
	480	-	-	1.30	2.46	1.24	2.02
Urea fertilizer	60	1.21	1.83	0.71	2.07	0.88	2.11
	120	1.21	1.86	1.63	2.22	1.35	2.55
Mean		1.09	1.78	1.07	2.11	1.07	1.96
LSD N source		0.24	0.24	0.52	0.5 **	0.7	0.54*
LSD N rate		0.28 ns	0.26 ns	0.48 *	0.66 **	0.36 ns	0.72 ns
% C.V		16	9	28	19	21	21

3.4 Conclusions

1. Maize dry matter yield responded to N application irrespective of the source. Optimal N rate was 60 kg N ha^{-1} urea fertilizer and 120 kg N ha^{-1} mucuna green manure. Mucuna green manure has potential to increase maize dry matter yields when applied at 6 t DM ha^{-1} (equivalent of 120 kg N ha^{-1}).

2. Mucuna application rate of 30 kg N ha^{-1} did not have notable effect on maize dry matter yield but when applied at 60 kg N ha^{-1} it improved maize growth but the magnitude varied among seasons. Mucuna applied at 120 kg N ha^{-1}, equivalent to 6 t DM ha^{-1} of the green manure, increase in maize dry matter yield significantly in all the seasons but rates exceeding 120 kg N ha^{-1}; i.e. at 240 and 480 kg N ha^{-1} corresponding to 12 and 24 t DM ha^{-1} equivalent of the green manure, respectively, did not result in considerable improvement in maize growth.

3. Within application range of 30 to 120 kg N ha^{-1} maize response to nitrogen was comparable irrespective of N source, mucuna green manure or inorganic fertilizer-urea. Fertilizer rates higher than 30 kg N ha^{-1} at 60 and 120 kg N ha^{-1} did not increase dry matter yield significantly.

4. There was no fertilizer N residual effect on maize dry matter yield and N uptake, irrespective of N source or rate.

5. Maize grain yield improvement depends on mucuna green manure application rate.

6. Maize grain yield was not substantially increased by application of 30 kg N ha^{-1} equivalent of mucuna green manure. Its application at 60 kg N ha^{-1} increased maize yield but fell short of giving consistent significant improvement over all seasons.

7. Maize grain yield was substantially and consistently increased by mucuna application at the rate of 120 kg N ha^{-1} equivalent to 6 t DM ha^{-1} of the green manure. Its application in excess of 120 kg N ha^{-1} had no yield gain.

8. Maize production in short rain season by application of mucuna green manure as N source may be unsuitable. The optimum economic application rate of mucuna N for maize yield in short rains at 297 kg N ha^{-1} is high and unattainable.

9. Maize grain yield attributed to nitrogen at the conventional application rates of 30, 60 and 120 kg N ha^{-1} is similar whether N source is mucuna or inorganic fertilizer-urea.

10. The optimum biological application rate of mucuna at 222 kg N ha^{-1} on average is high and unachievable in conventional production systems. Comparatively, it is at 73 kg N ha^{-1} for inorganic N. Hence, it is speculated that legume biomass rate less 73 kg N ha^{-1} could require supplementation of N, if maximum maize grain yield is to be anticipated.

11. There was no residual effect of nitrogen on maize grain yield, irrespective of N source or application rate.

CHAPTER FOUR

MUCUNA DECOMPOSITION AND AVAILABLE SOIL NITROGEN RELEASE UNDER FIELD CONDITIONS

4.1 Introduction

Maize productivity in Kenya is most often limited by nitrogen supply (Hassan *et al.*, 1989). Decomposition is an important process in the conversion of organic N to available N. Decomposition pattern of organic biomass is indicative of N mineralization (Jama and Nair, 1996). Organic biomass decomposition controlled is mainly by three factors: crop residue factors for example residue particle size and residue quality; edaphic factors such as soil pH and texture, temperature, moisture; and residue management factors for instance application rate; and climatic factors such as rainfall and temperature (Kumar and Goh, 2000). It is important to manage organic biomass so that most of the N is taken up by crops with little or no loss through leaching beyond the rooting zone to avoid groundwater contamination. The quantity of organic biomass applied and the application methods influence N supply (Fageria and Baligar, 2005). The objective of this study was to determine the effect of mucuna green manure application rate on mucuna decomposition and the amount soil available N, in maize rooting zone in both application and subsequent seasons.

4.2 Materials and Methods

4.2.1 Climate and soils

The research was carried out on-farm at Bokeabu village of Mosocho division, Kisii district, southwest Kenya. Climate and soil characteristics are as described in Chapter Three, sections 3.2.1 and 3.2.2, respectively.

4.2.2 Experimental design

Decomposition in the field was studied using micro-lysimeter method (Brady, 1994). Soil available N (SAN) changes in the micro-lysimeter and soil profile of plots were monitored.

4.2.2.1 Field incubation

Soil mixed with different rates of fresh green mucuna biomass, was incubated in micro-lysimeters made of polyvinyl chloride tubes. The application rates of mucuna green manure evaluated were 0, 30, 60, 120, 240 and 480 kg N ha^{-1}. Five micro-lysimeters were installed in each treatment plot. Fresh mass of 0, 0.5, 1, 2, 4 and 8 g mucuna green manure per lysimeter equivalent to dry mass of 0, 0.1, 0.2, 0.4, 0.8 and 1.6 g, respectively were applied to the soil prior to incubation. Sampling was done at 1, 2, 4 and 8 weeks after application for determination of remaining green manure, and soil available N levels. The micro-lysimeter was to provide for simultaneous observations on decomposition pattern and soil available N levels. Lysimeter length was 25 cm, with soil column of 20 cm and each was placed in the field the same day when the green manure was incorporated in plots. The holes were drilled in plots using a soil auger, in "W" shaped pattern, prior to maize planting. The tubes protruded 5 cm above the soil surface as recommended by Anderson and Ingram (1993) to avoid inflow of runoff. Each micro-lysimeter had a diameter of 2.5 cm and was filled with 98 g of disturbed soil.

4.2.2.2 Direct field sampling

The sampling was done in the maize field experiment, presented in Chapter Three. The treatments, experimental design and cultural practices are the same as described for both, application and first subsequent cropping seasons in sections 3.2.3 and 3.2.5.

4.2.3 Data collection

4.2.3.1 Mucuna decomposition

Micro-lysimeters sampled from field incubation experiment were taken to laboratory, in cool-box filled with ice blocks. The plastic tubes were each separately soaked in a bucket of water, and gently stirred to float remaining mucuna residue. The floating residue was removed using 2 mm sieve and oven-dried at 105°C for 72 hours, to determine undecomposed mucuna biomass. Decomposition observation in field incubation experiment was done during application seasons in long and short rains 2004. In short rain 2004, observation extended to end of season at 16 WAP.

4.2.3.2 Soil available nitrogen

4.2.3.2.1 Soil available N in micro-lysimeters (field incubation)

The micro-lysimeters set up for decomposition study in the field incubation experiment were the same as those which were used in determining available N levels in the incubated soil. So, every time that destructive sampling of the lysimeters was done for observation on left over mucuna green manure, soil sub-samples were collected into nylon bag and icebox, for laboratory analysis of available N levels. The observation dates were 1, 2, 4 and 8 weeks after application of mucuna. These dates corresponded to those for measurement of same parameter in, direct field sampling method, described in section 4.2.3.2.2. Soil available N determination in field incubation experiment was done during long rains 2004. The procedures used are described in section 4.2.3.2.2.

4.2.3.2.2 Direct field sampling for available soil N

Soil samples from plots where mucuna N at 0, 30, 60, 120, 240 and 480 kg N ha^{-1} and urea fertilizer at 60 and 120 kg N ha^{-1} were collected using an auger at 0-15, 15-30, 30-50 and 50-100 cm at 1, 2, 4 and 8 weeks. A "W" pattern was used to randomize sampling points. The soil was bulked and thoroughly mixed on nylon sheet. Two 100g sub-samples taken and kept in labeled polythene bags, placed in portable cooler box filled with ice-cubes, and transported to laboratory. One of the samples was oven dried at 105°C in 72 hours, and re-weighed to determine field soil moisture. The other to be used in determination of NH_4^+-N and NO_3^--N was refrigerated at 4°C until analysis time, when laboratory soil moisture was again measured. Soil analysis for available N in field experiments was done by colorimetric method, using spectrophotometer at Kenya Forestry Research Institute (KEFRI)/Kenya Agricultural Research Institute (KARI) Maseno Laboratory, Kisumu.

Available N levels in experimental plots were measured in the season of mucuna application during long rain 2004. Residual N in maize rooting zone was determined in first subsequent season during short rain 2004.

Procedures in colorimetric analysis of available N (ammonium-N and nitrate-N) are detailed in the Maseno laboratory manual version 1.1, of 26th September 1994. In the procedure, there was soil extraction, which was followed by colour development in the filtrate and spectrophotometer use in reading, first concentration of NH_4^+, and later NO_3^-, in accordance with Okalebo *et al.* (2002). For the analysis of nitrate, some of the procedures in the manual have been adopted from Dorich and Nelson (1994). Sample preparation for analysis was done in triplicate.

During extraction process, 10 g of the wet freshly sampled soil was scooped and put in Nagelene bottles, into which 100 ml of 2 M KCl extractant was added. The bottles were put on horizontal mechanical shaker that made 125 rotations per minute, for one hour. Thereafter, the samples were removed from mechanical shaker, filtered using Whatman filter paper no. 42, and refrigerated at 4°C awaiting analysis. From the filtrate 2 ml aliquot was used in NH_4^+ - N analysis.

Determination of extractable soil ammonium was done first, before proceeding to analyse for extractable soil nitrate so as to avoid contamination from ammonium chloride that is used in the analysis of the nitrate-N. The analyte was placed in spectrophotometer for absorbance readings at wavelength of 655 nm to determine NH_4^+- N. The intensity of the colour is directly proportional to the concentration of NH_4^+- N.

The analysis of NO_3^-- N was done using 2 ml aliquot taken from the 2 M KCl extractant filtrate prepared as detailed above. The procedure for NO_3^- and NO_2^- consisted of three steps: Preparation of reduction column, sample reduction and colour development and, monitoring performance of the cadimium column with NO_2^-. In the procedure, NO_3^- in the extractant is reduced almost quantitatively to NO_2^- in the presence of copper-coated cadmium granules. The nitrite produced is diazotized with sulphanilic acid (4-aminobenzene sulphonic acid), and coupled with 5-2 ANSA (5-amino-2-naphthalene sulphonic acid) solution to form a highly coloured azo dye. The intensity of the reddish-purple colour developed is directly proportional to the concentration of NO_3^--N plus NO_2^- -N in the sample. This is measured colorimetrically using spectrophotometer absorbance readings at wavelength of 550 nm to determine NO_3^--N.

4.2.4 Data analysis

This is described in Chapter Three, section 3.2.6.

4.3 Results and Discussion

4.3.1 Mucuna decomposition in microlysimeters

Decomposition pattern of mucuna green manure was bi-phasic, with an initial rapid phase, followed by a long but slow second one (Figure 4.1). By the end of first week, 30 to 90 % of the biomass had decomposed. The remaining green manure decomposed at a slower rate and by the 8 and 16 weeks in the second phase approximately 5 to 30 % of the initial biomass remained (Figure 4.1). The initial phase of decomposition may be attributed to breakdown of water-soluble organic matter such as sugars and starch, cellulose, hemicellulose and amino acids mainly in the leaves and the second slower phase possibly due to decomposition of lignin and other resistant material in the stems (Wong and Nortcliff, 1995; Quemada and Cabrera, 1995).

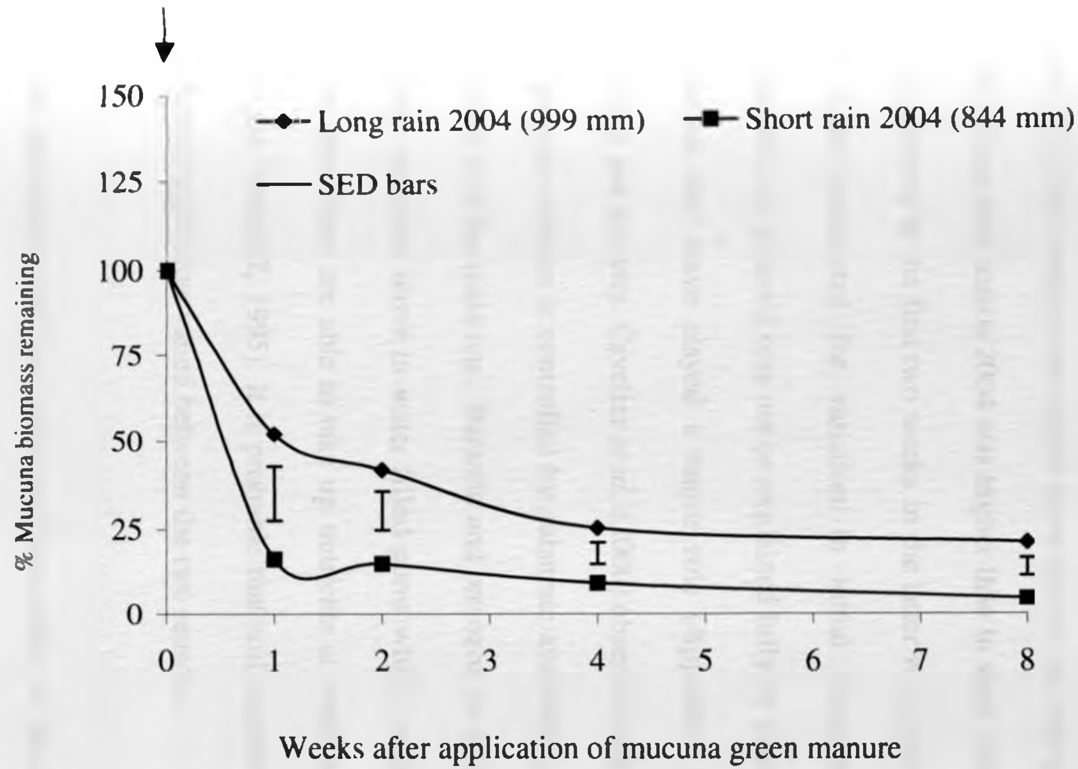


Figure 4.1. Mucuna green manure decomposition rate in filed incubated micro-lysimeters at Mosocho, Kisii, southwest Kenya: Arrow shows planting date.

The leaves and stems of cover crop species have different mineralization kinetics due to differences in lignin and C:N ratios. In the mucuna green manure applied, lignin was higher in stems while leaves had higher N concentration and lower C: N ratio than stems.

The percentage of remaining mucuna biomass was less in short than in long rain season suggesting faster decomposition in the former season (Figure 4.1). This was probably due to differences soil moisture, which is indicated by the amount and distribution of rainfall (Figure 3.1). Soil temperature might have played an important role. Although the total rainfall in long rain season 2004 was higher than in short rain season 2004, the amount of rainfall received in the first two weeks in the latter was higher than in the former and this might have accounted for variation in initial decomposition rates. Variation in decomposition in phase 2 may not be explained fully by variation in soil moisture but soil temperature may have played a major role (Appendix 1) influencing soil biomass availability and activity. Cavelier *et al.* (2000) observed that though microbial activity in decomposing residues is controlled by substrate availability, temperature and water, the latter factor was the main one. Bacteria and protozoa are sensitive to low matric potential since they can only move in water filled pores while, fungi and actinomycetes are less sensitive since they are able to take up nutrients at water potentials as low as -10 MPa (Wong and Nortcliff, 1995). It is probable that soil microbial biomass composition and populations might have varied between the two seasons.

Biomass application rate had non-significant effect on decomposition of mucuna green manure biomass in both seasons; with the exception at 2 and 4 weeks after planting in long rains 2004 but the trend was inconsistent (Figure 4.2). Nitrogen release pattern is influenced by chemical characteristics for instance tissue N concentration, C: N ratio, lignin and polyphenols (Constantinides and Fownes, 1993; Woomer *et al.*, 1994). The tissue N, lignin and polyphenol concentration of mucuna applied is 1.6%, 7 % and 3%, respectively. The N concentration is within threshold for transition from net immobilization to net mineralization (Wong and Nortcliff, 1995) and lignin and polyphenol contents are below the thresholds of 15 % and 4% considered to slow N release and result in net immobilization of N (Palm, 1997; Palm, 2001).

There was significant interaction between mucuna biomass application rate and the % mucuna biomass remaining at two and 4 weeks after application (Table 5.1). The % mucuna biomass remaining two weeks after application decreased significantly with increasing application rate in long rain 2004 season, whereas there was no distinct pattern in the variation in short rains 2004. Higher but comparable amounts remained at 60 and 240 kg mucuna N ha^{-1} compared to 120 and 480 kg mucuna N ha^{-1} application rates. At four weeks planting the % mucuna biomass remaining was significantly higher where mucuna N was at 60 and 120 kg mucuna N ha^{-1} in the long and short rain 2004, respectively. The high %CV values in short rain 2004 season indicate that the variation among N application rates was due to other reasons and not N rates. One highly probable source of error might be the biomass recovery process. The biomass was extracted manually and change of the people extracting mostly likely explains the variation in amounts within a given treatment. A possible remedy of dealing with this problem is assigning samples from a specific rate to one person.

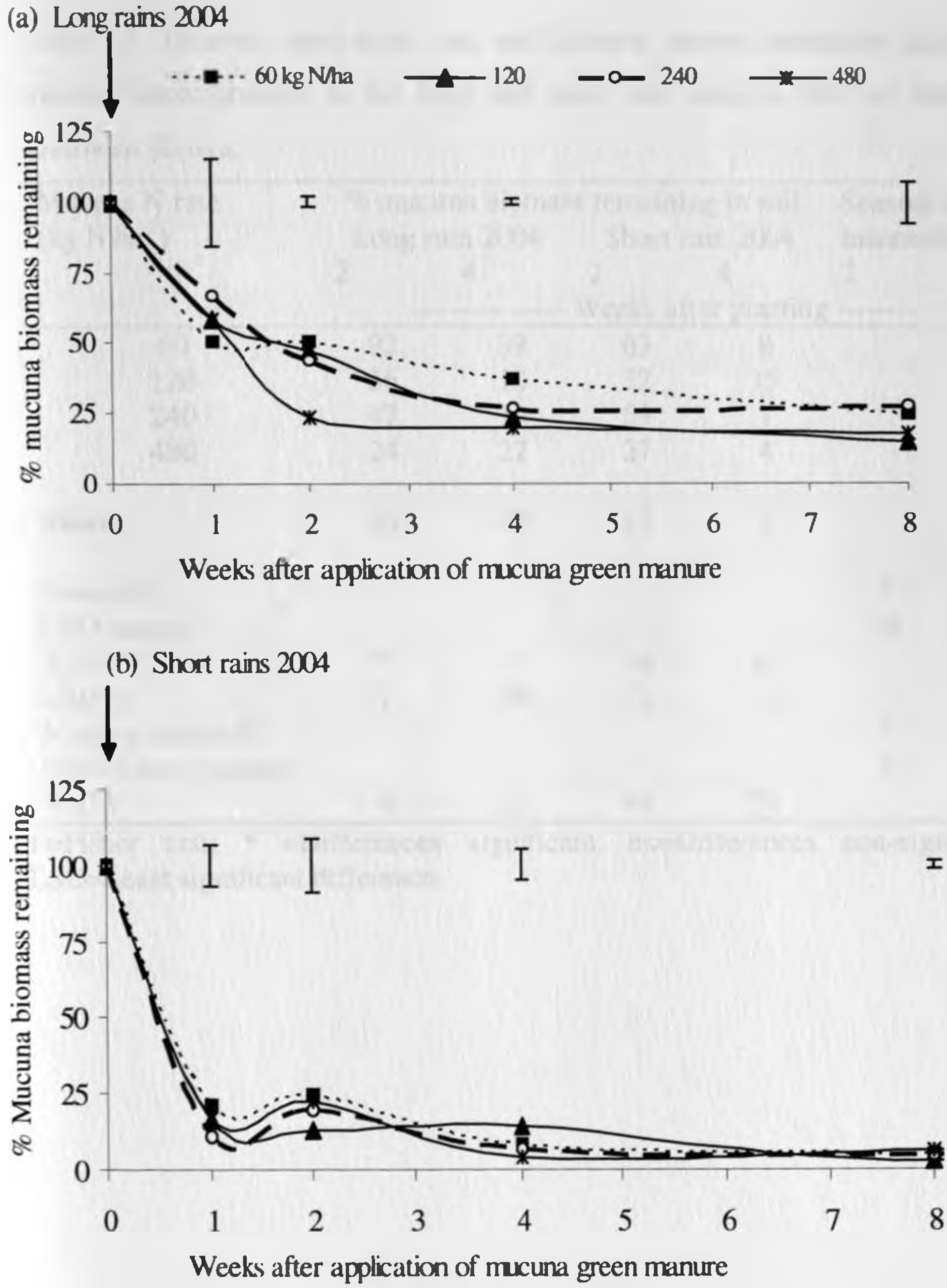


Figure 4.2. Effect of application rate on decomposition of mucuna green manure in field incubated micro-lysimeters at Mosocho, Kisii, southwest Kenya in the long and short rain 2004 seasons. SED bars indicated and arrows show planting dates.

Table 4.1. Biomass application rate and planting season interaction effects on mucuna decomposition in the long and short rain seasons 2004 at Mosocho, southwest Kenya.

Mucuna N rate (kg N ha^{-1})	% mucuna biomass remaining in soil				**Season and interactions**	
	Long rain 2004		Short rain 2004			
	2	4	2	4	2	4
	--------------- Weeks after planting ---------------					
60	92	39	63	8		
120	56	13	32	15		
240	47	19	59	7		
480	24	22	27	4		
Mean	56	45	23	8		
Season F					*	*
LSD season					18	14
N rate F	*	*	Ns	ns		
LSD N	7	20	21	13		
N rate x season F					*	*
LSD N rate x season					6	10
% C.V	6	22	44	78		

F=Fisher test; * =Differences significant, ns=Differences non-significant; LSD=Least significant difference.

4.3.2 Soil available nitrogen in field incubated micro-lysimeters

Nitrogen release pattern was similar irrespective of mucuna green manure N application rate (Figure 4.3). Soil available nitrogen was initially low at one week after application (WAA) but increased rapidly at two WAA and decreased rapidly by the fourth week, then changed thereafter. The similarity in the SAN at different times irrespective of application rates was possibly because of similarity in the chemical properties of the applied material and the environmental factors controlling N mineralization process, like soil temperature and moisture (Cabrera *et al.* 2005). The variation in the amount of SAN occurred only at two WAA but was primarily influenced by amount of biomass applied. Soil available N was comparable at 0-60 kg N mucuna ha^{-1} application rate but higher at 240 and 480 kg N mucuna ha^{-1}, but comparable between the latter.

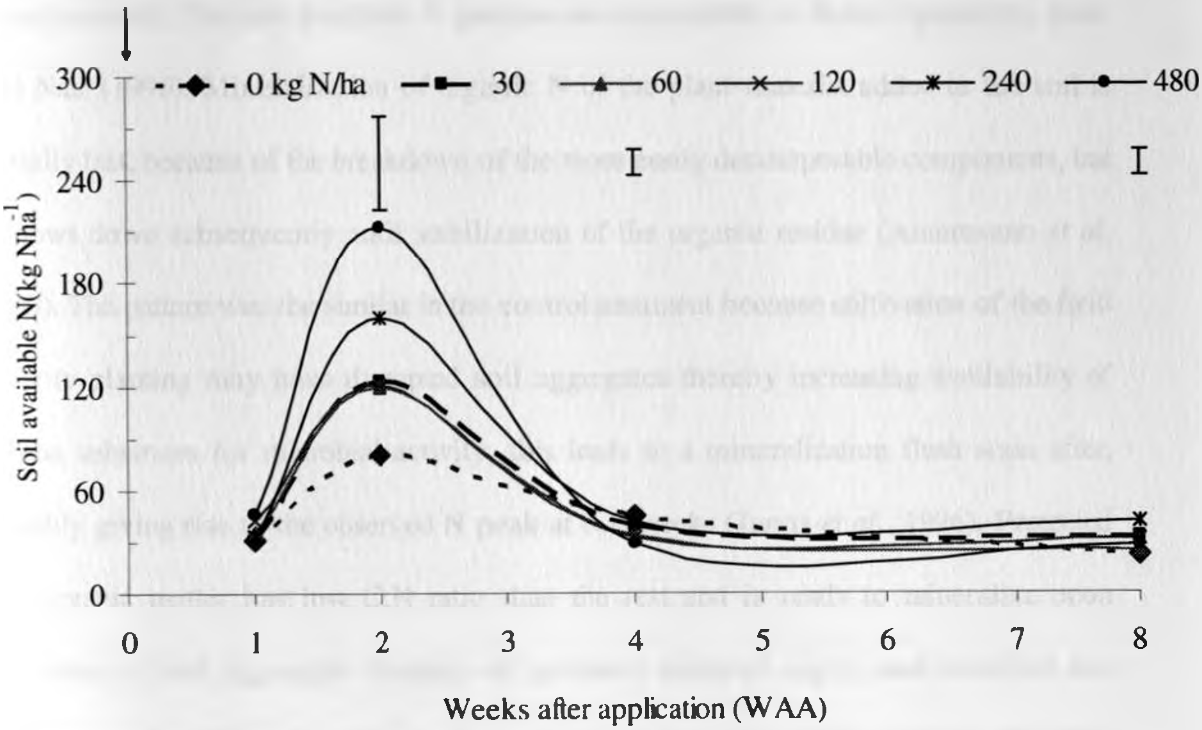


Figure 4.3. Soil available N levels from different application rates of mucuna green manure in micro-lysimeters at Mosocho, Kisii, southwest Kenya (Short rain 2004). Arrow shows planting date.

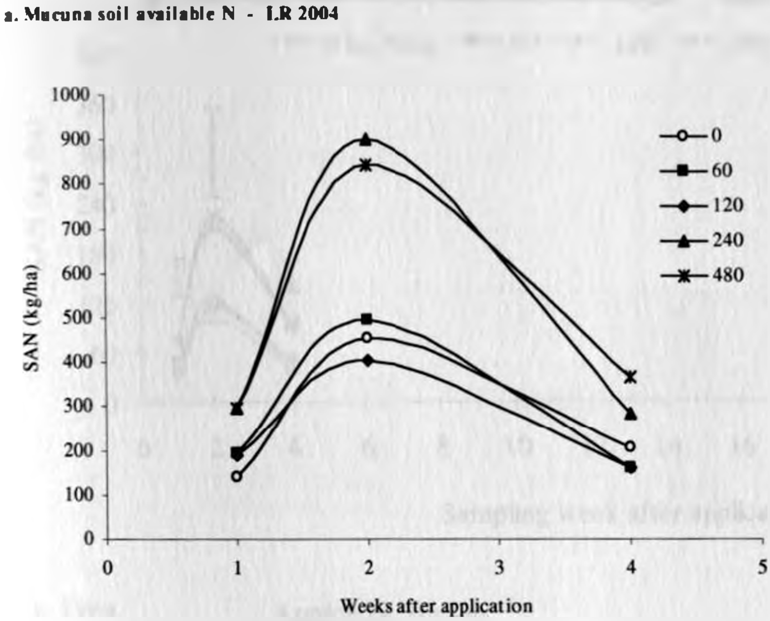
The N release trend was comparable to the decomposition trends (Figure 4.1 and 4.2). This is not surprising because biomass decomposition and N mineralization occur simultaneously. The soil available N patterns are comparable to those reported by Jama and Nair (1996). Mineralization of organic N of the plant material added to the soil is initially fast, because of the breakdown of the more easily decomposable components, but it slows down subsequently until stabilization of the organic residue (Ambrosano *et al.* 2003). The pattern was the similar in the control treatment because cultivation of the field prior to planting may have disrupted soil aggregates thereby increasing availability of carbon substrates for microbial activity, this leads to a mineralization flush soon after, possibly giving rise to the observed N peak at two weeks (Jarvis *et al.*, 1996). Protected soil organic matter has low C:N ratio than the rest and is ready to mineralize upon disruption of soil aggregates because of increased substrate supply and modified soil environment conditions (aeration, water content, temperature), which enhance microbial activity (Silgram and Shepherd, 1999).

At week 4 after mucuna application and maize planting, the soil available N stabilized at 25 to 50 kg N ha^{-1}, with or without addition of green manure (Figure 4.3). This is probably because some N is tied up in the recalcitrant material left over perhaps from stem tissues which are high in lignin and polyphenols contents and are considered to regulate the slow and second decomposition phase (Jama and Nair, 1996). Twigs and leaves from agroforestry species, namely, *Leucaena leucocephala* and *Cassia siamea* were found to get to steady level of decay at 6 to 10 weeks (Jama and Nair, 1996). From the SAN results, it is clear that whatever crop response to applied green manure obtained was dependent on amounts of N released at about 2 week. Also, the response could have been dependent on N amounts released thereafter (Figure 4.2b).

4.3.3 Soil available N in the cropped field area in the season when fertilizer N was applied

Soil available N in the cropped area was only measured for only one application season and one season after application to assess the residual N. The total soil available nitrogen (SAN) in the cropped area in the top 100 cm varied significantly in response to applied N irrespective of source and was highest two weeks after application then decreased both in the application season (Figure 4.4) and in the residual experiment (Figure 4.5). The SAN was comparable at 60 and 120 kg at all times irrespective of N source but were significantly lower compared to where mucuna N was applied at 240 and 480 kg N ha^{-1}. Soil available N in the residual experiment (Figure 4.5) was not influenced by the source or amount on N applied in the previous season. As stated in section 4.3.1 and 4.3.2 above most decomposition and mineralization occurred by the second week after N application irrespective of source or rate. Besides the amount of soil available N was significantly influenced by N fertilizer application rate.

The available N levels in soil varied significantly in the profile depth sampled. The levels increased with depth and were highest at 50–100 cm (Figure 4.6; Table 4.2) possibly due to leaching of N in soil water over time (Brady, 1994). Bowen *et al* (1988) observed that upon incorporation of legume green manure, inorganic N accumulated in the top 60 cm but by 12 weeks, most of it had leached due to heavy rainfall and was located between 60 cm and 120 cm. It is probable that the decrease in the 50-100 cm soil layer may have been primarily due to leaching into the soil profile where measurements were made and to a lesser extent due to uptake by plants.



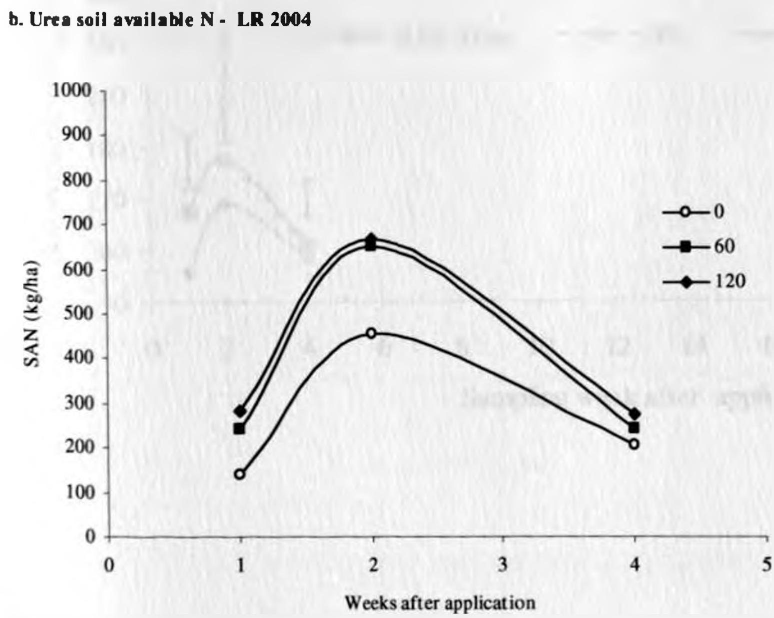
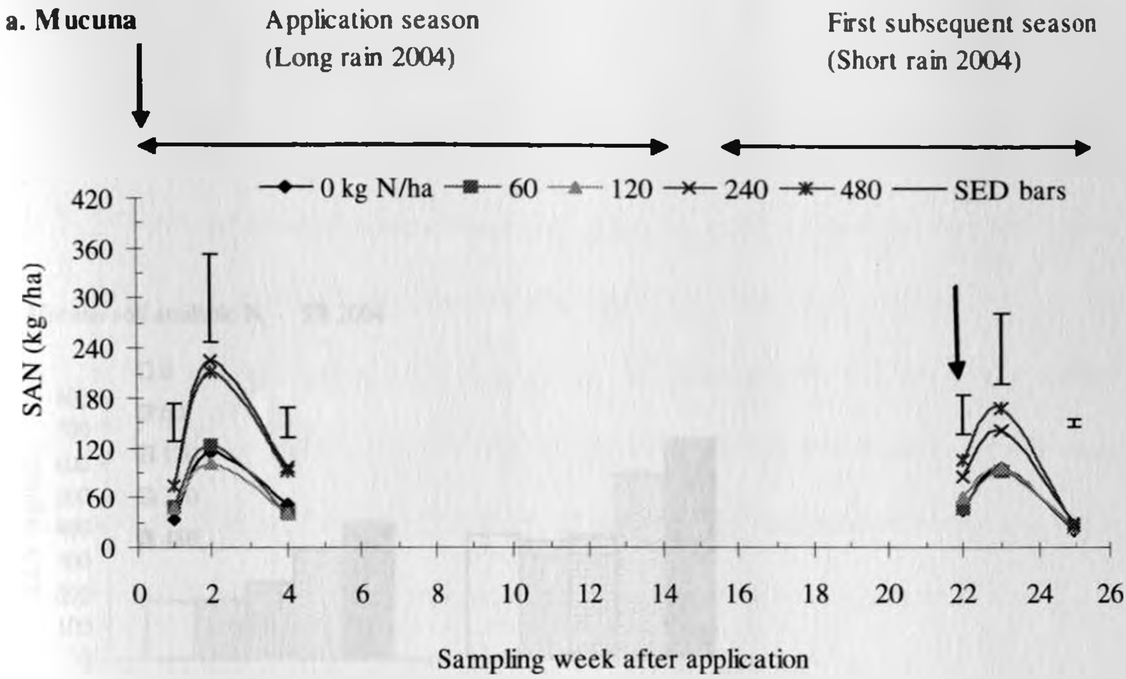


Figure 4.4. Effect of mucuna and urea fertilizer application rate on available soil N in the top 100 cm in the season of application at Mosocho, Kisii, southwest Kenya (Long rains 2004) (Rainfall=999 mm).



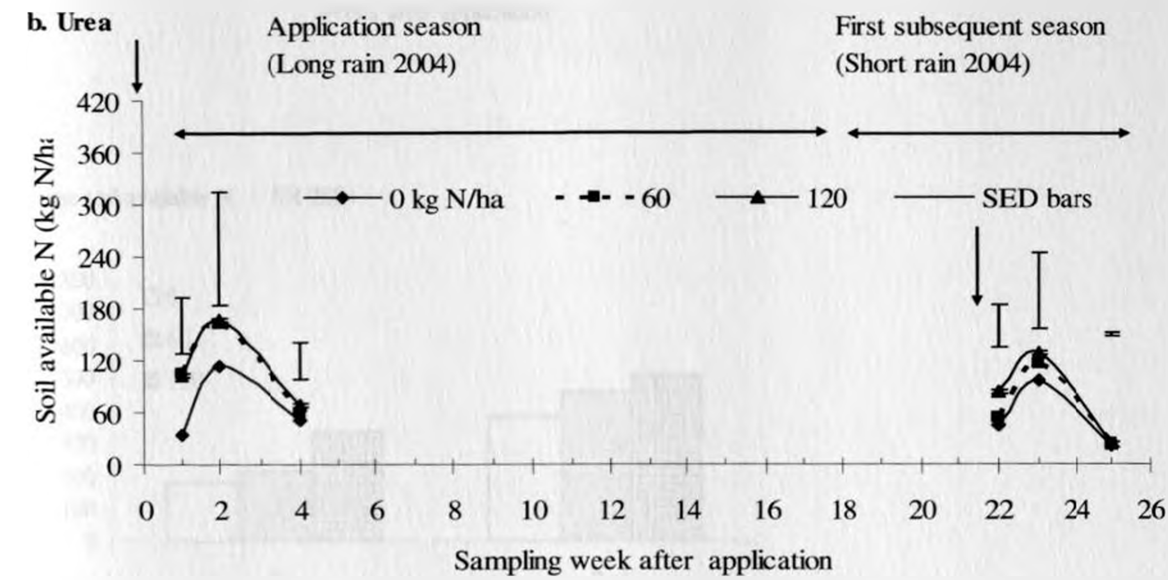
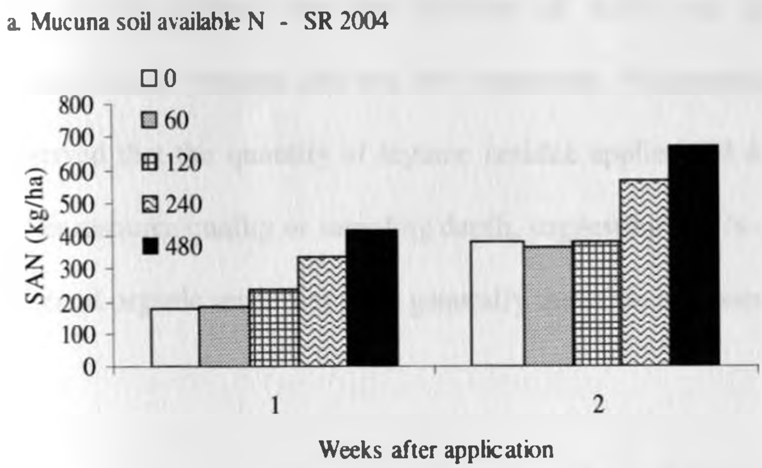


Figure 4.5. Soil available nitrogen (SAN) in cropped field in the top 100 cm in the season of N application (Long rain 2004) and first subsequent season (short rain 2004) at Mosocho, Kisii. Arrows indicate time of planting.



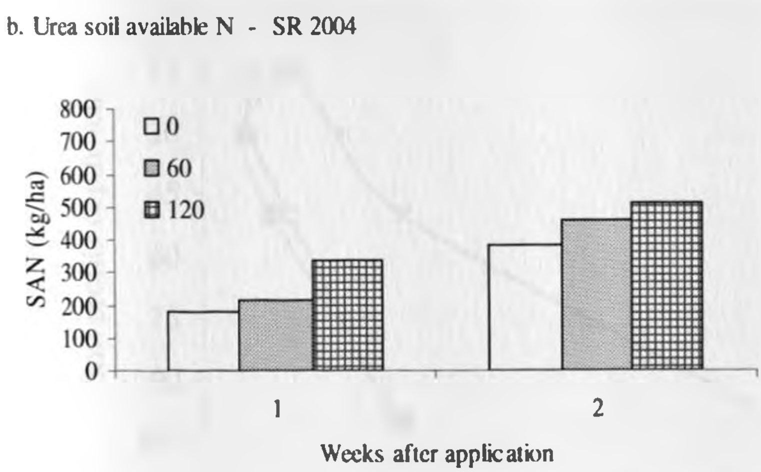


Figure 4.6. Effect of mucuna and urea fertilizer application rate on available Soil N in the top 100 cm in one season after N application (1 and 2 weeks after application in subsequent planting season, correspond to 22 and 23 weeks after incorporation).

The SAN was highest in all soil layers at 2 WAP and then declined at 4 WAP (Figure 4.7) and there was no significant interaction effect between application rate and depth. The results suggest that the quantity of SAN was primarily influenced by the mineralization process and not the treatments. Mtambanengwe and Mapfumo (2006) observed that the quantity of legume residue applied did not significantly interact with either resource quality or sampling depth, suggesting that N-mineralization patterns of the different organic resources were generally the same irrespective of application rate.

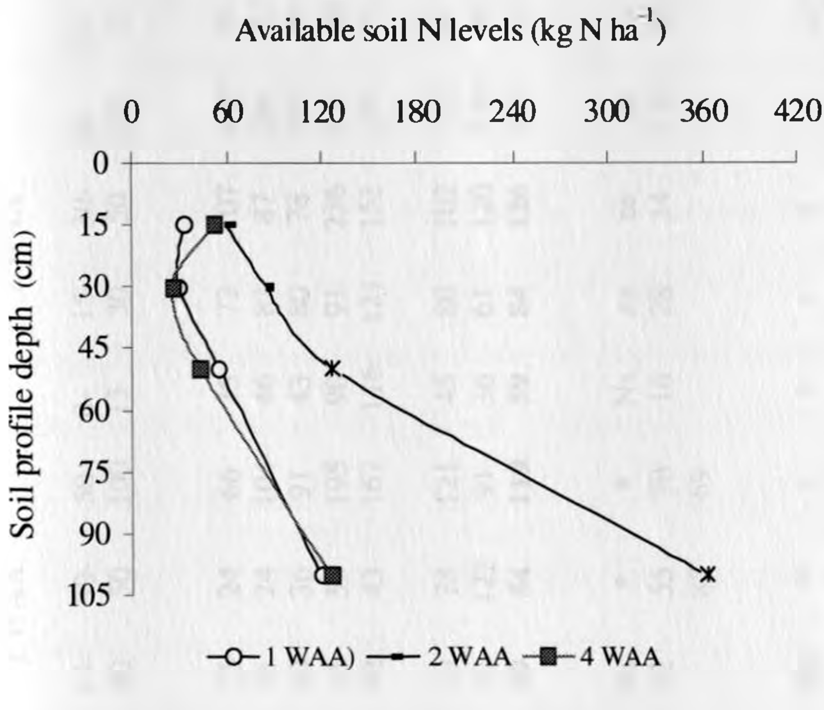


Figure 4.7. Available soil N levels at different soil depths at 1, 2 and 4 weeks after planting at Mosocho, Kisii, southwest Kenya

Table 4.2. Effect of mucuna green manure and inorganic fertilizer-urea application rate on soil available nitrogen in 1, 2 and 4 weeks after application (WAA), during application season, at Mosocho, Kisii, southwest Kenya (Long rain 2004) (Rainfall = 999 mm).

Applied fertilizer N source and rate (kg N ha^{-1})		**Soil available nitrogen (kg N ha^{-1}) at 1, 2 and 4 weeks after application (WAA)**															
		1 WAA				**2 WAA**				**4 WAA**				**Sampling time and interactions**			
		0-15	15-30	30-50	50-100	0-15	15-30	30-50	50-100	0-15	15-30	30-50	50-100	0-15	15-30	30-50	50-100
Source	N kg/ha																
Mucuna	0	24	25	24	66	35	72	107	242	34	23	38	110				
	60	41	26	24	104	46	82	87	281	42	15	22	81				
	120	34	30	36	91	43	80	78	203	39	17	34	73				
	240	23	26	53	195	90	91	236	485	50	28	54	154				
	480	46	42	43	167	116	121	153	455	73	51	71	172				
Urea	60	24	19	78	121	45	80	102	425	41	21	34	147				
	120	33	37	122	91	36	61	120	449	76	20	39	138				
Mean		**32**	**29**	**54**	**119**	**59**	**84**	**126**	**363**	**51**	**25**	**42**	**125**				
Time F test														*	*	*	*
LSD time (T)														16	13	27	102
N Source (NS) F		ns	Ns	*	*	Ns	ns	ns	ns	ns	ns	ns	*				
LSD N Source		16	32	55	70	16	28	34	132	31	14	13	43				
LSD N Source rates				85	69								74				
N Source x time F														ns	ns	*	ns
LSD NS x time														11	22	32	77
Nitrogen rate F test		ns	Ns	*	*	*	*	*	*	ns	*	*	*				
LSDN rate (NR)		22	32	57	49	36	33	69	170	34	12	14	60				
Nitrogen rate x time														*	*	*	*
LSD NR x time														31	25	23	102
%C.V Treatment		39	48	59	18	35	22	31	26	38	28	19	27				

F=Fisher test; * =Differences significant, ns=Differences non-significant; LSD=Least significant difference; N source rates=60 and 120 kg N ha^{-1}

4.3.4 Soil available N a season after N fertilizer application (residual effect)

Nitrogen source had a non-significant residual effect on soil available N (SAN) (Table 4.3). This was possibly due to the chemical characteristics of mucuna green manure that favour its rapid mineralization, making N readily available, like in the case of inorganic fertilizer-urea. Ssali (1985) showed that urea fertilizer lacked residual benefit in maize and bean production. Lack of residual effects due to application of legume biomass, and tithonia, has been demonstrated independently (Carsky, 1989; Lathwell, 1990; and Delve and Bashir, 2002), repectively.

Residual effect of mucuna green manure applied in the previous season at rates of 60 and 120 kg N ha^{-1} on soil available N (SAN) was non-significant but was significant at 240 and 480 kg N ha^{-1} only at one week after planting in the subsequent season (Table 4.3). This was possibly because N supplied at 60 and 120 kg N ha^{-1} was taken up by maize during the application season but there was carry over effect because of high quantities of mucuna biomass at 240 and or 480 kg N ha^{-1}. Probably not all the N mineralized in the application period, and some did in the following season. The apparent carry-over mucuna N effect never went beyond first week of the first subsequent season and it was not reflected maize growth, N uptake or yield at the end of the season. Lack of residual effects of N fertilizers has sometimes been attributed to the high mobility of available N forms in the soil (Ambrosano *et al.*, 2003). This was possibly the case because rainfall in the area is high early in the season; hence the residual N may have been leached beyond the rooting zone by the time maize roots were established.

Mucuna decomposes rapidly releasing N to the soil (Cadisch and Giller, 1997). This attribute though beneficial, is the reason why soil organic N is not likely to accumulate in the short term in mucuna N based system. Soil organic N improvement through sustained application of organic residues has been demonstrated but tends to take several years and use of low quality residues (Cadisch and Giller, 1997).

Table 4.3. Effect of mucuna and urea rate on soil available N in 22, 23, 25 and 29 weeks after application, or at 1, 2, 4 and 8 weeks after planting, in first subsequent season, at Mosocho, Kisii, southwest Kenya (Short rain 2004) (Direct field sampling method).

		Soil available nitrogen (kg N ha^{-1}) at 1, 2 and 4 weeks after application (WAA)														
Weeks after use		22				23				25		29	**Sampling time and interactions**			
Planting (time)		**1**				**2**				**4**		**8**				
Profile depth (cm)		0-15	15-30	30-50	50-100	0-15	15-30	30-50	50-100	0-15	15-30	0-15	0-15	15-30	30-50	50-100
Treatment (kg N ha^{-1})																
	0	31	23	24	101	34	40	68	243	16	26	23				
Mucuna green manure	60	35	34	22	93	32	46	83	205	20	31	15				
	120	38	33	33	134	34	53	71	223	23	26	16				
	240	31	32	49	225	46	91	137	296	32	29	13				
	480	65	64	84	205	55	92	190	336	28	23	19				
Inorganic fertilizer-urea	60	24	21	33	137	35	80	82	263	25	24	14				
	120	37	33	61	205	38	58	121	296	22	22	14				
Mean		37	34	44	157	39	66	107	266	24	26	16				
Time F test													*	*	*	*
LSD time (T)													7	14	27	50
N Source (NS) F		ns	ns	*	ns	ns	ns	ns	ns	ns	ns	ns				
LSD N Source		10	13	18	80	5	38	44	99	8	7	2				
LSD Source rates				6												
N Source x time F													ns	ns	ns	Ns
LSD NS x time													10	20	30	83
N rate F test		*	*	*	*	ns	ns	*	ns	ns	ns	ns				
LSDN rate (NR)		12	18	15	86	17	62	67	156	18	13	10				
N rate x time F test													ns	ns	ns	Ns
LSD NR x time													16	34	45	128
%C.V Treatment		18	30	19	31	24	53	35	33	44	29	34				

F=Fischer test; *=Differences significant, ns=Differences non-significant, LSD=Least significant difference; N source rates=60,120 kg N ha^{-1}

4.5 Conclusions

1. Mucuna green manure has two phases of decomposition: an initial rapid phase and a slower second one. Half-life of incorporated mucuna green manure under field conditions was 1 week. Decomposition pattern remained the same irrespective of application rate of mucuna green manure. Nitrogen release peaked at 2 weeks after application and planting.

2. At application rates of 60 and 120 kg N ha^{-1}, available soil N attributed to application of mucuna green manure and inorganic fertilizer were the same.

3. During application season, mucuna and inorganic fertilizer used at rates of 60 and 120 kg N ha^{-1} had non-significant effect on soil available N under field planted with maize, possibly due to uptake. It required mucuna applied at 240 kg N ha^{-1} or higher at 480 kg N ha^{-1} to significantly raise available N levels over the control. Similarly, under field conditions protected from maize N uptake in micro-lysimeter tubes, it required mucuna applied at rate of 240 kg N ha^{-1} to significantly increase SAN over the control.

4. In the first following maize cropping season, only mucuna green manure application rate of 480 kg N ha^{-1} showed significant effect on SAN level and only in 22 weeks after application. This was at 1 week after planting in the subsequent season. Lower application rates of mucuna including use of 240 kg N ha^{-1} lacked residual effect on available N supply. Inorganic fertilizer-urea had non-significant residual effect on SAN.

CHAPTER FIVE

SOIL MOISTURE AND MUCUNA NITROGEN RATE EFFECTS ON AVAILABLE NITROGEN SUPPLY FOR MAIZE GROWTH UNDER GREENHOUSE CONDITIONS

5.1 Introduction

Understanding variable soil moisture influence on maize growth, decomposition pattern of different quantities of mucuna green manure applied, and available N levels are critical for efficient resource management. Decomposition of residue is controlled by substrate availability, temperature and water among other factors (Schomberg *et al.*, 1994). Although all the three factors are essential, soil moisture seems to be the most important (Cavelier *et al.*, 2000). In Chapter Three of this study, maize growth and yield varied among planting seasons, apparently because of changing rainfall patterns hence soil moisture conditions. This shows, there was need to assess the extent to which soil water content could potentially influence maize uptake of mucuna N.

Determination of available N levels attributed to different application rates of mucuna by direct field sampling of soils from experimental plots planted with maize, has its disadvantages. Maize N uptake may interfere with levels of mineralized N to the extent that treatment differences are distorted. There may be leaching of N, runoff, and the field environment is characterized with changes in weather conditions, particularly rainfall which affects soil moisture levels. All these may affect response trends obtained under field conditions. To overcome some of the shortfalls, effects of mucuna green manure application rate on maize, decomposition and soil available N were studied in imperforated plastic pots under glasshouse conditions where soil moisture was controlled. This was done to verify the role that soil moisture under rain fed conditions in the field might have played in influencing mucuna decomposition, mineralization and maize N uptake. The objective was to determine potential effect of mucuna green manure quantity applied on maize dry matter yield, root length, N uptake and also, varying soil moisture level effects on decomposition pattern of mucuna green manure and soil available N.

5.2 Materials and Method

5.2.1 Experimental design

There were two treatments evaluated in the experiment: Mucuna green manure application rate, and soil moisture level. The rates of mucuna green manure tested were 0, 60, 120 and 240 kg N ha^{-1}. Soil moisture levels studied were potentials (Ψ) at field capacity (ψ=-0.01 MPa), wilting point (ψ =-1.5 MPa), and intermediate moisture (ψ =-0.75 MPa). The treatments were combined factorially and replicated three times in completely randomized design (CRD). The amount of soil used in 10 litre plastic non-perforated pots was 4 kg. The green manure was chopped manually using a machete into small pieces of less than 2 cm and mixed with soil in quantities calculated according to rate of application. At tissue N concentration of 1.6 % for mucuna, application rates of green manure at 0, 60, 120 and 240 kg N ha^{-1} worked out to 0, 7, 14 and 28 g DM/pot. The pots were planted with maize variety H 614D. The experiment was conducted in

greenhouse at the Kabete Field Station, University of Nairobi.

5.2.2 Data collection

5.2.2.1 Soil water retention characteristics

Water retention properties of sandy clay soil from the field experimental site at Mosocho, Kisii, southwest Kenya, were determined prior to its use in greenhouse pot experiment. The soil was transported to Kabete and dried to constant weight in the sun to mimic field condition, and to minimize disruption of soil aggregates. Plant residues and other foreign particles were physically picked out, and large clods broken by hand. There are two soil moisture conditions that are important consideration in connection with plant growth (Al-Khafaf and Hanks, 1974): Field capacity is taken as the maximum amount of water that can be stored in a soil; Wilting point is lower limit of readily available water. These occur at soil water potentials (ψ) of -0.01 MPa and -1.5 MPa, respectively (Salisbury and Ross, 1989). The two water contents and an intermediate one were determined for the soil. A sub-sample was taken, and using filter paper method (Hamblin, 1981), soil moisture levels at wilting point (-1.5 MPa) and field capacity (-0.01 MPa) were determined. The intermediate moisture level was computed as the median between field capacity and wilt point, and this came to –0.75 MPa. The three moisture level treatments were maintained by weighing pots on sensitive balance thrice daily and making up loss in weight by addition of water.

5.2.2.2 Decomposition of mucuna green manure

Decomposition was recorded as percentage of mucuna green manure remaining at 1, 3, 5 and 8 weeks after application (WAA). Anderson and Ingram (1993) state that, direct measure of weight loss is one of the methods that have been used to measure decomposition. Carbon dioxide emission is used as a measure of the process as well. In this study the attributes observed were: soil available N levels and maize uptake at 1, 3 and 5 WAA. Also, dry matter yield and root length at 1, 3, 5 and 8 WAA were measured.

5.2.2.3 Soil available nitrogen

The analysis to determine available N level in the soil was done at The Soil Science laboratory of the University of Nairobi. The procedure used is detailed in the laboratory manual, and is described as titrimetric method. Wet soil samples from the field were sub-sampled into aluminum tins, and oven-dried at 105°C for 72 hours to determine moisture content. At the same time, another sub-sample from the same sample, weighing 2 g was placed into a plastic bottle, and 20 ml of 2 M KCl was added. The bottles were tightly closed and put on shaking machine for 1 hour, after which they were removed and filtered using Whatman No. 42 paper. The filtrate was pipetted into a distillation flask. Magnesium oxide was added into the flask prior to its distillation to release ammonia gas, which was captured in 20 ml of 1 % boric acid, and up to 150 ml of the distillate was collected. This was to be used in determination of NH_4^+ available in the soil. Devarda's alloy was then added to the mixture in the same flask, to reduce NO_3^- and NO_2^- to ammonia gas, which was absorbed in 20 ml of 1 % boric acid, and up to 150 ml of the distillate was collected. This was used in determination of NO_3^- available in the soil.

Mixed indicator was added to the boric acid carrying the absorbed ammonia, and titrated with 0.001 N H_2SO_4. The indicator turned from green to light pink as end point. The volume of 0.001 N H_2SO_4 involved in the titration was noted and used in computing the milligrams (μg) of N per gram (g) of soil, in both ammonium and nitrate forms. The two were added together to obtain the sum of the mineral N. Sample preparation for analysis was done in triplicate. (1.0 ml of 0.001 N H_2SO_4 = 14 μg).

5.2.2.4 Root length

Maize plants were removed from pots by gently washing off attached soil under running tap water in the buckets in which they were grown. Plants were cut at the base to separate roots from stem. The roots were cleaned and small samples placed and straightened on graph paper. Root length was determined as the total number of squares covered on the grid by all the roots of the plant (Rowell, 1994).

5.2.3 Data analysis

Data collected from the experiments was examined using the analysis of variance (ANOVA) procedures to determine the statistically significant result at probability level of 0.05. Genstat software was used in performing the analysis. The treatments found to be significant were subjected to mean separation using the least significant difference (LSD) test.

5.3 Results and Discussion

5.3.1 Soil water release characteristic curve

Moisture release characteristic curve developed using the filter paper method is presented in Figure 5.1. From the curve, soil water contents at wilting point (ψ=-1.5 MPa), intermediate potential (ψ=- 0.75 MPa) and field capacity (ψ=-0.01 MPa) were established as 12, 18 and 22 %, respectively. Regression co-efficient (R^2) for relationship between soil water potential (Ψ) and its water content (%) was 0.91, which is high and indicates close association between the two parameters for the sandy clay. This is possibly because water potential of moist soil kept in airtight container with filter paper for 3 days was probably the same and close to equilibrium. Hamblin (1981) recommended from minutes to days equilibration time for filter paper method. Al-khafaf and Hanks (1974) recommended 2 days for the same. When the filter paper is kept with moist soil, water or vapour will flow from the soil into the filter paper until equilibrium is achieved (Leong and Rahardjo, 2002).

The result shows that the filter paper method (Hamblin, 1981) and water release curve generated could be used with reliability. Certainty in using filter paper has been observed by Williams and Sedgley (1965) and, MacQueen and Miller (1968). The curve shows that available water is between 18 to 20%, with wilting point (ψ=-1.5 MPa) being at 14%, which are narrow ranges, possibly because the soil type was sandy clay (Figure 5.1). The advantages of the filter paper method include its simplicity, low cost, and ability to measure a wide range of suctions (Leong and Rahardjo, 2002).

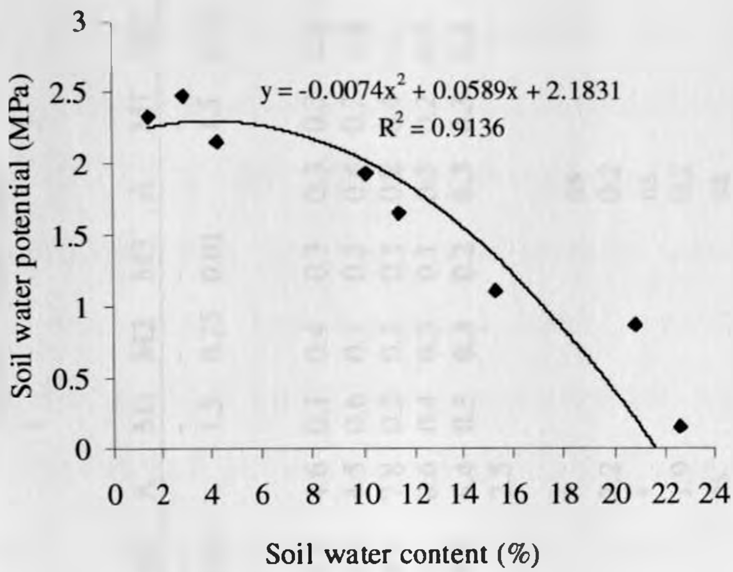


Figure 5.1 Water release characteristics curve of sandy clay topsoil (0-20 cm) collected from Mosocho, Kisii, southwest Kenya determined using filter paper method (Hamblin, 1981).

5.3.2 Maize dry matter accumulation

Maize total dry matter was significantly lower in the second season compared to the first season (Table 5.1). The difference was possibly due to heat stress in the second season, because the greenhouse used was not air-conditioned. The first season experiment was planted in March and the second one in May and it was warmer in May than in March. The May experiment possibly experienced mid-day water and temperature stress despite regular watering which possibly reduced growth and interfered with nitrogen metabolism.

Table 5.1. Effect of mucuna green manure application rate and sandy clay soil moisture on dry matter yield of potted maize, at Field station-Kabete, University of Nairobi (March-June, 2005)[♣]

		Maize dry matter yield (g/plant)																						
		Season 1 (March-April)												Season 2 (May-June)										
Weeks after planting		3				5				8				1				5				8		
Treatment																								
		M1	M2	M3	A	M1	M2	M3	A	M1	M2	M3	A	M1	M2	M3	A	M1	M2	M3	A	M1	M2	M
Soil water potential (ψ) (MPa)		-1.5	-0.75	-0.01		-1.5	-0.75	-0.01		-1.5	-0.75	-0.01		-1.5	-0.75	-0.01		-1.5	-0.75	-0.01		-1.5	-0.75	-0.
(kg N ha^{-1})																								
Mucuna	0	0.8	0.5	1.1	0.8	0.5	0.4	0.6	0.5	4.5	5.0	4.2	4.6	0.1	0.4	0.3	0.3	0.3	2.0	1.3	1.2	0.5	4.0	2.
green	60	0.5	0.3	0.8	0.5	0.5	0.2	0.8	0.5	4.4	3.2	5.7	4.5	0.6	0.3	0.3	0.4	0.2	0.8	0.9	0.6	0.6	3.2	7.
manure	120	0.6	0.6	0.6	0.6	0.6	0.5	0.7	0.6	7.8	7.5	8.0	7.8	0.2	0.3	0.1	0.2	0.4	1.1	0.3	0.6	1.0	4.0	3.
	240	0.6	0.4	0.7	0.6	0.8	0.6	1.0	0.8	8.7	5.9	11	8.6	0.4	0.3	0.1	0.3	0.2	0.5	1.0	0.6	0.5	5.2	4.
mean		**0.6**	**0.4**	**0.8**	**0.6**	**0.6**	**0.4**	**0.8**	**0.6**	**6.4**	**5.4**	**7.3**	**6.4**	**0.3**	**0.3**	**0.2**	**0.3**	**0.3**	**1.1**	**0.9**	**0.7**	**0.6**	**4.1**	**4.**
Seasonal mean													2.5											
LSD season mean																								
Nitrogen rate F test					ns				ns				*				ns				*			
LSD Nitrogen rate					0.2				0.4				2.2				0.2				0.5			
Moisture F test					*				*				*				ns				*			
LSD moisture level					0.2				0.3				1.9				0.2				0.4			
N rate x moist. F					ns				ns				ns				ns				ns			
LSD N x Moisture					0.4				0.7				3.7				0.3				0.9			
%C.V Treatment					37				62				34				71				71			

[♣]F=Fisher test; *=Differences significant, ns=Differences non-significant; LSD=Least significant difference; N source rates=30, 60,120 kg Nha^{-1}; (M1 = Soil moisture at wilt point (ψ=-1.5 MPa), M2 = intermediate soil water content (ψ=-0.75), M3 = field capacity (-0.01 MPa); A = Nitrogen rate mean; Moist. =soil moisture level.

Maize dry matter yield response to application of mucuna green manure was significant at 8 and 5 weeks after planting (WAP) in the first and second seasons, respectively (Table 5.1). At 8 WAP, maize dry matter in the control and mucuna application at 60 kg N ha^{-1}, equivalent to 3 t DM ha^{-1} of green manure, was comparable. This is possibly because mucuna application rate of 60 kg N ha^{-1} may be small to make a substantial difference in supply of N for maize growth. Similar result was obtained under field planted maize experiment described in Chapter Three. However, maize dry matter attributed to mucuna applied at 120 and 240 kg N ha^{-1} was comparable but significantly higher than in the control (Table 5.1). These results corroborate findings in Zimbabwe that maize growth and yield increased with increasing mucuna biomass (Whitbread *et al.*, 2004). Bogale *et al.* (2001) reported that the minimum dry biomass from Sesbania to be incorporated for increased productivity of maize was 5 t DM ha^{-1}. It is probable that N applied at 240 and 480 kg N ha^{-1} may have been lost through volatilization and/or remained in the soil (Silgram and Shepherd, 1999).

Soil moisture level effect on maize dry matter (DM) yield was significant at 3, 5 and 8 weeks after planting (Table 5.1). In all seasons and stages, maize dry matter was highest at field capacity than at wilting point moisture content. In the first season, maize dry matter yield at wilting point and intermediate soil moisture were the same. But in the second season, maize dry weight in intermediate moisture was significantly superior to that at wilting point throughout, and had comparable DM as in field capacity (Table 5.1). High soil water content enhances nutrient transport, expansive leaf growth, N uptake and increased dry matter yield while the converse is true (Eastin and Sullivan, 1984; Mburu, 1996).

5.3.3 Root length

Maize planting season had non-significant effect on root length (Table 5.2). Maize root length response to mucuna green manure application rate was non-significant possibly because the soil was adequately supplied with P and K (from previous application, Chapter Three), which may have stimulated root growth in at all N levels (Aldrich *et al.* 1975).

Soil water had a significant effect on root length. Maize roots grown at field capacity were significantly longer than those in the wilting point moisture at 3 and 8 weeks after application (WAP) in first season and, at 5 and 8 WAP in second season (Table 5.2). Maize roots under intermediate soil moisture were comparable, or significantly longer than at wilting point (Table 5.2). Nelson and Larson (1984) attributed retardation of plant growth and development as a result of water stress to cell dehydration (Eastin and Sullivan, 1984). Water stress reduces cell expansive growth, photosynthetic rate, assimilate translocation and nutrient uptake, which all contribute to growth of both leaves and roots (Salisbury and Ross, 1988). The best root growth occurs when soil moisture is near field capacity, soil fertility is near optimum, and oxygen availability is sufficient for normal aerobic respiration (Nelson and Larson, 1984). This possibly explains why maize at field capacity and intermediate soil moisture content had higher dry matter yield compared to that at wilting point (Figure 5.2).

Table 5.2. Effect of mucuna green manure application rate and soil moisture on root length of potted maize in a sandy clay soil, at Field station-Kabete, University of Nairobi (March-June, 2005)[♣]

		Maize root length (cm)																						
		Season 1 (March-April)												Season 2 (May-June)										
Weeks after planting		3				5				8				1				5				8		
Treatment																								
Soil water potential (ψ) (MPa)		M1 -1.5	M2 -0.75	M3 -0.01	A	M1 -1.5	M2 -0.75	M3 -0.01	A	M1 -1.5	M2 -0.75	M3 -0.01	A	M1 -1.5	M2 -0.75	M3 -0.01	A	M1 -1.5	M2 -0.75	M3 -0.01	A	M1 -1.5	M2 -0.75	M3 -0.01
(kg N ha^{-1})																								
Mucuna	0	58	32	83	58	129	80	178	129	129	111	146	129	50	55	39	48	30	80	155	88	124	137	173
green	60	55	47	62	55	135	92	179	135	107	88	126	107	65	79	34	59	36	126	115	93	127	166	265
manure	120	61	59	63	61	129	95	164	129	141	122	160	141	47	58	23	43	76	109	132	106	87	110	194
	240	61	58	64	61	176	143	208	176	121	99	144	121	19	39	50	36	38	78	117	77	94	221	246
Moist. mean		59	49	68	59	142	102	182	142	124	105	144	124	45	58	37	47	45	98	130	91	108	159	220
Seasonal mean													108											
LSD seasonal mean																								
Nitrogen rate F test					ns				Ns				ns				ns				ns			
LSD Nitrogen rate					16				41				33				18				31			
Moisture F test					*				*				*				*				*			
LSD moisture level					14				36				29				16				27			
N rate x moist. F					ns				Ns				ns				ns				ns			
LSD N x Moisture					28				71				58				32				53			
%C.V Treatment					28				29				27				40				35			

[♣]F=Fisher test; *=Differences significant, ns=Differences non-significant; LSD=Least significant difference; N source rates=30, 60,120 kg Nha^{-1}; Moist. =soil moisture level; A =Nitrogen rate mean; (M1 = Soil moisture at wilt point –1.5 MPa), M2 = intermediate soil water content (-0.75 MPa), M3 = field capacity (-0.01 MPa).

5.3.4 Maize nitrogen uptake

Plant total N is an indication of N uptake (Rowell, 1994). Maize total nitrogen levels in the two seasons were comparable and showed significant response to applied mucuna N in the first planting season (Table 5.3). Total maize N in the control and where mucuna green manure was applied at 60 kg N ha^{-1} was comparable. Also, it was similar at 120 and 240 kg N ha^{-1} though significantly higher than in the control. The trend was different in the second planting season, where N uptake was only significantly higher at 240 kg N ha^{-1} but comparable among the other three levels. It is probable that variation of temperature in the greenhouse in the two seasons may have influenced transformation (Jarvis *et al.*, 1996; Fageria and Balgar, 2005; Singh *et al.*, 2005).

There was non-significant interaction effect between mucuna application rate and soil moisture level on maize nitrogen uptake in both planting seasons. Soil moisture effect on maize total N was significant only in the second planting season (Table 5.3). Maize at field capacity and intermediate soil moisture conditions had similar total N levels while maize at wilting point moisture had significantly lower total N. This was probably because there was insufficient soil moisture at wilting point to facilitate N transport and uptake in the plant and also general plant growth (Eastin and Sullivan, 1984). The effects of soil moisture on crop growth were exemplified by Pilbeam *et al.* (1995) who observed low maize dry matter and grain, and low fertilizer N recovery (less than 20%) under semi-arid conditions in Kenya where non response of maize yield to fertilizer applied at up to 120 kg N ha^{-1} was noted in three seasons out of four.

Table 5.3. Effect of mucuna green manure application rate and soil moisture on maize total N at 8 weeks after incorporation and planting under potted greenhouse conditions at Field station-Kabete, University of Nairobi (March-June, 2005)♣

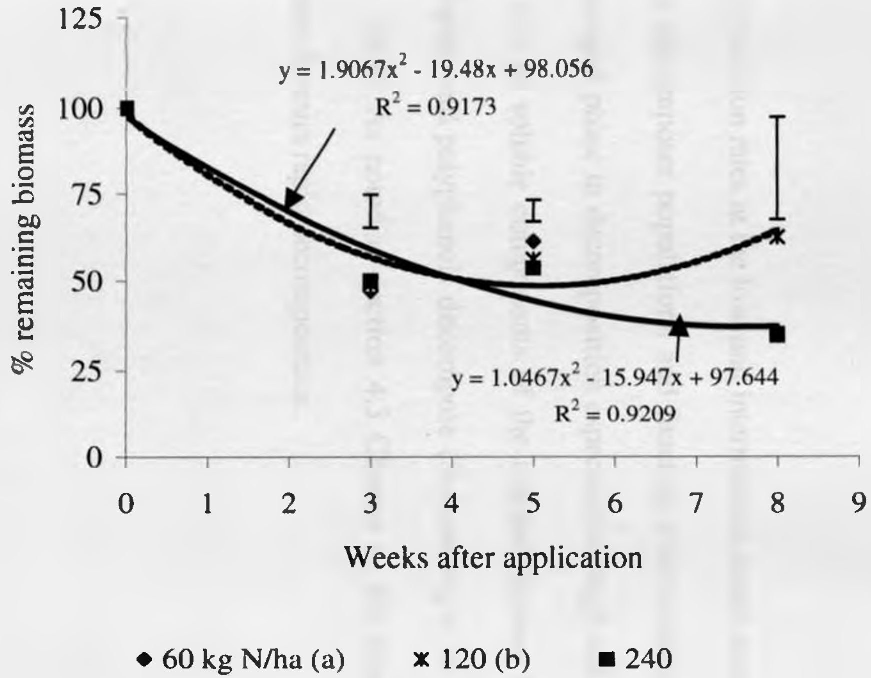
Soil water and Mucuna N rates		Maize total nitrogen (g N/plant)							
		Season 1 (March-April)				Season 2 (May-June)			
		---------------- Soil moisture level -------------------							
Soil water potential (ψ) (MPa)		M1	M2	M3	mean	M1	M2	M3	mean
		-1.5	-0.75	-0.01		-1.5	-0.75	-0.01	
Mucuna	0	0.06	0.05	0.07	0.06	0.01	0.05	0.05	0.04
green	60	0.05	0.05	0.05	0.05	0.01	0.05	0.12	0.06
manure	120	0.09	0.09	0.08	0.09	0.02	0.05	0.09	0.05
(kg N ha^{-1})	240	0.09	0.08	0.11	0.09	0.01	0.12	0.12	0.08
Moisture mean		**0.07**	**0.07**	**0.08**	**0.07**	**0.01**	**0.07**	**0.09**	**0.06**
Seasonal mean					0.07				0.06
LSD seasonal mean									0.02
Nitrogen rate F test					*				ns
LSD Nitrogen rate					0.02				0.03
Moisture F test					ns				*
LSD moisture level					0.02				0.03
N rate x moisture F test					ns				ns
LSD N rate x moisture					0.04				0.06
%C.V Treatment					31				57

♣F=Fisher test; *=Differences significant, ns=non-significant; LSD=Least significant difference; N source rates=30, 60,120 kg Nha^{-1}; M1 = Soil moisture at wilt point (ψ=-0.01 MPa), M2 = intermediate water content (ψ=--0.75 MPa), M3 = Soil moisture at field capacity (ψ=-1.5 MPa); A=Nitrogen rate mean; Moist. = Soil moisture level.

5.3.5 Effect of mucuna green manure application rate on decomposition

The rate of decomposition was evaluated used the percentage of biomass remaining over time. The percentage biomass remaining was significantly higher in second season (65%) compared to the first season (50%) (Figure 5.2). Mucuna green manure application rate had non-significant effect on percentage biomass remaining throughout the 8 weeks in the two seasons. The variation in time accounted for 82% to 92% of the variation in proportion of mucuna biomass decomposed in both seasons. The pattern of mucuna N decomposition in the greenhouse was comparable to the one observed in the field (Figure 4.1; Chapter 4). The difference between the % remaining biomass at 8 WAA was probably variation in soil microbial population and/or composition because the soil collected from the field was air-dried prior to setting up the experiments.

a. Season 1 (March-April, 2005)



b. Season 2 (May to June 2005)

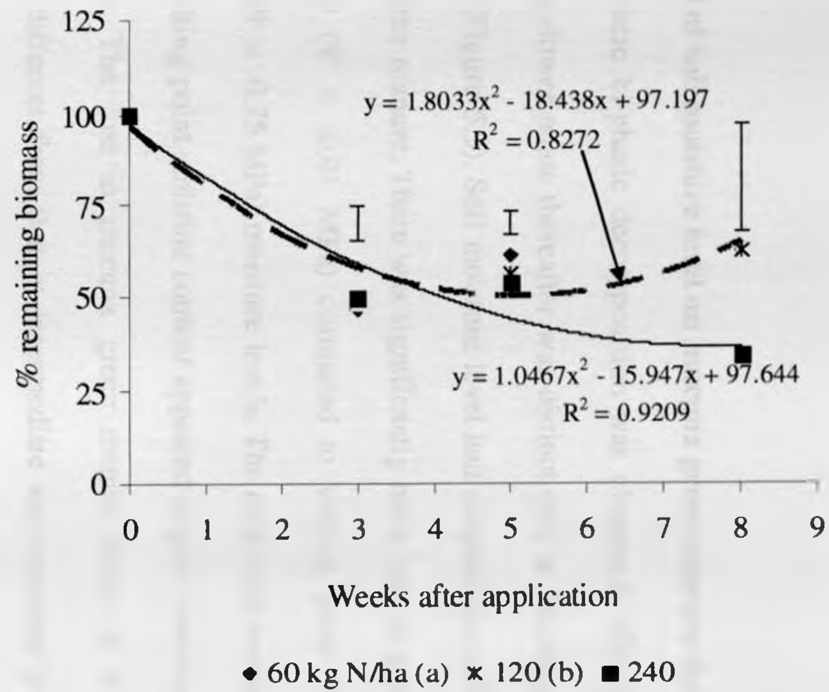


Figure 5.2. Effect of mucuna green manure application rate on decomposition under greenhouse conditions at the University of Nairobi (2005). Least significant difference bars shown.

5.3.6 Effect of soil moisture level on mucuna green manure decomposition

The characteristic bi-phasic decomposition was observed; with an initial rapid phase followed by a slower phase thereafter was distinct only at the high soil water content in both seasons (Figure 5.3). Soil moisture level had a significant effect on decomposition of mucuna green manure. There was significantly more loss in green manure biomass at field capacity (Ψ = -0.01 MPa) compared to wilting point (Ψ = -1.5 MPa) and intermediate (Ψ = -0.75 MPa) moisture levels. The exception was at 8 WAA when the % biomass at wilting point moisture content appeared to gain material possibly due to dead maize leaves. The loss in mucuna green manure mass at wilting point was not significantly different from that in intermediate soil moisture level throughout the 8 weeks.

The low decomposition rates at the low and intermediate water content were possibly due to sub-optimal decomposer populations and function (Sarrantonio, 1991; Schomberg *et al.* 1994). The rapid phase in decomposition especially at high soil water content may be attributed to loss of soluble components of the applied biomass followed by a slower phase when lignin and polyphenols decompose (Schomberg *et al.* 1994; Constantinides and Fownes, 1993). As noted in section 4.3 Chapter 4, the chemical composition of mucuna biomass favours rapid decomposition.

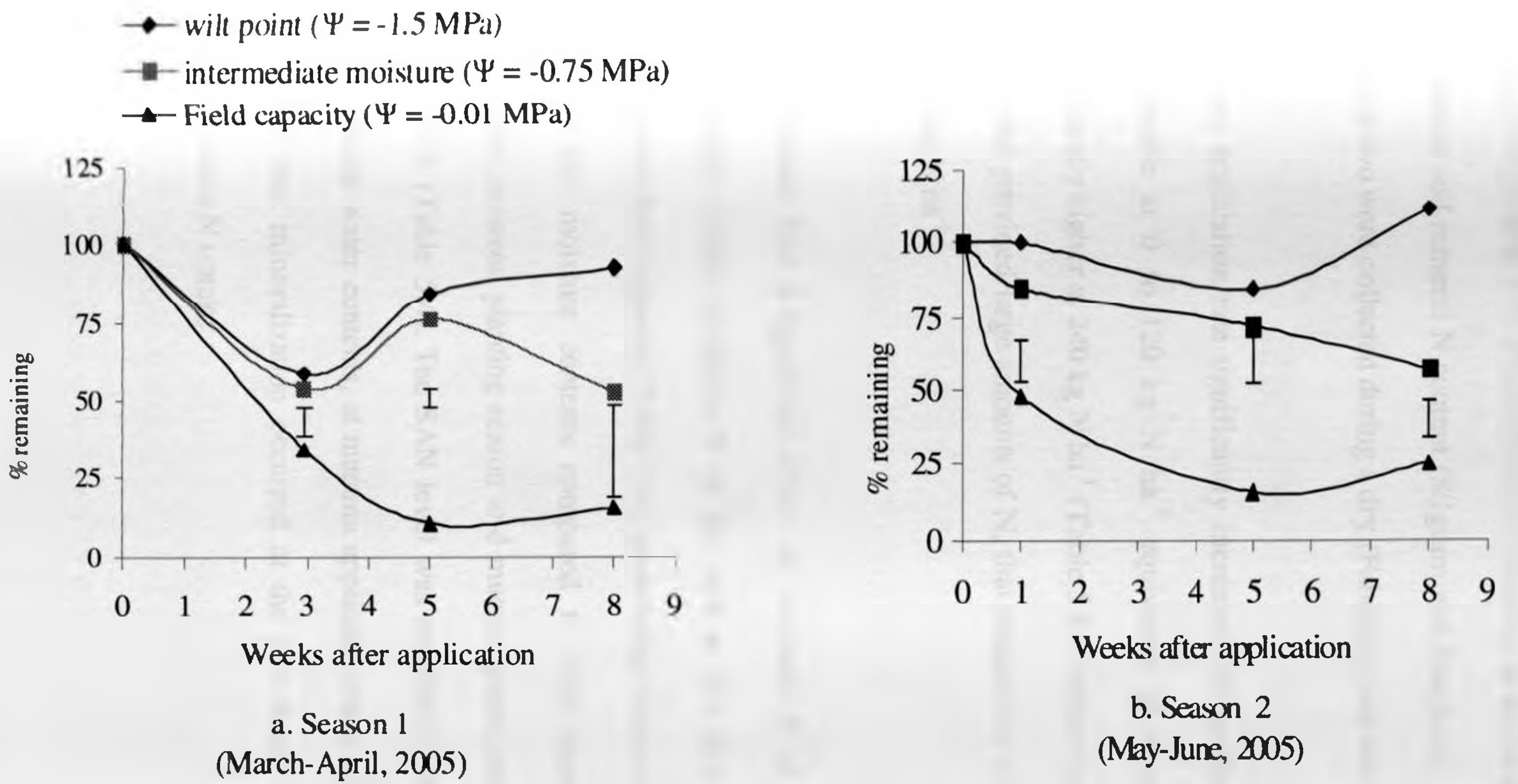


Figure 5.3 Effect of soil moisture level on mucuna green manure decomposition under greenhouse conditions at Field Station-Kabete, University of Nairobi: (March-June 2005). SED bars shown.

5.3.7 Soil available nitrogen

Soil available N was significantly higher in the second season compared to first season (Figure 5.4) (Table 5.4). Possibly due to variation in soil water content at sampling which influences soil mineral N content (Silgram and Shepherd, 1999). Soils used for seasons one and two were collected during a dry (February) and wet spell (April) respectively.

Mucuna application rate significantly increased soil available N. The available N was comparable at 0 to 120 kg N ha^{-1} equivalent of mucuna green manure but was significantly higher at 240 kg N ha^{-1} (Table 5.4). Perhaps organic matter that was already in the soil provided large amounts of N, that masked the N added at rates lower or equal to 120 kg N ha^{-1}.

Soil moisture had a significant effect on available N in the two seasons. There was significantly higher available N in the soil at low and intermediate water contents compared to field capacity (Table 5.4), presumably because of low maize N maize uptake at two soil moisture contents compared to field capacity. There was significant interaction between planting season and mucuna green manure application rate on SAN at 5 WAA (Table 5.4). The SAN level was specifically higher at wilting point and or intermediate water contents, at mucuna application rates of 120 and 240 kg N ha^{-1}. This indicates that mineralization occurred at the two water levels but the water content limited maize N uptake.

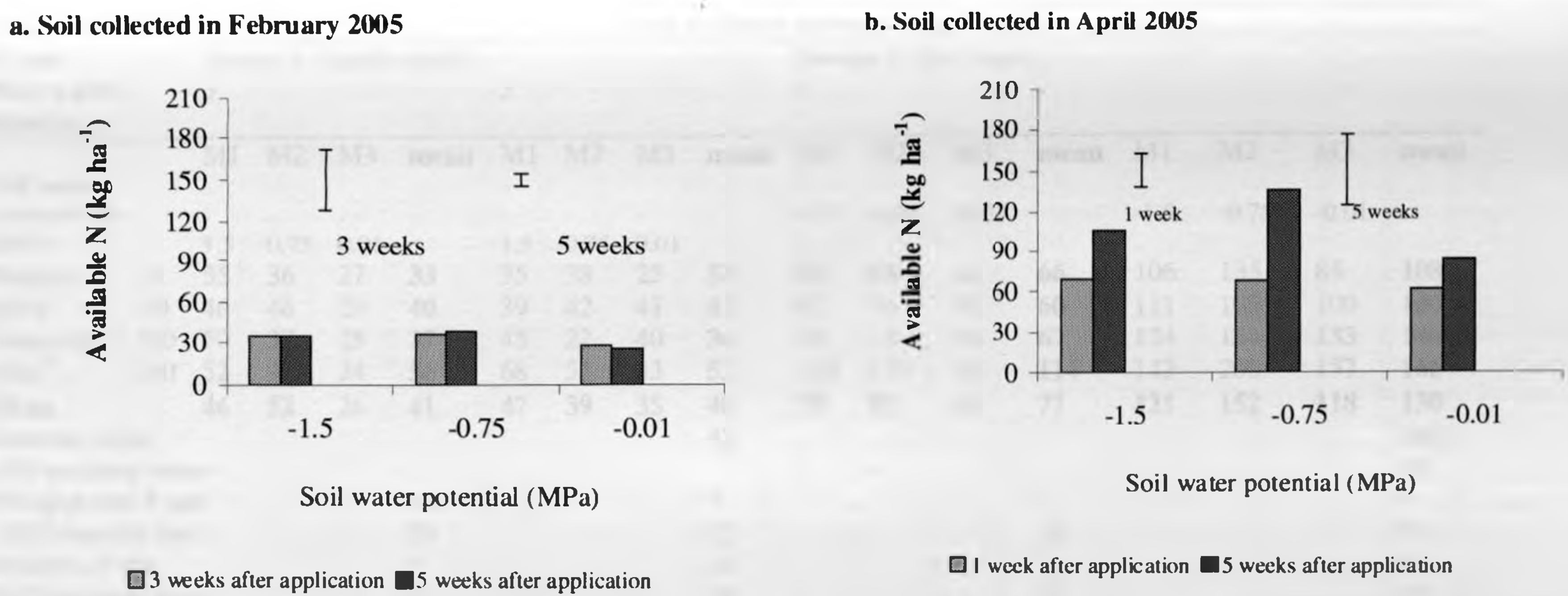


Figure 5.4 Effect of soil moisture level on available soil N of untreated soil collected from field experimental site at Mosocho, Kisii, southwest Kenya in February and April 2005. SED bars are shown.

Table 5.4. Effect of mucuna green manure application rate on available nitrogen under greenhouse conditions at Field station-Kabete, University of Nairobi (March-June, 2005)[♣]

Soil water and N rate		**Soil available nitrogen (kg N ha^{-1})**															
		Season 1 (March-April)								Season 2 (May-June)							
Weeks after planting		3				5				1				5			
		M1	M2	M3	**mean**	M1	M2	M3	**mean**	M1	M2	M3	**mean**	M1	M2	M3	**mean**
Soil water potential (ψ) (MPa)		-1.5	-0.75	-0.01		-1.5	-0.75	-0.01		-1.5	-0.75	-0.01		-1.5	-0.75	-0.01	
Mucuna	0	35	36	27	**33**	35	38	25	**33**	69	68	62	**66**	106	135	84	**108**
green	60	46	46	29	**40**	39	42	41	**41**	63	76	43	**60**	111	108	100	**106**
manure(kg	120	50	37	25	**37**	45	22	40	**36**	69	73	58	**67**	124	164	133	**140**
N ha^{-1})	240	52	91	24	**56**	68	55	33	**52**	110	150	83	**114**	142	200	157	**166**
Mean		**46**	**52**	**26**	**41**	**47**	**39**	**35**	**40**	**78**	**92**	**61**	**77**	**121**	**152**	**118**	**130**
Seasonal mean									**41**								**104**
LSD seasonal mean																	**12**
Nitrogen rate F test					Ns				*				*				*
LSD Nitrogen rate					24				12				26				31
Moisture F test					*				Ns				*				*
LSD moisture level					21				10				23				27
N rate x moist. F test					Ns				*				ns				ns
LSD N rate x moisture					42				20				46				55
%C.V Treatment					60				30				35				25

[♣]F=Fisher test; *=Differences significant, ns=Differences non-significant; LSD=Least significant difference; N source rates=30, 60,120 kg Nha^{-1}; M1 = Soil moisture at wilt point (-1.5 MPa), M2 = intermediate soil water content –0.75), M3 = Soil moisture at field capacity (-0.01 MPa); A = Nitrogen rate mean; Moist. = soil moisture level.

5.3.8 Relationship between plant N and available soil N

There was no well defined relationship between maize total plant N and soil available. Odhiambo (1989) observed lack of significant simple correlation between percentage total N in maize and available N in soil probably because the two processes are independent.

Regression between maize plant dry matter and available N was negative (Figure 5.5). The relationship is not direct *per se*, but is as a result on the negative effect of low soil water content on maize growth and nutrient uptake. High levels of nutrients reduce the soil water potential making it more difficult for plants to take water in moisture limited soils. This may explain the notion that fertilizers make soils dry especially in the semi arid areas.

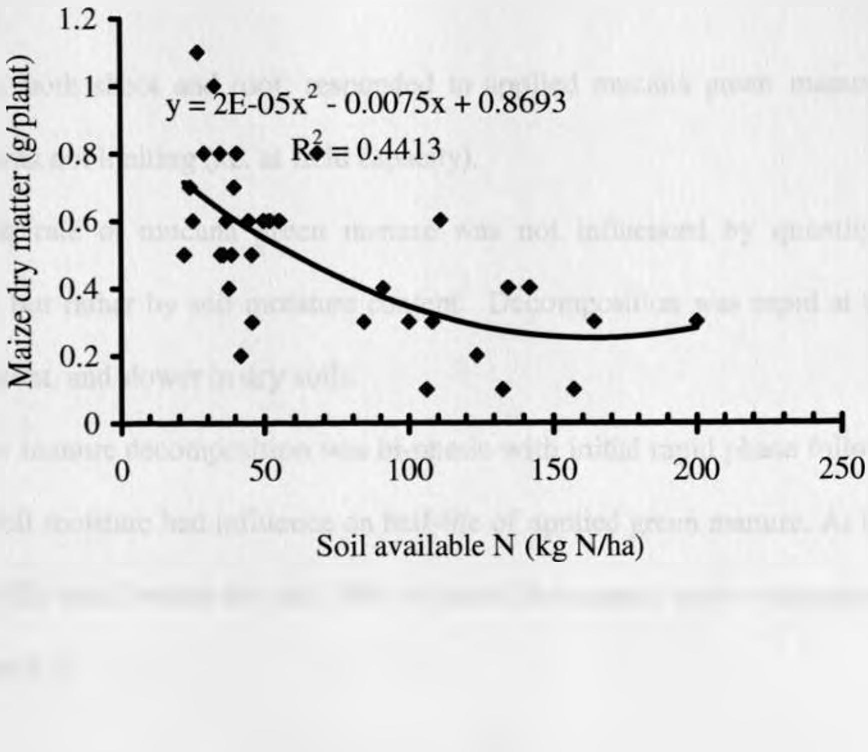


Figure 5.4. Maize plant dry matter response to soil available N under greenhouse conditions at the Kabete Field Station, University of Nairobi (March – June 2005).

Although the environmental conditions influence both plant growth and mineralization, the underlying processes are different. On average, soil mineralized N could supply most (> 69%) of the N for plant growth (Pilbeam and Warren, 1995) but lack of crop response is explained by the mismatch between soil mineral N supply and crop demand resulting in losses. Cropping systems that ensure presence of a crop in the field early in the season when mineralization is high i.e. permanent crop cover (pasture or tree crops) would optimize use of N mineralized. Additionally mixing crop residues with different decomposition rates to modulate N release rates would improve plant uptake of mineralized N from organic biomass.

5.4 Conclusions

1. Maize growth, both shoot and root, responded to applied mucuna green manure N when soil water was not limiting (i.e. at field capacity).

2. Decomposition rate of mucuna green manure was not influenced by quantity of biomass applied, but rather by soil moisture content. Decomposition was rapid at high soil moisture content, and slower in dry soils.

3. Mucuna green manure decomposition was bi-phasic with initial rapid phase followed by slower one. Soil moisture had influence on half-life of applied green manure. At field capacity the half-life was 2 weeks but only 50% or less of the organic matter decomposed in dry soil (Figure 5.3).

4. Mucuna application rate of 240 kg N ha^{-1} (equivalent to 12 t DM ha^{-1}) increased soil available N noticeably and consistently compared to lower rates.

CHAPTER SIX

ECONOMIC ANALYSIS OF MUCUNA GREEN MANURE APPLICATION IN MAIZE PRODUCTION

6.1 Introduction

One of the main goals in farming is increased income. Application of nitrogen in maize is one of the methods of increasing productivity and economic returns. Farmer's decision to apply fertilizer N to increase maize grain yield depends on accruing benefit. For this reason, the farmer will evaluate the effect of the substitute technology on yield in monetary terms, against own practice.

In Kenya, nitrogen is one of the most expensive inputs used in maize production because inorganic fertilizer used is imported and distribution costs are high. Production of inorganic fertilizer N is dependent on energy whose cost has been rising over time. Fertilizer is therefore unlikely to become cheaper in the future (Bowen *et al.*, 1988). This points to the need to identify alternative sources of N for sustained maize production, especially by smallholder farmers.

Studies carried out in the past, emphasized replacement of inorganic N fertilizers with organic sources such as compost and use of legumes. However, to our knowledge there are scanty investigations done on the role of legume biomass quantities produced, application rates involved and how these influence grain yield response and economics of mucuna N application in maize production.

The integration of soil improving legumes in maize production has been identified as an alternative source of N (Lathwell, 1990; Mureithi *et al.*, 2002). In Kenya, incorporation of its green manure in soil has been demonstrated to have capacity to improve maize yield in smallholder production systems (Maobe *et al.*, 1997c; Mureithi *et al.*, 1998).

Resource poverty among farmers is the main reason for adoption at sub-optimal level of soil fertility management interventions. Techniques that optimize the returns to scarce resources available to farmers and which rely on internally generated soil nutrient sources are likely to find ready acceptance. Hence, maize-legume rotations, intercrops or agro-forestry are important in this regard (Oluoch-Kosura *et al.*, 2001). Given farmers' poor access to inorganic fertilizers, a cropping system that makes optimal use of the available organic inputs and N-fixing abilities of legumes, while maintaining sufficient production of cereals that serve as staple food, could be the best option (Franke *et al.*, 2004).

Studies on profitability of using mucuna green manure as compared to inorganic fertilizer as N source are scanty. Yet there are opportunity costs incurred in the production of mucuna in form of land and labour used in its cultivation and incorporation into the soil. So, like inorganic fertilizer, legume based N has a cost that depends not only on agronomic need and economic return, but also, on its availability and risk associated with its production and use. Consequently, economic analysis of mucuna and inorganic N is essential so as to guide decision, on whether or not to promote it as an alternative maize production technology. Perrin (1976) defines good technology as the choice that the farmer would make if with all agronomic information available, adopt it and continue applying it.

The objective of this Chapter was to determine (1) the most profitable source of N for maize production, (2) its rate of application and, (3) available options for mucuna green manure and inorganic fertilizer N.

6.2 Materials and Methods

6.2.1 Treatments

Mucuna green manure and inorganic fertilizer N application rates evaluated and corresponding maize grain yield are presented in Table 6.1.

6.2.2 Costs[1] and prices

The costs listed below were considered for the various practices evaluated and values attached to each one of them are presented in Table 6.2.

Cost of mucuna seed ($ksh.kg^{-1}$)

Cost of mucuna green manure production ($ksh.kg^{-1}$ N)

Cost of harvesting mucuna green manure N ($ksh.ha^{-1}$)

Cost of plowing mucuna green manure into the soil ($ksh.ha^{-1}$)

Cost of inorganic fertilizer-urea (ksh kg^{-1} N)

Cost of renting land to produce mucuna (ksh. ha^{-1}) per cropping cycle (season)

Price of maize yield (ksh kg^{-1} grain).

[1] It would have been useful to measure and record the cost of applying inorganic fertilizer-urea, but under the on-farm situation studied, it was noted that family labour is used in application of fertilizer because the labour involved in negligible.

Table 6.1 Maize grain yield values used in economic computations for mucuna green manure and inorganic fertilizer-urea N, at Mosocho, Kisii, southwest Kenya (2002-04)*

Nitrogen source and application rate ($kg\ Nha^{-1}$)		Quantity of mucuna green manure ($t\ DMha^{-1}$)	**Maize grain yield ($kg\ ha^{-1}$)**				
			Short rain 2002	Long rain 2003	Short rain 2003	Long rain 2004	Short rain 2004
Control							
	0		1072	2072	987	1090	700
Mucuna	30	1.5	1300		985	1520	720
green	60	3	1143	3075	1515	2380	970
manure	120	6	1622	3955	2005	3550	1530
	240	12	1683	-	2076	3510	1480
	480	24	-	-	2355	4120	1290
Inorganic							
fertilizer-	30	0	1460	2827	1400	2410	680
urea	60	0	1550	3227	1420	2270	900
	120	0	1320	3592	1945	2070	470

* Maize yield was measured as grain dry matter.

Table 6.2 Estimated costs of mucuna N production, and inorganic fertilizer-urea at Mosocho, Kisii, southwest Kenya (2002-04) *

		Mucuna green manure and inorganic fertilizer application rate (kg ha^{-1})							
Item	Control	Mucuna green manure					Inorganic fertilizer-urea		
kg N ha^{-1}	0	30	60	120	240	480	30	60	120
Mucuna (t DM ha^{-1})	0	1.5	3	6	12	24	0	0	0
Land required (ha)	0	0.25	0.5	1	2	4	0	0	0
Variable costs (ksh.ha^{-1})									
Land preparation		525	1,050	2,100	4,200	8,400			
Mucuna seed		375	750	1,500	3,000	6,000			
Planting		500	1,000	2,000	4,000	8,000			
First weeding		500	1,000	2,000	4,000	8,000			
Mucuna green manure chopping		500	1,000	2,000	4,000	8,000			
Mucuna incorporation (Plowing)		600	1,200	2,400	4,800	9,600			
Inorganic fertilizer-urea cost							1,500	3,000	6,000
Total variable cost (ksh.)		3,000	6,000	12,000	24,000	48,000	1,500	3,000	6,000

* Price of maize grain =ksh. 20 kg^{-1} grain; Cost of urea fertilizer at village shop = ksh. 50 kg^{-1} N; Cost of urea at open-air market = ksh. 43 kg^{-1} N. Potential mucuna N accumulation per season (4 to 5 months) is 120 kg N ha^{-1} (6 t DM ha^{-1} of green manure); Mucuna tissue N = 1.6 %; Cost of mucuna seed is ksh.1, 500 ha^{-1} (ksh. 71.50 kg^{-1}); Mucuna seed rate = 42 kg ha^{-1}; Mucuna rates higher than 120 kg N ha^{-1}would entail use of more land and seed to produce it.

6.2.3 Economic analysis

This analysis determines the economic efficiency of resource use in a project. The project benefits and costs are evaluated at prices that reflect the relative scarcity of inputs and outputs (Anandajaysekeram *et al.*, 2004). Haisey and Mwangi (1996) describe partial budget analysis and value/cost ratio (VCR), as the most commonly used measures of profitability in application of fertilizer. In this study, the criteria used in evaluating returns to various treatments of mucuna green manure and inorganic fertilizer-urea N was marginal analysis. Partial budget was used to compute gross margins that were employed in carrying out dominance analysis, to identify treatments for marginal analyses.

6.2.3.1 Partial budget

Partial budgeting is a method of organizing experimental data and other information about the costs and benefits of various treatments, in such a way as to help make a particular management decision (Perrin *et al.*, 1976). In considering the expenses associated with this decision, only those costs, which are affected by the decision or variable costs, are of concern. Costs that are not affected by the decision or fixed costs are ignored for the purpose of the decision because they will be incurred regardless of which decision is made. The term "partial budgeting' is a reminder that not all production costs, and perhaps not all benefits are included in the budget-only those which are affected by the decision being considered (Perrin *et al.*, 1976).

The experimental data and costs attributed to different treatments were organized in such a way as to compute gross margins that would help in determining promising treatments from those evaluated, for marginal analysis (Table 6.3). Gross benefits were calculated as the product of maize grain yield and price. Storage of grain before selling is rare occurrence hence was excluded. Gross margin of treatment was computed as the difference between gross benefit and variable cost. Given that farmers will not necessarily choose the alternative technology with the highest average gross margin because of capital scarcity and associated risk, results of partial budget analysis were summarized in two forms: dominance arrangement and marginal rate of return. This analysis was used to identify and verify dominated treatments in order to describe treatments that take care of the farmer circumstance of capital scarcity, and need to avert risk associated with the gross margins.

Table 6.3 Net benefit of maize grain yield response to application of mucuna green manure and inorganic fertilizer-urea N, on a sandy clay soil, at Mosocho, Kisii, southwest Kenya (2002-04)*

	Nitrogen source								
	Control	Mucuna green manure					Inorganic fertilizer-urea		
Nitrogen rate (kg Nha^{-1})	0	30	60	120	240	480	30	60	120
Mucuna manure (t DM ha^{-1})	0	1.5	3	6	12	24	0	0	0
Item									
Gross benefits (ksh.)									
Short rains 2002	21,440	26,000	22,860	32,440	33,660	-	29,200	31,000	26,400
Long rains 2003	41,460	-	61,500	79,100	-	-	56,540	64,540	71,840
Short rains 2003	17,940	19,700	30,300	40,100	41,520	47,100	28,000	28,400	38,900
Long rains 2004	21,800	30,400	47,600	71,000	70,200	82,400	48,200	45,400	41,400
Short rains 2004	14,000	14,400	19,400	30,600	29,600	25,800	13,600	18,000	9,400
Mean	23,328	22,625	30,276	50,648	43,745	51,766	35,148	37,468	37,588
Total variable cost (ksh.)		3,000	6,000	12,000	24,000	48,000	1,500	3,000	6,000
Gross margin									
Short rains 2002	21,440	23,000	16,860	20,440	9,660	-	27,700	28,000	20,400
Long rains 2003	41,460	-	55,500	67,100	-	-	55,040	61,540	65,840
Short rains 2003	17,940	16,700	24,300	28,100	17,520	-900	26,500	25,400	32,900
Long rains 2004	21,800	27,400	41,600	59,000	46,200	34,400	46,700	42,400	35,400
Short rains 2004	14,000	11,400	13,400	18,600	5,600	-22,200	12,100	15,000	3,400
Mean	23,328	19,625	24,276	38,648	12,330	3,766	33,648	34,346	31,588

* Price of maize grain =ksh. 20 kg^{-1} grain; Cost of urea = ksh. 50 kg^{-1} N.

6.2.3.1.1 *Dominance analysis*

The treatments with the highest gross margins will not necessarily be chosen as the best alternatives because of the scarcity of capital in agriculture and due to risks that may be associated with the average gross margins from a given production (Perrin *et al.*, 1976). Dominance analysis was used to determine treatments that are consistent with both capital scarcity and risks. The analysis was done to identify non-dominated treatments, to use in marginal analysis. The procedure is based on understanding that, one treatment is said to dominate another when the first has higher gross margin and equal or lower variable cost compared to the second (Perrin *et al.*, 1976). In the analysis, treatment alternatives were arranged according to their gross margins in descending order. Those with higher gross margin at lower cost were identified as dominating those with the same gross margin levels but at higher variable cost. Under normal circumstances, no sensible farmer would choose dominated treatments for production. This is because it would mean unnecessary loss of capital since for each of these, there is another alternative with a higher gross margin and lower variable cost (Perrin *et al.*, 1976). This would negate the goal to increase income.

6.2.4 Marginal analysis

The increase in gross margin that can be obtained by changing from one production alternative to another is of considerable importance in making a decision to change technology. The purpose of marginal analysis is to reveal how the gross margins from an investment increase as the amount invested increases. The marginal rate of return (MRR) to a given increment in expenditure is the marginal gross margin divided by the marginal cost (increment in expenditure). This is calculated for non-dominated treatments only. The dominated treatment is one for which there is another alternative with a higher gross margin and lower variable cost (Perrin *et al.*, 1976). In this study, marginal rate of return (MRR) was computed to determine how the gross margin from investment in mucuna green manure and urea fertilizer N increased as the amount invested increased with the application rates. Opportunity cost is the sum of rate of return in the best alternative use of the investment capital and risk premium. Consequently, the marginal rate of return is an important component of opportunity cost for the investment capital. In selecting the appropriate treatment, some criteria were adopted from Perrin *et al.* (1976) and Gittinger (1972): The desirable treatment was considered to be that with a higher rate of return than opportunity rate of return. It is recommended that average returns over time should considerably be in excess of the direct cost of capital, because of risk aversion and scarcity of capital. As rule of thumb (Perrin *et al.*, 1976), a rate of return at least 20% per production season above the direct cost of capital is recommended. Where specific information is lacking on risk of alternatives, opportunity cost and the direct cost of capital, 40% rate of return to additional investment per cropping season is recommended (Anandajaysekeram *et al.*, 2004; Perrin *et al.*, 1976). However, it is notable that values as higher as 50 to 100% added to direct cost of investment capital will be appropriate in some cases, particularly for subsistence farmers in areas with high yield variability (Perrin *et al.*, 1976). A figure of 100% was adopted as minimum rate of return for mucuna green manure since it is a new technology. However, for comparison of urea fertilizer N rates a value of 50 % was applied as it is an existing technology, and therefore likely to have less risk. According to Shiluli *et al.* (2003) MRR of below 100 % is considered low and unacceptable as such a return would not offset the cost of capital and other related transaction costs while giving an attractive profit margin to serve as an incentive.

6.3 Results and Discussion

6.3.1 Dominance analysis

Inorganic fertilizer N dominated all mucuna green manure application rates during short rain season as shown in Table 6.4. For each of the mucuna green manure treatments, there was another alternative in inorganic fertilizer with a higher gross margin and lower variable cost. The dominance of fertilizer over mucuna in the short rain season is possibly because prevailing soil moisture during short rains was inadequate for its decomposition. The result indicates that application of green manure as N source for maize production in short rain is less economical than applying inorganic fertilizer N. With exception of 120 kg N ha^{-1}, all other mucuna application rates gave lower gross margins than the control (Table 6.4). The results further suggest that nitrogen availability interacts strongly with climatic conditions and that such relations affect maize response to its application. These results corroborate findings of Hikwa *et al.* (1989) in Zimbabwe. They found that crop response to fertilizer application varied from season to season and across sites due to low and uncertain rainfall coupled with soils of low plant-available water capacity.

Mucuna green manure rates of 240 and 480 kg N ha^{-1} were dominated treatments in all other planting seasons (Table 6.4).

Table 6.4 Dominance analysis of net benefits from maize grain yield response to application of mucuna green manure and urea fertilizer N, on a sandy clay soil, at Mosocho, Kisii, southwest Kenya (2002-04) ♣

Long and Short rains (mean) 5 seasons (SR 2002 to SR 2004)			
N source/ application rate (kg Nha^{-1})	Gross margin (ksh)	Variable Cost (ksh)	Dominated treatments (*)
Mucuna 120	38,648	12,000	
Urea 60	34,465	3,000	
Urea 30	33,608	1,500	
Urea 120	31,588	6,000	*
Mucuna 60	30,332	6,000	*
Control	23,328	0	
Mucuna 240	19,745	24,000	*
Mucuna 30	19,625	3,000	*
Mucuna 480	11,300	48,000	*

Long rains (mean) 2 seasons (LR 2003, LR2004)			
N source/ application rate (kg Nha^{-1})	Net benefit (ksh)	Variable Cost (ksh)	Dominated treatments (*)
Mucuna 120	63,050	12,000	
Urea 60	51,970	3,000	
Urea 30	50,870	1,500	
Urea 120	50,620	6,000	*
Mucuna 60	48,550	6,000	*
Mucuna 240	46,200	24,000	*
Mucuna 480	34,400	48,000	*
Control	31,630	0	
Mucuna 30	27,400	3,000	*

Short rains (mean) 3 seasons (SR 2002, 2003, 200			
N source/ application rate (kg Nha^{-1})	Gross margin (ksh)	Variable cost (ksh)	Dominat treatmen (*)
Urea 60	22,800	3,000	
Mucuna 120	22,340	12,000	*
Urea 30	22,100	1,500	
Urea 120	18,900	6,000	*
Mucuna 60	18,187	6,000	*
Control	17,793	0	
Mucuna 30	17,033	3,000	*
Mucuna 240	10,927	24,000	*
Mucuna 480	1,550	48,000	*

♣Price of maize grain =ksh. 20 kg^{-1} grain; Cost of urea fertilizer = ksh. 50 kg^{-1} N; Cost of mucuna green manure = ksh. 100 kg^{-1}

* Dominated treatments.

The result suggests that they might not be profitable practices for maize production in both long and short rains because they have higher variable costs than the control (Table 6.4).

In long rains, and on average for both long and short rains, the application of 120 kg N ha^{-1} equivalent of mucuna green manure gave non-dominated gross margins, (Table 6.4). This is the only mucuna green manure application rate that was non-dominated. Thus, applying 120 kg N ha^{-1} on maize has potential to increase gross margins in maize production. The reason for the superiority of this treatment lies in its gross benefits that were higher than those of urea N and comparable to those of higher levels of mucuna N at 240 kg ha^{-1} and 480 kg ha^{-1}. From the results, application of mucuna at the rate of 120 kg N ha^{-1} emerged as the only green manure treatment that could be compared with inorganic fertilizer N. Lower or higher application rates of the mucuna green manure are uneconomical, as accruing gross margins are inadequate for the investment capital involved.

Inorganic fertilizer showed non-dominated gross margins irrespective of N rate applied, in all seasons (Table 6.4). This was because of the low variable costs associated with inorganic N fertilizer compared to the organic source, mucuna. Consequently, even at low rate of 30 kg N ha^{-1} the fertilizer was found to be more economical to apply than mucuna. The above finding also applied to application of inorganic fertilizer at rate of 60 kg N ha^{-1}. Studies conducted elsewhere in Kenya support this finding. For instance, economic evaluation of organic manure technologies in maize and bean production in Vihiga district showed that application of inorganic fertilizer had a cost advantage over organic manure because less labour is involved because less labour is involved in the former (Kipsat, 2004). Results from the Vihiga study showed that application of agroforestry species biomass N namely Crotolaria in maize and bean production was more profitable than compost and farmyard manure with gross benefit of ksh.ha^{-1} 33,568, 6020, 4592, respectively (Kipsat, 2004).

6.3.2 Marginal analysis

The marginal rate of return (MRR) in maize production varied with season. This variation was attributed to similar changes in net benefits (Table 6.5). Hikwa *et al.* (1989) attribute seasonal changes in maize response to nitrogen application to variations in rainfall and low plant-available water capacity. Perrin *et al.* (1976) state that as a general rule farmers will not want to make an investment unless the average rate of return is at least 40% per crop season. Sometimes higher opportunity costs of additional investment capital ranging from 50% to 100% are used. Some authors suggest that the MRR for a new technology must be at least 30% higher than for the traditional technology before farmers will be willing to consider adopting it (Norman *et al.*, 1994). On average, for long and short rain seasons, the MRR for mucuna green manure applied at 120 kg N ha^{-1} was 47 % (Table 6.5). Consequently if 100% is assumed as the minimum rate of return then mucuna green manure application rate of 120 kg N ha^{-1} failed to pass the test as alternative N source worth investment in. However, in the long rains season alone, the MRR attributed to mucuna at the rate of 120 kg N ha^{-1} was higher at 123 % compared to 73 % for urea fertilizer used at 60 kg N ha^{-1}.

Table 6.5 Marginal analysis of maize grain yield response to application of mucuna green manure and urea fertilizer N, on a sandy clay soil, at Mosocho, Kisii, southwest Kenya (2002-04) *

	N source/application rate (kg N/ha)		Net benefit (NB) (ksh.)	Variable cost (ksh.)	Change from next highest benefit: Marginal increase in net benefit (ΔNB) (ksh.)	Marginal increase in variable cost (ΔVC) (ksh.)	Marginal rate of return (%) (ΔNB/ΔVC) * 100
Long and short rains (mean)	Mucuna	120	38,648	12,000	4,183	9,000	46
	Urea	60	34,465	3,000	857	1,500	57
	Urea	30	33,608	1,500	10,280	1,500	685
	Control	0	23,328	0			
Long rains (mean)	Mucuna	120	63,050	12,000	11,080	9,000	123
	Urea	60	51,970	3,000	1,100	1,500	73
	Urea	30	50,870	1,500	19,240	1,500	1283
	Control	0	31,630	0			
Short rains (mean)	Urea	60	22,800	3,000	700	1,500	47
	Urea	30	22,100	1,500	4,307	1,500	287
	Urea	0	17,793	0			

*Price of maize grain =ksh. 20 kg^{-1} grain; Cost of urea fertilizer = ksh. 50 kg^{-1} N; Cost of mucuna green manure = ksh. 100 kg^{-1} N

However, the MRR of 123% for mucuna applied at 120 kg N ha^{-1} was lower than 1283 % for inorganic fertilizer-urea applied at rate of 30 kg N ha^{-1} (Table 6.5). These results established that it is more profitable to apply mucuna green manure at 120 kg N ha^{-1} or urea N rate of 30 kg ha^{-1} than 60 kg N ha^{-1} of the inorganic fertilizer in long rain season. The reason for the difference was attributed to rainfall received in long rain season, which may have been adequate for mucuna decomposition, N uptake and hence higher maize grain yield. Key *et al.* (2006) found for example that plant available N from soils was most strongly influenced by rainfall. The MRR for fertilizer used at 60 kg N ha^{-1} was lower than that of 30 kg N ha^{-1} probably because of less variable cost in the latter treatment, despite similar gross margins. The implication of this finding is that application of mucuna green manure is still beneficial in long rains when applied at 120 kg N ha^{-1}. Applying mucuna green manure at that rate is profitable to farmers and equivalent to the use of inorganic N at 30 kg N ha^{-1}. However, the application of fertilizer at 60 kg N ha^{-1} with MRR of 73 % in long rains is still beneficial since its MRR surpasses 50% considered minimum for a traditional technology (Shiluli *et al.*, 2003).

Inorganic fertilizer applied at 30 kg N ha^{-1} had average marginal rate of return above 200 % in both long and short rain seasons (Table 6.5). This is due to its lower variable cost compared to its application at 60 kg N ha^{-1} with an average MRR of 47%. Mucuna green manure applied at 120 kg N ha^{-1} was dominated in the short rain season as a result of which it was not included in the MRR analysis. For short rains, application of mucuna green manure for maize production was ruled out because decomposition of applied biomass did not go past 50%, and therefore most of the N was not released for maize N uptake (Figure 6.3). It is likely that the efficiency of N applied is affected as well if the moisture is less by the time the N is released from green manure into the soil. These findings suggest that it is better to apply inorganic fertilizer at the rate of 30 kg N ha^{-1} than mucuna N at rate of 120 kg ha^{-1} in maize production because MRR is much higher (Table 6.5). However, the result may be so possibly because economic analysis may have over-emphasized risk judging unrealistically high premium for it. This extreme fear for loss of gross margin while pursuing higher ones might condemn production to that of low level because it is secure that way. That will deny the farmer opportunity to reap higher gross margins as it is evident in this study for mucuna rate of 120 kg N ha^{-1} compared to urea fertilizer at 30 kg N ha^{-1} during long rains (Table 6.4). The percentage of return at mucuna application rate of 120 kg N ha^{-1} might be still adequate in meeting the opportunity cost involved, depending on the minimum rate of return set. In this case for the farmer who can raise the investment required in long rain season, the application of mucuna instead of urea fertilizer for maize production is worthwhile. This is because of the accruing higher gross margin. The generally high rate of return associated with mucuna rather than urea fertilizer was attributed to improved productivity of the soil in the case of the former because of non-N benefits. Fischler (1996) and Demeke *et al.* (1997) noted that organic fertilizers in the form of green-manure crops, farmyard manure, compost and organic waste might supply the soil and crops with nutrients, and improve soil physical conditions giving better crop response than inorganic fertilizers.

6.4 Conclusions

1. The application of legume green manure from mucuna as N source for maize production is beneficial in long rains. However, it has to be developed at the rate of 120 kg N ha^{-1}. It is not profitable to apply in short rain season possibly because of inadequate soil moisture. This implies that mucuna cultivation can be done in short rains when opportunity cost for land is expected to be lower, and the green manure produced applied in long rains. Due to land constraint, suitable intercropping systems for maize with mucuna may have to be developed as means of producing substantial legume biomass.

2. The beneficial application rate of mucuna green manure is at 6 t DM ha^{-1} to supply 120 kg N ha^{-1} with MRR of 123%. In the absence of investment capital for mucuna production, inorganic fertilizer rate of 60 kg N ha^{-1} is profitable and can be used but with expectation of comparatively lower gross margin with MRR of 73%.

3. The marginal rate of return of 685% to 1283% for inorganic N application rate of 30 kg N ha^{-1} is very high irrespective of planting season, because of its low variable cost. However, urea applied at 30 kg N ha^{-1} has higher season-to-season grain yield variation compared to the fertilizer added at 60 kg N ha^{-1} and mucuna rate of 120 kg N ha^{-1}.

4. The best alternative N source and the rate to apply in maize production would vary with farmers' accessibility to investment capital and its opportunity cost. In the absence of required capital, inorganic fertilizer applied at 30 kg N ha^{-1} is the most beneficial and safest to apply in all seasons. Means to raise N use efficiency at low fertilizer application levels are required.

CHAPTER SEVEN

GENERAL DISCUSSION

7.1 Introduction

Nitrogen supply for maize production is a function of soil N supply. The N sources include N from the soil (N_S), N from the atmosphere (N_A) and externally applied fertilizer N (N_F). The latter (N_F) may be organic (NF_o) or inorganic (NF_i) and rate, time and method of application influences productivity. Inorganic N is readily available for crop uptake but costly. The availability of organic N based sources depends on factors that influence decomposition and mineralization. Some of the factors that influence the availability of N from organic source for plant uptake include soil pH, temperature, moisture and chemical composition of material. Organic N sources are cheap but the costs of production can be very high.

The crop response to applied N_F depends on synchronization of N supply and crop N demand. The latter is governed by factors that influence growth. Whereas chemical composition of N sources can be controlled to synchronize N release with plant demand, climatic factors cannot be changed and so have to be taken into account when planning management measures (Dahlin *et al.*, 2005).

Legumes can play a major role in improving farm productivity in smallholder agriculture as short-term fallow species. Green manure legumes can increase plant nutrient supply in soil (especially nitrogen) and can improve soil physical properties, thereby improving crop yields. Legumes also cover the ground, thereby minimizing soil erosion (Mureithi *et* *al.*, 2004). In addition, grain legumes are important as a human food source as they are rich in protein, while herbaceous and tree legumes are important livestock feeds (Mureithi *et al.*, 2004).

Legume green manure and cover crop species (GMCC) produce variable quantities of green manure biomass because of varying (a) agro-ecological environmental factors, such as soil moisture and temperature, which are likely to influence plant growth, (b) soil nutrient status due to land use history, (c) cropping system in which the species is grown, (d) niche, species type, and plant age at time when the green manure is harvested and applied (Maobe *et al.*, 1997a; Mureithi *et al.*, 1998; Burle *et al.*, 1992).

Green legume cover crops that produce quantities of biomass may play an important role in small holder subsistence production systems where little or no external fertilizer are applied especially to maize, a major food crop in southern and eastern Africa, whose productivity is greatly constrained by N. The quantity of legume biomass produced and applied may influence maize yield in the season it is applied and may have residual effect and thus minimize NF_i requirement in a subsequent season.

Farmers would be expected to adopt mucuna as NF_o source if it is economically competitive with existing alternatives. For that reason, economic comparison of using mucuna green manure and inorganic fertilizer N for maize production is essential. Mucuna was used as NF_o source in maize because it produces large quantities of biomass, has high quality green manure biomass.

7.2 Maize growth, total nitrogen and grain yield response to mucuna N

Maize total dry matter, N uptake and grain yield responded significantly to rate of mucuna biomass N applied among seasons (Chapter Three). Mucuna green manure application rate of 30 kg N ha^{-1} failed to show notable effect on maize TDM, total N and grain yield. Perhaps N supply from 30 kg N ha^{-1} quantity failed to trigger positive priming effect (Kuzyakova *et al.*, 2000). Priming effect accelerates or retards mineralization of soil organic matter after addition of substrates to the soil (Hammer and Marschner, 2004). The activation of microorganisms through supply of easily available substrates is considered to be the main reason for positive priming effect in soil releasing mainly C, N, P and S (Kuzyakova *et al.*, 2000). The finding is significant given that 30 kg N ha^{-1} equivalent to 1.5 t DM ha^{-1} of mucuna is within the range of the commonly attained biomass level in maize-mucuna intercrop systems, and low soil moisture areas. Therefore, N supply from 30 kg N ha^{-1} equivalent of green manure may be inadequate for maize production improvement.

Mucuna rate of 60 kg N ha^{-1} corresponding to 3 t DM ha^{-1} green manure improved maize growth but not consistently in short rains, suggesting that it may be inadequate. Therefore, biomass productivity and N level accumulated has considerable bearing on potential of the legume to improve maize production. Mucuna applied at 120 kg N ha^{-1} equivalent to 6 t DM ha^{-1} of the green manure made significant increase in maize TDM, total nitrogen and grain yield, in all seasons. For that reason, 120 kg N ha^{-1} may be the requisite level of biomass N application for maize production improvement, probably because it is sufficient for positive priming effect (Kuzyakova *et al.*, 2000). Unpredictable maize response to mucuna application is probably because of this reason.

Application of biomass less than 120 kg N ha^{-1} could possibly require supplementation in combination with inorganic N, for significant and consistent maize yield increase.

Since the amount of N supplied from mucuna for maize depends on the growth of the legume it is important to consider other non-legume N sources and develop integrated nutrient management strategy with the available resources, to optimize maize productivity. These may include legume management systems that increase biomass productivity and also efficient utilization of accruing N by the target crop. Potential alternatives may include inter and /or relay cropping systems that raise adequate biomass, without depressing maize yields and with additional management benefits like weed control.

Mucuna rotations of 4 to 5 months, which generate high biomass output, should be tried to rehabilitate the badly degraded parts of farmland. In striga-infested areas where productivity is low and opportunity cost for alternative crops may be low, mucuna rotation could be useful in raising adequate biomass; only that initial labour cost may be high. In high potential areas where opportunity cost for land is high, innovative ways to produce adequate legume N should be devised. For example, under sowing in tree crops to minimize weed control costs and as fodder supplement. Application of mucuna in excess of 120 kg N ha^{-1} at 240 and 480 kg N ha^{-1} equivalent to 12 and 24 t DM ha^{-1} of green manure, respectively, did not make further considerable increase in maize growth, total N and grain yield. Hence, biomass produced in excess of 120 kg N ha^{-1} is available and recommended for use elsewhere, i.e. as animal bedding, mulch or fodder.

Mucuna has low C:N ratio, polyphenol and lignin contents and mineralized fairly rapidly (over 75% of the biomass within two weeks after application) resulting in non significant residual effect (Chapters Four and Five). Varying the time and methods of application may synchronize mucuna N supply and maize demand. The legume biomass may be mixed with comparatively low quality biomass like maize stover or even other legumes with higher C:N ratio to slow down decomposition and mineralization, and to synchronize with maize N uptake and build residual N effect (Scivittaro *et al.*, 2004).

Rainfall is the major source of soil water for crop production. Soil water influences crop growth, nitrogen mineralization and uptake by crop. The seasonal maize total dry matter and grain yield was analyzed in relation to seasonal rainfall (Chapter Three). The variation in amount of seasonal rainfall explained only 21% of the variability in maize total dry matter (TDM) and 74% grain in the season fertilizer N was applied and 96% in grain in residual N trials (Figure 7.1). This suggested that factors other than total seasonal rainfall had substantial influence on maize growth. The factors are such as the on-set of rainfall during the season, planting date, and distribution of rain (Figure 3.1 and Chapter Three). This indicates that maize growth response to applied N prediction based on total rainfall can be complicated by these factors.

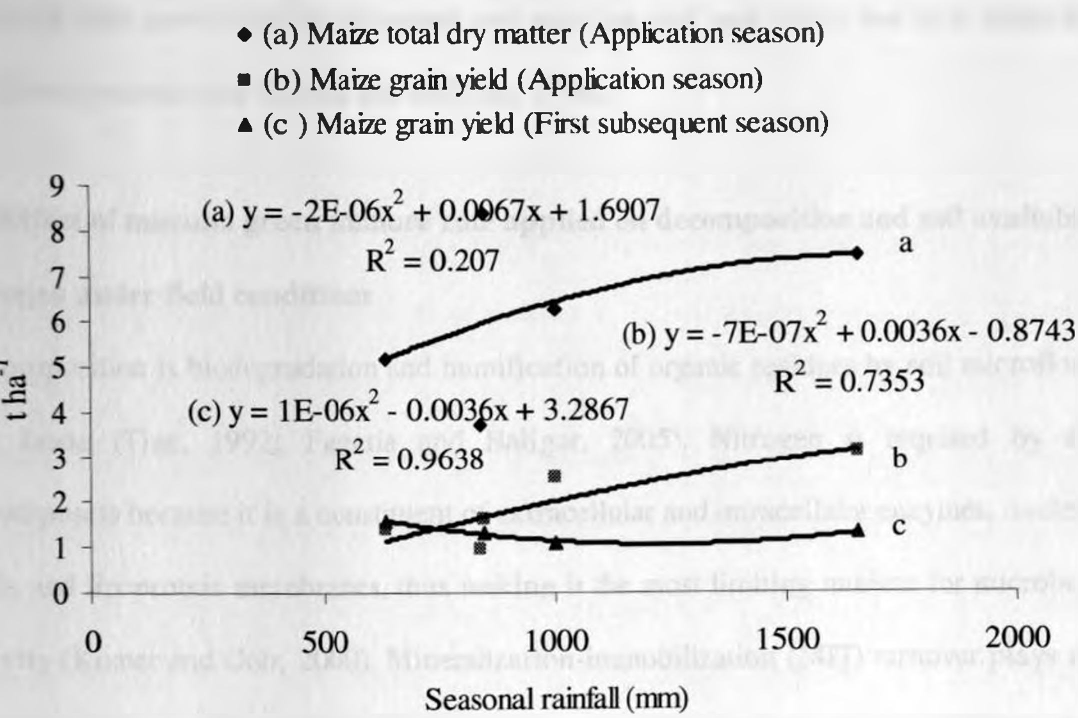


Figure 7.1 Seasonal maize total dry matter and grain yield response to rainfall

Soil moisture above 50% of the field water capacity in the rooting depth is vital throughout the growing season, to maximize yields, although this not always the case (Shaxson and Barber, 2003). Adequate moisture at anthesis is essential to have a full set of kernels on the ear at harvest (Aldrich *et al.*, 1975). Maize is relatively insensitive to water stress imposed during early vegetative growth stages because water demand is relatively low and plants can adapt to water stress to reduce the impact of subsequent periods of the same. However, maize grain yield is sensitive to water stress from just before silking through grain fill, with the greatest degree of sensitivity between tasseling and just after silking (O'Neill *et al.*, 2004). Nitrogen stress as is likely to occur in drought period when N uptake is low reduces kernel number and ultimately grain yield by delaying plant growth and development and reducing leaf area index, leaf area duration, and photosynthetic rate (Eastin and Sullivan, 1984).

7.3 Effect of mucuna green manure rate applied on decomposition and soil available nitrogen under field conditions

Decomposition is biodegradation and humification of organic residues by soil microflora and fauna (Tian, 1992; Fageria and Baligar, 2005). Nitrogen is required by all decomposers because it is a constituent of extracellular and intracellular enzymes, nucleic acids and lipoprotein membranes, thus making it the most limiting nutrient for microbial activity (Kumar and Goh, 2000). Mineralization-immobilization (MIT) turnover plays an important role in soil available N for crop uptake. The environmental conditions and chemical composition of decomposition influence nutrient availability.

Mucuna biomass decomposition was bi-phasic, with an initial rapid phase and a slower second one, depicting exponential decay process, regardless of applied quantity of NF_0 (Chapters Four and Five). The length of the initial rapid phase is two weeks and the second slow phase may last up to eight weeks with insignificant change in the % remaining biomass over time. The similarity in decomposition pattern amongst the various quantities of mucuna biomass applied suggested that chemical characteristics rather than quantity prevailed in its determination (Woomer *et al.*, 1994). Between 40 to 90 % of the applied mucuna decomposed in the rapid phase by the end of one week after application with the remaining material stabilizing at about 25% thereafter to end of season (Chapters Four and Five).

Prevailing soil moisture conditions at on-set of season that may be at field capacity most of the time probably accelerates the initial phase. For that reason, proper utilization of the released N may require either delayed application i.e. 2 or 3 weeks after maize emergence to ensure that the crop initially takes up N from the soil (Ns) and that mucuna N is available when maize has large enough root system i.e. at 4 to 5 weeks after emergence, to take up mucuna N. Other potential management strategies may include mixing the mucuna with material having high C:N ratio such as maize stover or legume species *Crotalaria juncea* L., and possibly Sesbania (*Sesbania rostrata*), to slow down decomposition, mineralization and reduce loss through leaching of N.

During application season, in field conditions planted with maize, mucuna applied at rates of 30, 60 and 120 kg N ha^{-1} had non-significant effect on soil available N (SAN). Application rates of 240 kg N ha^{-1} or 480 kg N ha^{-1} increased the available N noticeably (Chapters Four and Five). An increase in soil available N may not necessarily translate into increased crop yield because the N may be leached beyond the rooting zone or volatilize.

At conventional mucuna application rates of 60 to 240 kg N ha^{-1} equivalent to 0.3 to 12 t DM ha^{-1} green manure, residual benefit in maize was unexpected. Application of inorganic N had non-significant effect on SAN in first subsequent season. These findings confirmed lack of residual N effect. Hence, chemical characteristics of legume biomass rather than quantity applied might be the major determinant of residual effect. Residual benefit reported in some past work failed to separate rotational effects of herbaceous legume and that of maize stover incorporated alongside, leading to impression that there was gain. Thus, N benefit of mucuna and inorganic fertilizer is confined within season of application.

7.4 Potential effect of mucuna green manure quantity applied on maize growth, decomposition and available nitrogen under varying soil moisture conditions

Maize growth response to different application rates of mucuna green manure and variations in soil moisture levels was evident from 8 weeks after incorporation and planting (Chapter Five). This is possibly because maize water requirement at earlier growth stage is low as the plant is small, with roots still developing (O'Sullivan, 2006; Pioneer, 2006). Potted studies to monitor maize response to soil moisture level should target periods longer than 8 weeks. Maize response to application of mucuna green manure N was significant only at intermediate and field capacity soil moisture contents (Chapter Five). So, good supply of soil moisture is necessary possibly for decomposition and mineralization of mucuna biomass and subsequent maize N uptake. The processes are apparently slowed under soil water supply (Sarrantonio, 1991; Aldrich *et al.*, 1975). This demonstrates effects of rainfall fluctuations on available N attributed to different application rates of legume biomass, and maize response.

Maize dry matter and root length increased with soil moisture level (Chapter Five). They were significantly highest at field capacity and lowest at wilting point. Improved soil moisture enhanced maize dry matter accumulation and N uptake because of an extensive rooting system (Aldrich *et al.*, 1975). This possibly further explains the variability in maize growth and yield from season-to-season with changes in rainfall amounts and distribution.

Mucuna green manure application rate had non-significant effect on decomposition pattern of soil in pots under greenhouse conditions but soil moisture did (Chapter Five). Decomposition rate was higher at field capacity than at wilting point and intermediate soil moisture levels. The quantity of mucuna biomass applied did not probably alter N release pattern but the soil water content did. At field capacity, at least 50 % of the applied material decomposed by the end of first week after incorporation but it took no less than 5 weeks for 50 % of the applied mucuna to decompose at ψ = -075 and -1.5 MPa. This indicates that low soil moisture under field conditions would be expected to limit decomposition and mineralization. Residual N effects of biomass would be expected in areas where soil moisture is low because water limited mineralization and plant N uptake.

7.5 Economic analysis of mucuna green manure as compared to inorganic fertilizer nitrogen application in maize production.

The profitability of mucuna as fertility enhancing technology is expected to influence its adoption. Farmers' decision would depend on accruing benefit of the substituting new technology with own practice. Of the mucuna application rate alternatives, only application rate of 120 kg N ha^{-1} was non-dominated (Chapter Six). Hence, profitability of legume based N for maize production depends on quantity of biomass applied as different levels would have varied maize yield responses and associated costs. Also, that the technology would be applicable and beneficial where alternative use for labour and land are not highly priced. High land cost for green manure N production could be overcome by provision of multiple services for mucuna compared to inorganic fertilizer (Cherr *et al.*, 2006): Mucuna seed can be sold so as to increase the benefit: cost ratio (Vissoh *et al.*, 1998; Manyong *et al.*, 1990). Alternative uses can be developed for mucuna seed, such as human consumption and possibly livestock feed (Manyong *et al.*, 1990).

Mucuna N production could be done in maize-legume rotations, using abandoned degraded section of farmland that requires rehabilitation. Novel intercropping systems that substantially raise mucuna biomass production without depressing maize grain yields and requiring extra land for its production could be used where available. Alternative labour saving technologies such as surface mulch application of the biomass may be tested depending on maize yield response. Application of inorganic fertilizer at 120 kg N ha^{-1} was dominated alternative so consequently it was dropped (Chapter Six). Marginal analysis for the non-dominated alternatives confirmed that mucuna rate of 120 kg N ha^{-1} was more beneficial compared to inorganic fertilizer at 60 kg N ha^{-1} only if used in long rains. But, the choice amongst the two would depend on investment required by alternative, availability and opportunity cost. The application of mucuna N in short rains was ruled out in dominance analysis, raising doubt on suitability of the technology under low soil moisture environments (Chapter Six). For that reason, mucuna production for N would be done in short rains so that it is available for application in long rain seasons. Although, application of inorganic fertilizer at 30 kg N ha^{-1} showed very high marginal rate of return because of low variable cost, its net benefit in long rains was lower than that from mucuna rate of 120 kg N ha^{-1}.

The best alternative N source and rate to use would vary with farmer's accessibility to investment capital and its opportunity cost. In the absence of the required capital, inorganic fertilizer applied at 30 kg N ha^{-1} is the most beneficial and safest in all seasons, but the income would be low. But if the required capital can be raised then mucuna rate of 120 kg N ha^{-1} is the most beneficial in long rains. In long rain season, poor resource farmer might find inorganic fertilizer rate of 30 kg N ha^{-1} most attractive option because of low variable cost at ksh. 1,500 compared to ksh. 3,000 for its application at 60 kg N ha^{-1}, but with marginal rate of return of 1283% and 73%, respectively. Comparatively, application of mucuna at 120 kg N ha^{-1} with a variable cost of ksh. 12,000 and marginal rate of return (MRR) of 123% would appeal to a farmer who has access to investment capital at low opportunity cost. The MRR for inorganic fertilizer at 30 kg N ha^{-1} is high possibly not only due to low variable cost, but because 50 to 80% of N uptake is from soil reservoir (Fageria and Baligar, 2005). Also, because selling of maize grain in the study area is done in periods of extreme shortage of the product in the market, when prices are very high. The finding on high MRR for inorganic fertilizer at 30 kg N ha^{-1} is possibly the reason why half of the recommended inorganic fertilizer rate (30 kg N ha^{-1})

is popular in Kenyan smallholder maize production. As a result, the need is urgent to search for ways to minimize legume based N cost, to make it a more viable option. One way is to possibly apply legume biomass without chopping into pieces and as mulch on soil surface, but the mechanics of field operations such as planting and first weeding would be difficult. Also, applying mucuna combined with inorganic fertilizer N may possibly lower mucuna biomass quantity requirement thus lowering its N cost.

Overall, there is no difference between mucuna and urea as N sources for maize. They both do not have residual benefit regardless of rate applied and are also readily available for uptake. Maize yield response to applied fertilizer was primarily influenced by soil moisture, which is dependent on rainfall because it influences both soil N supply and demand processes. The highest response occurred in long rain seasons when total rainfall is higher and rain falls for longer. The rapid rate of mucuna decomposition may require to be modulated to optimize uptake by maize.

7.6 The way forward

1. Identification of herbaceous legume species that produce higher quantity and quality of biomass than mucuna, accumulating more N, and which are adapted to local agro-ecological conditions.

2. Multiple services of mucuna need to be investigated beyond the residual effect studied, to make the N source economically competitive to chemical inputs. Mucuna role in pest, weed control, food and feed if any, needs to be quantified. In striga-infested soils, mucuna N production cost is likely to be minimized, as land productivity is low.

3. Identification of crop production systems that enhance complementarity between mucuna and the crop would enhance adoption of mucuna as a green manure cover crop for soil- fertility improvement through increased N supply.

4. Other techniques that might reduce mucuna N production and management costs, such as conservation tillage, need to be assessed to establish strategies that enhance adoption. The methods should also optimize mucuna N supply and demand for crop production.

5. Production of food legumes, especially species where N harvest index is low such as pigeon pea to produce biomass for soil-improvement, is still an open option. Such multiple service sources of N should have a high benefit: cost ratio to stimulate their adoption.

6. In the absence of inorganic fertilizer N that is cheaper and affordable by smallholder community, alternative options are clearly limited. There is need to devise ways to produce substantial legume biomass quantities, as way of increasing N supply. Applying mucuna green manure combined with inorganic fertilizer may possibly lower biomass quantity requirement thus reducing mucuna N cost.

REFERENCES

Abifarin, A. O. 1984. A dictionary of commonly used terms in crop improvement with particular reference to rice. International Institute of Tropical Agriculture (IITA), Nigeria. p. 108.

Agarwal, A. S., Singh, B. R. and Kanehiro, Y. 1971. Nitrogen and carbon mineralization as affected by the drying and rewetting cycles. *Plant and Soil 35*: 454-457.

AHI. 2000. Legume cover crops for soil fertility improvement in eastern Africa region. African highlands initiative (AHI), Technical note series number 11, 24 p.

Aldrich, S. R., Scott, W. O and Leng, E. R. 1975. Modern corn production. A & L publications, USA. 377 p.

Al-Khafaf, S. and Hanks, R. J. 1974. Evaluation of the filter paper method for estimating soil water potential. *Soil Science 117 (4)*: 194-199.

Allan, A. Y. 1971. The influence of agronomic factors on maize yields in Kenya with special reference to time of planting. PhD Dissertation, University of East Africa.

Anandajaysekeram, P., van Rooyen, C. J., Liebenberg, F. 2004. Agricultural project planning and analysis, Intenational Food Policy Research Institute (IFPRI), pp. 390-393.

Ambrosano, E. J., Trivelin, E.C.O, Cantarella, H., Cantarella, G. M. B. Muraoka, T. 2003. Nitrogen mineralization in soils amended with sunnhemp, velvet bean and common bean residues. *Scientia Agricola 60 (1)*, Piracicaba Jan./Mar.

Anderson, J. M. and Ingram, J.S.I. 1993. Tropical soil biology and fertility: A handbook of methods. C.A.B. International. 221 p.

Anonymous 2001. Plant tissue analysis procedures National Agricultural Research Laboratories (NARL), Nairobi.

Ariga, J., Jyne, T. S. and Nyoro, J. 2006a. Factors driving the growth in fertilizer consumption in Kenya 1990-2006: Can the momentum be sustained? Tegemeo Agricultural policy conference, May 18th 2006, Safari park hotel, Nairobi. 22p.

Ariga, J., Jyne, T. S. 2006b. Can the market deliver: Lessons from Kenya's rising use of fertilizer following liberalization: Policy brief, Number 7. Tegemeo Institute for Agricultural development and policy. 4 p.

Balasubramanian, V., Nadi, L. A. and Mokwunye, A. U. (1978). Fertilizing sole crop maize for high yields. Samaru miscellaneous paper number 76, Occasional Publication, Institute for Agricultural Research, Ahmadu Bello University, Samaru, Zaria, Nigeria.

Beckie, H. J. and Brandt, S. A. 1997. Nitrogen contribution of field pea in annual cropping systems. I. Nitrogen residual effect. *Canadian Journal of Plant Science 77. 311-322.*

Below, F. E., Brandau, P. S. and Yockey, J. A. 1996. Sources and forms of nitrogen for optimum corn production. Illinois fertilizer conference proceedings January 29-31, 5 p.

Birch, H. F. 1958. The effect of soil drying on humus decomposition and nitrogen availability. *Plant and Soil X (1)*: 9-31.

Birch, H. F. 1960. Nitrification in soils after different periods of dryness. *Plant and soil 12*: 81-96.

Birch, H. F. 1964. Mineralization of plant nitrogen following alternate wet and dry conditions. *Plant and Soil 20*:43-49.

Bogale, T., Assenga, R. H., Mmbaga, T.E., Friesen, D. K, Kikafunda, J. and Ransom, J. K. 2001. Legume fallows for maize-based systems in eastern Africa: contributions of legumes to enhanced maize productivity and reduced nitrogen requirements. In: Seventh eastern and southern Africa regional maize conference, 11th-15th February 2001. pp. 324-329.

Bowen, W. T., Quintana, J.O., Pereira, J., Bouldin, D. R., Reid, W. S. and Lathwell, J.J. 1988. Screening legume green manures as nitrogen sources to succeeding non-legume crops: The fallow soil method. *Plant and Soil 3:* 75-80.

Brady, N. C. 1974. The nature and properties of soils. 8th edition. Macmillan publishing co., Inc., USA. 635 p.

Brown, R. H. 1984. Growth of the green plant. In: Tesar, M. B. (ed.) Physiological basis of crop growth and development. American society of Agronomy, Crop science society of America, Madson, Wisconsin. pp. 153-174.

Buckles, D., Triomphe, B and Sain, G. 1998. Cover crops in Hillside agriculture: Farmer innovation with Mucuna. International Development Research Centre (IDRC)

Ottawa, Canada and International Maize and Wheat Improvement Centre (CIMMYT) Mexico DF, Mexico. 218 p.

Burle, M. L.. 1992. Legume green manures: Dry-season survival and the effect on succeeding maize crops. Soil management collaborative support programme Bulletin Number 92-04. North Carolina State University, Raleigh.USA. 35 p.

Cabrera, M. L., Kissel, D. E., Vigil, M. F. 2005. Nitrogen mineralization from Organic Residues. *Journal of environmental Quality 34*:75-79.

Cadish. G., Giller, K.E., 1997. Driven by nature: Plant litter quality and decomposition. CAB int., Wallingford, U.K.

Carsky, R. J., Becker, M. and Hauser, S. 2001. Mucuna cover crop fallow systems: Potential and limitations. Soil Science Society of America (SSSA), Special publication number 58, pp. 111-135.

Carsky, R. J., Oyewole, B. and Tian, G. 1999. Integrated soil management for the savanna zone of W. Africa: Legume rotation and fertilizer nitrogen. *Nutrient cycling in agro ecosystems 00*:1-11

Cavelier, J., Tanner, E. and Santamaria, J. 2000. Effect of water, temperature and fertilizers on soil nitrogen net transformations and tree growth in an elfin cloud forest of Colombia. *Journal of Tropical Ecology 16*: 83-99.

CIMMYT, 1998 and KARI, 1998. Maize technology development and transfer: A GIS application for research planning in Kenya, ed. Hasssan, R. M. International maize and wheat improvement center (CIMMYT) and Kenya Agricultural Research Institute (KARI). Cambridge, U.K. 230 p.

Chae, Y. M. and Tabatabai, M. A. 1986. Mineralization of nitrogen in soils amended with organic wastes. *Journal of environmental Quality 15 (2)*: 193-197.

Cherr, C. M., Scholberg, J. M. S. and McSorley, R. 2006. Green manure approaches to crop production: A synthesis. *Journal of agronomy 98*:302-319.

Clement, A., Ladha, J.K. and Chalifour, F.P. 1998. Nitrogen dynamics of various manure species and relationship to lowland rice production. *Agronomy Journal 90:* 149-154

Constantinides, M. and Fownes, J. H. 1993. Nitrogen mineralization patterns of leaf-twig mixtures from tropical leguminous trees. *Agroforestry systems 24:* 223- 231.

Crawford, E. W., Jayne, T. S., and Kelly, V. A. 2005. Alternative approaches for promoting fertilizer use in Africa with particular reference to role of subsidies. Department of agricultural economics, Michigan State University. 65 p.

Costa, F. J. S. A., Bouldin, D. R. and Suhet, A. R. 1990. Evaluation of nitrogen recovery from mucuna placed on the surface or incorporated in a Brazilian oxisol. *Plant and Soil 124*:91-96.

Cruz, S.1996. Soil Master Plan. Souza Cruz research / development centre, Brazil.40 p.

Dahlin, S., Holger, K., Thomas, K., Sophie, G., and Lars, B., 2005. Possibilities for improving nitrogen use from organic materials in agricultural cropping systems. *Ambio 34 (4):* 288-295.

Deckers, J. 1993. Soil fertility and environmental problems in different ecological zones of developing countries in sub-saharan Africa. *In*: van Reuler, H and Prins, W. H. (eds.) The role of plant nutrients for sustainable food crop production in sub-saharan Africa. Dutch Association of Fertilizer Producers, Netherlands pp 37 - 52.

De Groote, H., Owour, G., Doss, C., Ouma, J., Muhammad, L. and Danda, K.2005. The maize green revolution in Kenya revisited. *e-journal of agricultural and development economics 2(1):* 32-49.

Delve, R. and Bashir, J. 2002. Developing organic resource management options with farmers in eastern Uganda. In: 17[th] WCSS, 14-21 August 2002, Thailand. pp. 1173 (1) – 1173 (7).

Demeke, M., Said, A. and Jayne, T. S. 1997. Promoting fertilizer use in Ethiopia: The implications of improving grain market performance, input market efficiency, and farm management. Working Paper 5. Grain market research project. Ministry of economic development cooperation, Addis Ababa, Ethiopia. 45 pp.

Derek, B., Collinson, M., *et al.* 1980. Planning technologies appropriate to farmers: Concepts and procedures, CIMMYT, Mexico, 1980. 71 p.

Dorich, R. A. and D. W. Nelson, 1984. Evaluation of manual cadmium reduction methods for determination of nitrate in potassium chloride extracts of soil. *Soil Science Society of America Journal 48*:72-75.

Drechsel, P., Steiner, K. G. and Hagedorn, F. 1996. A review on potential of improved fallows and green manure in Rwanda. *Agroforestry systems 33(2)*: 109-106.

Dahlin, S., Holger, K., Thomas, K., Sophie, G., and Lars, B., 2005. Possibilities for improving nitrogen use from organic materials in agricultural cropping systems. Ambio 34 (4): 288-295.

Dyck, E and Maobe, S.N. 1996. Improved soil productivity through incorporation of legumes into Kenyan smallholder farming systems. 8 p. In: Proceedings of the Soil Science Society of East Africa (SSSEA) conference held on 19th to 23rd August 1996 at Nanyuki, Kenya.

Dyck, E., Maobe, S.N., Onyango, S.N., Mwangi, T and Kirungu, B. 1997. Legumes in every farm: Strategies for adoption of soil-improving legumes by Smallholders in Kenya. In: Proceedings of the International Workshop on green manure cover crop systems for smallholders in tropical and sub-tropical regions held on 6th to12th April, 1997 at Santa Catarina, Brazil 8 p.

Eastin, J. D. and Sullivan, C. Y. 1984. Environmental stress influences on plant persistence, physiology, and production. In: Tesser, M. B. (ed.) Physiological basis of crop growth and development, American Society of Agronomy, Crop Science of America, Madison, Wisconsin, U.S.A. pp. 201-233.

Eilitta, M. 1997. Agronomic monitoring and on-farm experiments to assess green manure cover crops systems: The case of a maize-mucuna system in South Veracruz, Mexico, South America. Paper presented at the International workshop on Green manure cover crops system for smallholders in Tropical and sub-tropical region on 6th to 12th April, 1997 at Chepaco, Santa Catarina, Brazil.12 p.

El-Lakany. M. A. and Russel,, W. A. 1971. Relationship of maize characters with yield in test crosses of inbreds at different plant densities. *Crop science 11*:698-701.

FAO, 1977. Assessing soil degradation. Bulletin No. 34, FAO, Rome.

Fageria, N. K. and Baligar, V. C. 2005. Enhancing nitrogen use efficiency in crop plants. *Advances in Agronomy, Volume 88*, pp. 97-159.

Farshad, A and Zinck, J. A. 1993. Seeking agricultural sustainability. *Agriculture, ecosystems and environment 47*:1-12.

Fayez, R. 2004. Soil properties and nitrogen application effects on microbial activities in two winter wheat cropping systems. *Biology and fertility of soils (40)2*: 88-92.

Ferrera, L., Gomez, E., Toresani, S., Firpo, I. and Rotondo, R. 2006. Effect of organic amendments on some physical, chemical and biological properties in a horticultural soil. *Bioresource technology (97) 4*: 635-640.

Fischler, M. 1996. Research on green manures in Uganda: Results from experiments conducted in 1995. Institute of Plant Sciences, Zurich, Switzerland. 24 p.

Fitz Patrick, E.A. 1986. An introduction to soil science, 2nd Ed. Longman scientific and Technical, U.K. 255 p.

Franke, A. C., Schultz, S., Oyewole, B. D. and Bako, S. 2004. Incorporating short-season legumes and green manure crops into maize-based systems in moist Guinea Savanna of West Africa. *Experimental Agriculture 40*: 463-479.

Franzel, S., Phiri, D. and Kwesiga, F. (1999). Assessing the adoption potential of improved fallows in Eastern Zambia. AFRENA report No. 124., ICRAF, Nairobi.

Ford, D. J., Cookson, W. R., Adams, M. A. and P.F. Grierson, P. F. 2007. Role of soil drying in nitrogen mineralization and microbial community function in semi-arid grasslands of north-west Australia. *Soil Biology and Biochemistry (39) 7:*1557-1569.

Frye, W. W., Blevins, R. L., Smith, M. S., and Corak, S. J. 1988. Role of annual legume cover crops in efficient use of water, nitrogen In: Cropping strategies for efficient use of water and nitrogen. ASA Special publication Number 51*:* 129–154.

Fujita, K., Ofusu, B. and Ogata, S, 1992. Biological nitrogen fixation in mixed legume - cereal-cropping systems. *Plant and Soil 141:* 155-175.

FURP. 1987. Fertilizer Use Recommendation Project (FURP) phase I. Description of the first priority trial sites in the various districts. Volume 1: Kisii district. Ministry of Agriculture, National Agricultural Laboratories. 334 p.

FURP. 1988. Fertilizer Use Recommendation Project (FURP), Phase I. Main report, Methodology and inventory of existing information.

FURP. 1994. Fertilizer Use Recommendation Project (FURP). Fertilizer Use Recommendations, Volumes 1 to 24. Kenya Agricultural Research Institute (KARI), National Agricultural Research Laboratories, Nairobi.

FURP. 1995. Fertilizer Use Recommendation Project (FURP). Final report. Kenya Agricultural Research Institute (KARI).

Fuso. M., Kuhne. R. F., Vlek, P. G. 2003. Recovery of cover crop N in soil plant system in savannah zone of Ghana. *Biological Fertility of soils 39*: 117-122.

Gachene, C. K. K., Jarvis, N. J., Linner, H and Mbuvi, J. P. 1997. Soil erosion effects on soil properties in a highland area of Central Kenya. *Soil Science Society of America Journal 61 (2)*: 559 - 564.

Gachene, C. K. K., Mureithi, J.G, Anyika, F. and Makau, M. 2002. Incorporation of green manure cover crops in maize-based cropping system in semi-arid and sub-humid Kenya. In: Mureithi J. G., Gachene C. C. K, Muyheko, F. N., Onyango M., Mose. L and Magenya, O (Eds.) Participatory Technology Development for soil management by smallholders in Kenya. Proceedings of the second scientific conference of soil management/legume research network projects, June 2000, Mombasa. Kenya Agricultural Research Institute, pp.153-164.

Giller, K. 1997. Practical approaches to soil organic matter management for smallholder maize production in Southern Africa. Draft paper prepared for the Network on Soil Organic Matter Management. Wye College, University of London. 16 p.

Giller, K. E., Gilbert, R., Mugwira, L. M., Muza, L., Patel, B. K. and Waddington, S. R. 1998. Practical approaches to soil organic matter management for maize production in southern Africa. In: Soil Fertility Research for Maize-based Farming Systems in Malawi and Zimbabwe, (Eds S. R. Waddington, H. K. Murwira, J. D. T. Kumwenda, D. Hikwa and F. Tagwira). SoilFertNet/CIMMYT-Zimbabwe, Harare, Zimbabwe, pp. 139–153.

Gitari J.N.; F.K. Kanampiu and F.M. Murithi 1996. Maize yield gap analysis for mid-altitude areas of Eastern and Central Kenya region. In focus on Agricultural research for sustainable development in changing economic environment. Proceedings of the fifth KARI scientific conference. Eds. P.O. Fungoh and G.C.O. Mbadi, Nairobi, Kenya. pp. 216-225.

Gitari, J. N., Mureithi, J. G., Karumba, S. K. and Mwaniki, K. 2002 a. Integrated use of legume green manure, cattle manure and inorganic fertilizer for increased production in mid altitude areas of central Kenya. In: Mureithi *et al.* (eds.). Participatory technology development for soil management by smallholders in Kenya, Proceedings of the second scientific conference of the soil management and legume research network projects, June 2000, Mombasa, Kenya. KARI, Nairobi, Kenya. pp. 115-120.

Gitari, J. N., Mureithi, J. G., Karumba, S. K and Mwaniki, K. 2002 b. Legume green manuring for maize production on smallholder farms in eastern and central Kenya region. In: Mureithi *et al.* (eds.). Participatory technology development for soil management by smallholders in Kenya, Proceedings of the second scientific conference of the soil management and legume research network projects, June 2000, Mombasa, Kenya. KARI, Nairobi, Kenya. pp.121-128.

Gittinger, J. P. 1972. Economic analysis of agricultural projects, Baltimore, John Hopkins, U.P, 221p.

Gregory, P. J., Simmonds, L. P. and Warren, G. P. 1997. Interactions between plant nutrients, water and carbon dioxide as factors limiting crop yields. *Phil. Trans. R. Soc. Lond. B 352*: 987-996.

Hadas, A. and Portnoy, R. 1994. Nitrogen and carbon mineralization rates of composted manures incubated in soil. *Enviromental Quality Journal 23:*1184-1189.

Hamer. U and Marschner, B. 2004. Priming effects in different soil types induced by fructose, alanine, oxalic and catechol additions. Soil biology and biochemistry xx (xxxx) 1-10.

Hamblin, A. P. 1981. Filter-Paper method for routine measurement of field water potential. *Journal of hydrology 53*: 355-360.

Hassan, R. M., and Karanja, D. D. 1997. Increasing maize production in Kenya: Technology Institutions and policy In: Africa's emerging maize revolution. Byerlee, D and Eicher, E. K (Eds). Colorado, Lynn Rienna Publishers.

Hassan, R. M., Muriithi, F. M. and Kamau, G. 1998. Determinants of fertilizer use and gap between farmers' maize yields and potential yields in Kenya. *In*: Hassan, R. M. (ed.) Maize technology development and transfer: A GIS Application for research planning in Kenya. CAB International, Wallingford, U.K pp. 137-161

Heisey, P. W. and Mwangi, W. 1996. Fertilizer use and maize production in sub-saharan Africa. CIMMYT Economics working paper 96-01, Mexico, D. F. CIMMYT.

Hesterman, O. B. 1988. Exploiting forage legumes for nitrogen contribution in cropping systems. Cropping strategies for efficient use of water and nitrogen. ASA Special publication Number 51, pp. 155-166.

Hikwa, D., Mataruka, D. F. and Natarajan, M. 1989. Response of maize to nitrogen and phosphorous application on small-scale farms in Zimbabwe. In: Maize Improvement, Production and Protection in Eastern and Southern Africa. Proceedings of Third Eastern and Southern Africa Regional Maize Workshop. Nairobi and Kitale, Kenya, 467-476.

Hillel, D. 1980. Fundamentals of soil physics. Academic press Inc., Florida,U.S.A. 413 p.

Ibewiro, B., Vanlauwe, B., Sanginga, N. and Merckx, R. 1986. Nitrogen contributions of roots to succeeding maize in herbaceous legume cover cropping systems in a tropical derived savanna. *In:* Renard, G. *et* al. (ed). Soil fertility management in West African Land Use Systems, Margraf Verlag, Germany. p 123-128.

Jama, B. A. and P. K. R. Nair 1996. Decomposition-and nitrogen-mineralization patterns of Leucaena leucocephala and Cassia siamea mulch under tropical semi-arid conditions in Kenya. *Plant and Soil 179*: 275-285.

Jarvis, S. J., Stockdale, E. A., Shepherd, M. A., and Powlson, D. S. 1996. Nitrogen mineralization in temperate agricultural soils: Processes and measurement. *Advances in Agronomy, Volume 57.* pp. 187-237.

Jeranyama, P., Hesterman, O. B., Waddington, S. R., and Harwood, R. R. 2000. Relay intercropping of sunnhemp and cowpea into a smallholder maize system in Zimbabwe. *Agronomy Journal* 92:239–244.

Jenkinson, D.S., Fox, R.H., Rayner, J. H., 1985. Interactions between fertilizer nitrogen and soil nitrogen - the so-called "priming effect". *Journal of Soil Science 36*, 425-444.

Jyne, T. S., Kelly, V. and Crawford, E. 2003. Fertilizer consumption trends in Sub-Saharan Africa. Policy synthesis for cooperating U.S agency for international development (USAID) offices and country missions, Number 69. 4p.

Kaboneka, S., Sabbe, W.E. and Mauromoustakos, A. 1997. Carbon decomposition kinetics and nitrogen mineralization from corn, soybean, and wheat residues. *Commuication in Soil Scenc and. Plant Analysis 28 (15 and 16)*: 1359 – 1373.

Kaizzi, C. K., Ssali, H and Vlek, P.L.G. 2006. Differential use and benefits of velvet bean (Mucuna pruriens var. utilis) and N fertilizers in maize production in contrasting agro-ecological zones of E. Uganda. *Agricultural Systems 88*: 44–60.

Karen, A., Oglesby, Fownes, J. H. 1992. Effects of chemical composition on nitrogen mineralization from green manures of seven tropical leguminous trees. *Plant and Soil 143*: 127-132.

KARI. 1990. The Fertilizer Use and Recommendation Project (FURP): Manual 1. National Agricultural Research Laboratories (NARL), KARI, Nairobi, Kenya.

KARI/CIMMYT, 1992. Maize data base project. Kenya Agricultural Research Institute (KARI) and International Maize improvement Center (CIMMYT), Nairobi, Kenya.

KARI. 1992. Review of the National Maize Research Program. Proceedings of a workshop held November 19-23, 1991, Kakamega, Kenya. Kenya Agricultural

Research Institute (KARI), Nairobi. 99 p.

KEFRI/ICRAF/KARI Maseno RRC Labs (1994). Soil laboratory manual for analysis of extractable ammonium and nitrate. Version 1.1. Kenya Forestry Research Institute /International Centre for Research in Agroforestry, and Kenya Agricultural Research Institute, Maseno Regional Research Centre Laboratories, 12 p.

Kiiya, W. W., Mureithi, J. G. and Kiama, J. M. 2006. Improving production of Irish potato (Solanum tuberosum L.) in Kenya: The use of green manure legumes for soil fertility improvement. In: Enhancing agricultural productivity in East Africa: Developing and up-scaling of green manure technologies in Kenya. (Eds.) Mureithi, J. G., Gachene,K. K., Wamuongo, J. W. and Eilitta, M. 2006. KARI. pp. 83-95.

Kikafunda, J., Bogale, T. T., Mmbaga, T. E. and Assenga, R. H. 2001. Legume fallows for maize-based cropping systems in East Africa: Screening legumes for adaptability, biomass and nitrogen production. In: Seventh Eastern and Southern Africa Regional maize conference, 11th –15th February 2001, pp. 319-323.

Kimemia, J. K. 1998. Studies on green manure application and intercropping in *Coffea arabica* L. production. Ph.D. thesis. University of Nairobi. 237 p.

Kipsat, M.J. (2001) Economics of Non-Conventional Fertilizers in Vihiga District, Western Kenya. M.Phil. Thesis Department of Agricultural Resource Economics, Moi University. Kenya.

Kipsat, M. J., Maritim, H. K. and Okalebo, J. R. 2004. Economic analysis of non-conventional fertilizers in Vihiga district, Western Kenya. In: Managing nutrient cycles to sustain soil fertility in sub-saharan Africa. The African network for Tropical soil biology and fertility (TSBF) Institute of CIAT. pp. 536-544.

Khaemba, E. 1992. Combining ability for yield components of early maturing prolific maize. M.Sc. thesis, University of Nairobi, Nairobi, Kenya, 91 p.

Kumar, K and Goh, K. M. 2000. Crop residues and management practices: Effects on soil quality, soil nitrogen dynamics, crop yield, and nitrogen recovery. Advances in *Agronomy, Volume 68*, pp.197-279.

Kuzyakov, Y., Friedel, J. K., Stahr, K. 2000. Review of mechanisms and quantification of priming effects. *Soil Biology and Biochemistry 32*:1485- 1498.

Lapedes, D. N. 1978. McGraw-Hill dictionary of scientific and technical terms. McGraw-Hill, Inc., Philippines. p. 1134.

Lathwell, D. J. 1990. Legume green manures: principals for management based on recent research. Tropsoils Bulletin number 90-01, Soil management collaborative research support program, North Carolina state University, Raleigh, U.S.A.

Leong, E. C., He, L. and Rahardojo, H. 2002. Factors affecting filter paper method for total and matrix suction measurements. *Journal of Geotechnical testing, 25 (3)*: 198-253.

Ma, B. L and Dwyer, L. M. 1998. Nitrogen uptake and use of two contrasting maize hybrids differing in leaf senescence. *Plant and Soil* 199: 283–291.

Makken, F. 1993. Overview of the agricultural sector in sub-saharan Africa. *In:* Rauler, H.V. and Prins, W.H. (eds). The role of plant nutrients for sustainable food crop production in sub-saharan Africa. Dutch Association of fertilizer producers (VKP) Netherlands, pp. 25-35.

Maithya, J. M., Kimenye, L. N., Mugivane, F. I. and Ramisch, J. J. 2006. Profitability of agro-forestry based soil fertility management technologies: the case of smallholder food production in Western Kenya. *Journal of nutrient cycling in agro-ecosystems 76 (2-3)*: 355-367.

Maobe, S.N. and Dyck, E.A. 1995. Legume screening and cereal/legume green manuring studies in Kisii, southwest Kenya: Preliminary results. Paper presented in the Legume Screening Working group meeting on 21st to 22nd November 1995 at the National Agricultural Research Laboratories, Nairobi, Kenya.

Maobe, S. N., Nandwa, S., Wanyama, J and Kidula, N.L. 1996. Agronomic and economic aspects of nutrient dynamics in typical Kenyan farm systems: Case studies. 26 p. In: Proceedings of the Soil Science Society of East Africa (SSSEA) conference held on 19th to 23rd August 1996 at Nanyuki, Kenya.

Maobe, S. N., Dyck, E and Ondicho, A. 1997a. Legume Screening for soil fertility improvement in a high potential area of Kenya. 23 pp. In: Proceedings of the Soil management conference held on 23rd to 28th March 1997 at Kanamai Hotel, Mombasa, Kenya.

Maobe, S.N., Mbugua, D.M., Dyck, E and Makworo, S. 1997b. Researching with farmers on green manure technology in a high potential area in Southwest Kenya.

In: Proceedings of the Soil management conference held on 23rd to 28th March, 1997 at Kanamai Hotel, Mombasa, Kenya.

Maobe, S. N., Dyck, E and Mureithi, J. G. 1997c. Screening of soil-improving herbaceous legumes for inclusion into smallholder farming systems of Kenya. Paper presented in the soil fertility network results and planning workshop of southern Africa held on 7th to 11th July 1997 at the Africa University, Mutare, Zimbabwe. 18 pp. In: Proceedings of Soil Fertility Research for smallholder Maize-Based Farming systems in Malawi and Zimbabwe.

Manyong, V. M., Houndekon, V. A., Sanginga, P.C. and Honlonkou, A. N. 1999. Mucuna fallow diffusion in southern Benin. International Institute of Tropical Agriculture (IITA), 23 p.

Mburu, M. W. K. 1996. The effect of irrigation, fertilizer nitrogen and planting density on bean (Phaseolus vulgaris) yields under different weather conditions. Ph.D Thesis, University of Reading.

Mburu, M. W. K. and Gitari, J. N. 2006. Maize-Mucuna intercropping systems in Kenya. In: Enhancing agricultural productivity in East Africa: Developing and up-scaling of green manure technologies in Kenya. (Eds.) Mureithi, J. G., Gachene, C. K. K., Wamuongo, J. W. and Eilitta, M. 2006. KARI. pp. 125-142.

McQueen, I. S. and Miller, R. F. 1968. Calibration and evaluation of a wide-range gravimetric method for measuring moisture stress. *Soil Science 106*: 225-231.

Mead, R., Curnow, R. N and Hasted, A. M (1983). Statistical methods in agriculture and experimental biology. Chapman and Hall, Washington. 415 p.

Meelu. O. P., Morris, R. A., Furoc, R.E., and Dizon, M.A. 1992. Grain yield response in rice to eight tropical green manures. *Tropical Agriculture Journal 69 (2):* 133-136.

Meisinger J J, Hargrove WL, Mikkelsen RL, Williams JR and Benson VW (1991) Effects of cover crops on groundwater quality. In: Hargrove WL (ed) Cover Crops for Clean Water, pp 57-68. Soil and Water Conservation Society, Ankeny, Iowa.

Miller, P. R., Williams, W. A. and Madson, B. A. 1989. Cover crops for California Agriculture. University of California, Division of Agriculture and National resources, Publication 21471.

Mkhabela, M. S., Mkhabela, M. S and Pali-Shikhulu, J. 2001. Response of maize to different levels of nitrogen in Swaziland. Seventh eastern and southern Africa regional maize conference, 11th-15th February 2001. pp. 377-381.

Morris, M., Kelly, V. A., Kopicki, R. J. and Byerlee, D. 2007. Fertilizer use in African agriculture: Lessons learned and good practice guidelines: Directions in development, Agriculture and rural development, Number 39037. The International Bank for reconstruction and development/World Bank. 162 p.

Mose, L., Nyangito, H. O and Mugunieri, L. G. 1996. An analysis of socio-economic factors that influence chemical fertilizer use among smallholder maize producers in Western Kenya. In: Proceedings of the Fifth Eastern and Southern Africa Regional Maize conference, 3rd to 7th June 1996, Arusha, Tanzania. pp. 43-46.

Mose, L. O., Nyangito, H. O. and Mugunieri, G. L. 1997. An economic analysis of the determinants of fertilizer use among smallholder maize producers in western Kenya. In: Fungoh, P.O and Mbadi, G. C. O. (eds.) Focus on agricultural research for sustainable development in a changing economic environment. Proceedings of the 5th KARI scientific conference, KARI Headquarters 14th-16th October 1996. Kenya Agricultural Research Institute (KARI), Nairobi, Kenya. pp. 504-510.

Moss, D. N. 1984. Photosynthesis, respiration, and photorespiration in higher plants In: Tesser, M. B. (ed.) Physiological basis of crop growth and development, American Society of Agronomy, Crop Science of America, Madison, Wisconsin, U.S.A. pp. 131-151.

Mtambanengwe, F. and Mapfumo, P. 2006. Effects of organic resource quality on soil profile N dynamics and maize yields on sandy soils, Zimbabwe. *Plant and Soil 281*:173–191.

Mugendi, D. N., Nair, P. K. R., Mugwe, J. N., O'Neil, M. K. and Woomer, P. L. 1999. Alley cropping of maize with calliandra, leucaena in subhumid highlands, Kenya. Part 1. Soil fertility changes and maize yield. *Agroforestry systems 46*: 39-50.

Mukhebi, A. W and Onim, J.F.M. 1987. Economics of intercropping maize with forage crops in small-scale farming systems in western Kenya. In: Animal feed resources for small-scale livestock producers - Proceedings of the second PANESA workshop, held in Nairobi, Kenya, 11-15 November 1985. International Development Research Centre (IDRC), IDRC-MR165e, November.

Mulagoli, I.J.W. 1996 and 1997. Fertilizer Extension Project Report for 1996 and 1997.

Ministry of Agriculture, Livestock Development and Marketing (MALDM) in co-operation with GTZ.

Mulagoli, I. J. W. 1997. Progress in the implementation of fertilizer extension project (FEP) 1994-97. In: Proceedings of the FEP/FURP review workshop held in Ambwere Alliance hotel, Chevakali, Vihiga, 9th – 13th June 1997. Ministry of Agriculture, livestock development and marketing (MALDM), Nairobi, Kenya.

Mulagoli, I.J.W. 1999. Accomplishments of fertilizer extension project and the way forward. The 5th fertilizer meeting. Hilton Hotel, 4 -5th March 1999, 7 pp.

Mureithi, J.G, Mwaura, P. M and Nekesa, C. O. 2002. Introduction of legume cover crops to smallholder farms in Gatanga, Central Kenya. In: Mureithi J. G., Gachene C. C. K, Muyheko, F. N., Onyango M., Mose. L and Magenya, O (Eds.) 2002. Participatory Technology Development for soil management by smallholders in Kenya. Proceedings of the second scientific conference of the soil management and legume research network projects, June 2000, Mombasa. Kenya Agricultural Research Institute (KARI), pp. 153-164.

Mugunieri, G. L., Nyangito, H. O., Mbatia, O. L.E. and Mose, L. O. 1997. An economic analysis of fertilizer use in maize production among smallholder farmers in Kisii district In: Fungoh, P.O and Mbadi, G. C. O. (eds.) Focus on agricultural research for sustainable development in a changing economic environment. Proceedings of the 5th KARI scientific conference, KARI Headquarters 14th-16th October 1996. Kenya Agricultural Research Institute (KARI), Nairobi, Kenya. pp. 658-665.

Mureithi, J. G. and Gachene, C. K. K. K. 1998. An overview of legume screening network activities in Kenya. Paper presented at the workshop on improving rural livelihoods through conservation farming techniques, 27th February 1998, KARI Headquarters, Nairobi.

Mureithi, J. G., Maobe, S. N., Gachene, C.K.K., Gitari, N., Kirungu, B., Muli, B. M., Ojiemu, J. Saha, H.M. and Tana, P. 1998. Screening of legume germplasm in Kenya: Effect of rhizobia inoculation on performance of best bet legumes. 7 pp. Final Network Report. In: Proceedings of the 16th conference of the Soil Science Society of East Africa (SSSEA) held at Tanga; 13-19 December.

Mureithi, J. G., Mwendia, C. W., Muyekho, F. N., Onyango, M. A., Maobe, S. N. 2000. Participatory Technology Development for soil management by smallholders in Kenya: Special Publication of Soil Management and Legume Research Network Projects. Kenya Agricultural Research Institute, Soil Management and Legume Research Network Projects. 32-3. 267 pp.

Mureithi, J. G., Gachene, C.K.K. and Wamuongo, J. W. 2003. Legume cover crops research in Kenya: experiences of legume research network project. Highlights of phase I (1994-2000). KARI technical notes series no. 12. Legume research network project (LRNP) and Kenya Agricultural Research Institute (KARI). 26 p.

Mureithi, J. G. and Gitahi, F. M. 2004. Legume screening database and instructional manual. Legume Research Network projects. Kenya Agricultural Research Institute, 23 p. Database CD attached.

Muriuki, A. W. and Qureshi, J. N. 2001. Fertilizer use manual. Kenya Agricultural Research Institute (KARI), Nairobi. 149 p.

Mutuo P., Marandu, A. E., Rabeson, R., Mwale, M., Snapp, S. and Palm, C. 1998. Nitrogen fertilizer equivalency values of organic materials of differing quality: Network trial results from East and Southern Africa. Paper presented to the Soil Science Society of East Africa held Tanga; 13-19th December 1998. 16 p.

Nabwile, S. M. 1996. Comparison of economic analysis methods to get the most appropriate agronomic recommendation. In: Soil technologies for sustainable smallholder farming systems in East Africa. Proceedings of the 15th annual general meeting, Sportsman's Arms Hotel, Nanyuki, Kenya. Soil Science Society of East Africa (SSSEA), pp. 387-394.

Nelson, C. J. and Larson, K. L. 1984. Seedling growth. In: Teser, M. B. (ed.), Physiological basis of growth and development. American Society of Agronomy-Crop Science of America. U.S.A. 341 p.

Norman, D. W., Siebert, J. D., Madiakgotla, E. and Wortman, F. D. 1994. Farming systems Research Approach: A Primer for Eastern and Southern Africa. Regional Farming systems programme.

Odhiambo, J. J. O. 1989. The effect of nitrogen fertilization on maize (Zea mays. L. katumani composite B) performance and nitrogen mineralization in Kabete nitisols. M.Sc. thesis, University of Nairobi, 141 p.

Odongo, O. M. 1986. Genetic architecture of yield and earliness components in maize.

M.Sc. thesis, University of Nairobi, Nairobi, Kenya, 167 p.

Odendo, M., Barakutwo, J. K., Gitari., N., Kamidi, M., Kirungu, B., Lunzalu, E, Mureithi, J. G., Nekesa, C., Ojiem, J., Okumu, M., Okwuosa, E., Onyango, R. and Saha, H. M. 2000. Potential for adopting green manure legumes for soil fertility in Kenya. In: Mureithi *et al.* (eds.). Participatory technology development for soil management by smallholders in Kenya, Proceedings of second scientific conference of soil management and legume research network projects, June 2000, Mombasa, Kenya. KARI, Kenya. pp. 402-412.

Ojiem, J. O. Mureithi, J. G., Maobe, S. N., Okuosa, E. A. and Nekesa, C. O. 2000. Effect of phosphorus on legume green manure species, nodulation and dry matter yield. In: Proceedings of the Soil management and Legume research network projects conference held on 26th to 30th June 2000, at Continental Resort Hotel, Mombasa, Kenya, pp.183-188.

Okalebo, J.R. 1987. A study of the effect of phosphate fertilizers on maize and sorghum production in some East African soils. PhD Thesis, University of Nairobi. 293 p.

Okalebo, J.R., Gathua, K.W and Woomer, P.L. 2002. Laboratory methods of soil and plant analysis: A working manual, 2nd edition, Tropical Soil Biology and fertility and Soil Science Society of East Africa; Kenya Agricultural Research Institute and Sacred Africa, 128 p.

Okoth, P. F. and Wamae, D. K. 1999. Extrapolation of N fertilizer recommendation zones for maize in Kisii districts using geographical information system (GIS). In:

Agronomic services Ltd (ed.) Agricultural research and development for sustainable resource management and increased production. Proceedings of the 6th KARI scientific conference, KARI headquarters, 9th-13th November 1998. Kenya Agricultural Research Institute (KARI), Nairobi, Kenya. pp. 396-407.

Olson, R. A. and Kurtz, L. T. 1982. Crop Nitrogen requirements, utilization and fertilization. In: Nitrogen in agriculture soils. *Agronomy Monograph No. 22.*, ASA - CSSA - SSSA., Madison, USA. pp. 567- 585.

Oluoch-Kosura, W., Ariga, E. S., Okeyo, A. M., Waithaka, M. and Kyalo, A. M. 1999. Agricultural technology, economic viability and poverty alleviation in Kenya. Paper for the Agricultural transformation policy in sub-saharan Africa workshop. Serena Hotel, Nairobi, 27 – 30th June 1999. 60 p.

Oluoch-Kosura, W. A., Marenya, P.P and Nzuma, M. J. 2001. Soil fertility management in maize-based production systems in Kenya: Current option and future strategies in Kenya. Seventh Eastern and Southern Africa Regional maize conference, 11th–15th February 2001. pp. 350-355.

O'Neill, P. M., Shanahan, J. F., Schepers, J. S and Caldwell, B. 2004. Agronomic responses of corn hybrids from different eras to deficit and adequate levels of water and nitrogen. Agronomy Journal 96(1) 660–1667.

Onwueme, I.C. and Sinha, T.D. 1991. Field crop production in tropical Africa. Technical Centre for Agricultural, Rural Co-operation (CTA), Ede, The etherlands.479 p.

Onyango, C., Oduwo, A., Okoko, N., Kidula, N. and Mureithi, J. G. 2000. Green manuring to improve soil fertility and reduce striga in south Nyanza. In: Participatory technology development for soil management in Kenya. Proceedings of the 2nd scientific conference of the soil management and legume research network projects, (eds.) Mureithi, J. D., Gachene, C. K., Muyheko, F. N., Onyango, M., Mose, L. and Magenya, O. Kenya Agricultural Research Institute (KARI), Nairobi. pp. 173-176.

Onyango, J. W. and Chege, A. G. 2000. Grain yield losses in relation to rainfall regimes in maize growing areas of Kenya. In: Proceedings of the 15th annual general meeting of the soil science society of east Africa, Sportsman's Arms hotel, 19th to 23rd August 1996, Nanyuki, Kenya. pp. 43-160.

O'Sullivan, J. 2006. Snow river seeds maize technical update, Snowy river seeds pty ltd, Victoria, Australia. 2 p.

Palm, C. A. 1995. Contribution of agroforestry trees to nutrient requirements of intercropped plants. *Agroforestry systems 30*:105-124.

Palm, C.A., Myers, R.J.K. and Nandwa, S.M. 1997. Combined use of organic and inorganic nutrient sources for soil fertility maintenance and replenishment. In: R.J. Buresh et al., (ed.) Replenishing soil fertility in Africa. SSSA Special Publication no.51. SSSA, Madison, USA. pp.193-215.

Palm, C. A., Gachengo, C. N., Delve, R. J., Cadisch, G. and Giller, K. E. 2001. Organic inputs for soil fertility management in tropical agroecosystems: application of an organic resource database. *Agriculture Ecosystems and Environment 83*:27-42.

Peter J. A., Kleinman, M. S., Srinivasan, C. J., Dell, J. P., Schmidt, A. N. Sharpley and Ray B. B. 2006. Role of rainfall intensity and hydrology in nutrient transport via surface runoff. *Journal of environmental quality 35*:1248-1259.

Perrin, R. K., Winkelmann, D. L., Moscardi, E.R and Anderson, J. R. 1976. From agronomic data to farmer recommendations: An economics Training manual. International and maize improvement centre (CIMMYT), Mexico. 51p.

Pilbeam, C. J. and Warren, G. P. 1995. Use of ^{15}N for fertilizer N recovery and N mineralization studies in semi-arid Kenya. *Fertilizer Research 42*:123-128, 1995.

Pilbeam, C. J., Wood, M. and Mugane, P. G. 1995. Nitrogen use in maize-grain legume cropping systems in semi-arid Kenya. *Biology and fertility of soils 20 (1)*: 57-62.

Pioneer. 2006. Fertilizer application for maize. Pioneer technical insights, Number 332. Pioneer Hi-Bred International, Inc., Iowa, U.S.A. 3 P.

Quemada, M. and Cabrera, M. L. 1995. Carbon and nitrogen mineralization from leaves and stems of four cover crops. *Soil science Society of America Journal 59*: 471-477.

Ramos, C. 1996. Effect of agricultural practices on the nitrogen losses to the environment. *Fertilizer Research 43*: 183-189.

Rao, M. R., Niang, A., Kwesiga, F., Duguma, B., Franzel, S., Jama, B. and Buresh, R. 1998. Soil fertility replenishment in sub-sahan Africa: New techniques and the spread of their use on farms. In: The impact of agroforestry. International Centre for Research in Agroforestry (ICRAF). April-June 1998.

Raun, W. R. and Johnson, G. V. 1999. Improving nitrogen use efficiency for cereal production. *Journal of Agronomy 91*:357–363.

Republic of Kenya. 1980. Physical and Chemical methods of soil analysis (eds.) Hinga, G., Muchena, F. N. and Njihia, C. M., National Agricultural Research Laboratories (N. A. R. L.). pp. 2(1) – 2(8).

Republic of Kenya. 1994 a. Sessional Paper number 2 of 1994 on National Food Policy. Government Printer, Nairobi.

Republic of Kenya. 1994b. Development Plan, 1994-96. Government Printers, Nairobi.

Republic of Kenya, 1995-2000. Status of food and agricultural statistics in Kenya. Central bureau of statistics (CBS), Ministry of finance and planning, Nairobi, Kenya. 11p.

Rigobelo, E. C., Nahas, E. 2004. Seasonal fluctuations of bacterial population and microbial activity in soils cultivated with eucalyptus and *pinus*. Scientia Agricola 61(1), (Piracicaba, raz.) Piracicaba Jan./Feb.

Reversat, F. B. 1982. Measuring litter decomposition in a tropical forest ecosystem: Comparison of some methods. *International Journal of Ecology and Environmental Science 8*: 63-71.

Rigobelo, E. C., Nahas, E. 2004. Seasonal fluctuations of bacterial population and microbial activity in soils with eucalyptus and *pinus. Scientia Agricola, (Piracicaba, raz.) vol.61 no.1.* Piracicaba Jan./Feb. 2004.

Rowell, D.L 1994. Soil science: Methods and applications. 350 pp. John Wiley and sons, Inc., 605 Third Avenue, New York, USA.

Rutunga, V. 2000. Potential of Tephrosia vogelii Hook F. and Tithonia diversifolia (Hemsley) A. Gray short duration fallows for improving the productivity of maize in Western Kenya. PhD Thesis. University of Nairobi.

Sakala, W. D., Kumwenda, J. D. T., Saka, A. R. 2004. The potential of green manures to increase soil fertility and maize yields in Malawi. In: Managing nutrient cycles to sustain soil fertility in sub-Saharan Africa. The African network for soil biology and fertility (AfNet) of the Tropical soil biology and fertility (TSBF) Institute of CIAT. pp. 373-385.

Sanchez, P.A. 1976. Properties and management of soils in the tropics. John Wiley, New York.

Sanchez, P., Izac, A., Buresh, R., Shepherd, M., Soule, M., Mokwunye, U., Palm, C., Woomer, P., and Nderitu, C. 1997. Soil fertility replenishment in Africa as an investment in natural resource capital. In: Replenishing soil fertility in Africa. Buresh R. J., Sanchez, P.A., and Calhoun, F (Eds). Madson, WI: Soil science society of America.

Sanginga, N., Dashiell, K. E., Diels, J., Vanlauwe, B., Lyasse, O., Carsky, R. J., Tarawali, S., Asafo-Adjei, B., Menkir, A., Schulz, S., Singh, B. B., Chikoye, D., Keatinge, D. and Ortiz, R. 2003. Sustainable resource management coupled to resilient germplasm to provide intensive cereal-grain-legume-livestock systems in dry savanna. *Agriculture, Ecosystem and Environment* 100:305–314.

Sanginga, N., Ibewiro, B., Houngnandan, P., Vanlauwe, B., Okogun, J. A., Akobundu, I. O., and Versteeg, M. 1996. Evaluation of symbiotic properties and nitrogen contribution of mucuna to maize grown in the derived savanna of West Africa. *Plant and Soil 179*: 119-129.

Sigunga, D. O. 1997. Fertilizer nitrogen use efficiency and nutrient uptake by maize (*Zea mays* L.) in vertisols, Kenya. Ph.D. thesis, University of Wageningen, 207 p.

Salisbury, F. B. and Ross, C. W. 1986. Plant physiology. Wadsworth Publishing Co., U.S.A. 539 p.

Sarrantonio, M. 1991. Methodologies for screening soil-improving legumes. Rodale Institute, U.S.A.

Scivittaro, W. B., Muraoka, T, Boaretto, A. E. Trivelin, P. C. O. 2004. Fate of nitrogen (^{15}N) from velvet bean in the soil-plant system. *Scientia Agricola (Piracicaba, Braz.)* 61(2): 210-215.

Schnier, H. F. Recke, H., Muchena, F. N. and Muriuki, A. W. 1996. Towards a practical approach to fertilizer recommendations for food crop production in smallholder farms in Kenya. *Nutrient Cycling in Agroecosystems 47 (3)*: 213-226.

Schomberg, H. H., Steiner, J. L. and Unger, P. W. 1994. Decomposition and nitrogen dynamics of crop residues: Residue quality and water effects. *Soil Science Society of America journal 58*:372-381.

Schulz, S., Carsky, R. J. and Tarawali, S. 2001. Herbaceous legumes: the panacea for West African soil fertility problems? Sustaining soil fertility in West Africa. *Soil*

Society of America Special Publication 58:179–196.

Shaxson, F and Barber, R. 2003. Optimizing soil moisture for plant production: The significance of soil porosity. FAO Soils Bulletin 79, 126 p.

Shiluli, M. C., Macharia, C. N. and Kamau, A. W. 2003. Economic analysis of maize yield response to nitrogen and phosphorus in the sub-humid zones of western Kenya. *African Crop Science Journal, Volume No. 3*, pp. 181-187.

Silgram, M and Shepherd, M. 1999. The effects of cultivation on soil nitrogen mineralization. *Advances in Agronomy, Volume 65*, pp. 269-309.

Simango, V. A. 1976. Maize yield in relation to rainfall and solar energy in Kenya. M.Sc.thesis, University of Nairobi, Nairobi, Kenya. 152 P.

Simpson, J. R. 1960. The mechanism of surface nitrate accumulation on a bare fallow soil in Uganda. *Journal of Soil science 11*: 45-60.

Sinclair, T. R., 1998. Plants and Population: is there time? NAS Colloquium, Limits to crop yield. Beckman Center of the National Academy of Sciences, UC Irvine, USDA-ARS, Agronomy Department, University of Florida, U.S.A .

Singh, Y, Singh, B. and Timsina, J. 2005. Crop residue management for nutrient cycling and improving soil productivity in rice-based cropping systems in the tropics. *Advances in Agronomy, Volume 85*, pp. 269-381.

Skerman, P.J., Cameron, D.G and Riveros, F. 1998. *Tropical forage legumes*. Second edition. Food and Agriculture Organization of the United Nations (FAO), Rome. pp. 103-119.

Smaling, E.M.A. 1993. An agro-ecological framework for integrated nutrient management, with special reference to Kenya. Doctoral thesis, Agricultural university, Wageningen, Netherlands, (x) + 250 pp.

Ssali, H. 1990. Initial and residual effects of nitrogen fertilizers on grain yield of maize/bean intercrop grown on a Humic Nitosol and the fate and efficiency of applied nitrogen. *Fertilizer Research 23*: 63-72.

Stahl, M. 1993. Land degradation in East Africa. *Ambio 22*: 505-507.

Stanford, G. and Epstein, E. 1974. Nitrogen mineralization-water relations in soils. *Soil science Society of America Proceedings: 38*: 103-107.

Stevens, W. B., Hoeft, R. G. and Mulvaney, R. L. 2005. Fate of Nitrogen-15 in a Long-Term Nitrogen Rate Study: I. Interactions with Soil Nitrogen. *Journal of agronomy 97 (4)*: 1037-1045.

Streeter, J. G. and Barta, A. L. 1988. Nitrogen and minerals. In: Tesser, M. B. (ed.) Physiological basis of crop growth and development. American Society of Agronomy, and Crop Science Society of America, Wisconsin, USA. pp. 175-200.

Sutton, M. A., Pitcairn, C. E. R. Fowler, D. 1993. The exchange of ammonia between the atmosphere and plant communities. *Advances in Ecological Research 24*:301-393.

Tel, D.A. 1984. Soil and plant analysis: Study guide for agricultural laboratory directors and technologists working in the tropical region. International Institute of Tropical Agriculture (IITA), and University of Guelph. 277 p.

Tarawali, G., Manyong, V. M., Carsky, R. J., Vissoh, P. V., Osei-Bonsu, P. and Galiba,

N. 1999. Adoption of improved fallows in West Africa: lessons from mucuna and stylo case studies. *Agroforestry Systems 47*:93–122.

Tian, G. 1992. Biological effects of plant residues with contrasting chemical compositions on plant and soil under humid tropical conditions. Ph.D. thesis. Wageningen University. 144 p.

Tanimu, J., Iwuafor, E. N. O., Odunze, A. C. and Tian, G. 2007. Effect of incorporation of leguminous cover crops on yield and yield components of maize. *World Journal of Agricultural Sciences 3 (2)*: 243-249.

Tittonell, P. Vanlauwe, B. Leffelaar, P. A. and Giller, K. E. 2005. Estimating yields of tropical maize genotypes from non-destructive, on-farm plant morphological measurements. *Agriculture, ecosystems and environment, Volume 105, Issues 1-2*: 213-220.

Van Reuler, H. and Prins, W.H. (eds). 1993. The role of plant nutrients for sustainable food production in sub-Saharan Africa. 232 p.

Vissoh, P.V., Manyong, V. M., Galiba M., Carsky, R. J. and Borison, P. O. 1997. Green manure cover crops systems in West Africa: The case for mucuna planted fallows. Paper presented at the International Workshop on Green manure cover crops systems for smallholder in Tropical and Sub-tropical regions on 6th to 12th April 1997 at Chepaco, Santa Catarina, Brazil. 37 p.

Vissoh, P., Manyong, V. M., Carsky, J. R., Osel-Bonsu, P. and Galiba, M. 1998. Experiences with mucuna in West Africa. In: cover crops nin West Africa contributing to sustainable agriculture., edited by Buckles, D, Ereka, A., Osiname, O.,Galiba, M. and Caliano, G. , IDRC, Ottawa, Canada. IITA, Ibadan, Nigeria; Sasakawa Global 2000, Cotonou, Benein. pp.1-32.

Vinten, A.J.A, Howard, R.S and Redman, M.H. 1991. Measurement of nitrate losses from arable plots under different nitrogen input regimes. *Soil Use Management* 7:3-13.

Vlek, P. L. G. 1990. The role of fertilizers in sustaining agriculture in sub-Saharan Africa. *Fertilizer Research 26:* 327-339

Wander, M. M., Traina, S. J., Stinner, B. R. and Peters, S. E. 1994. Organic and conventional management effects on biologically active soil organic matter pools. *Soil Science Society of America Journal 58*:

Wangari, N and Msumali, G.P. 1996. Decomposition of Sesbania sesban and Lantana camara green manures: I. Effect of the type of manure and rate of application. 21 pp. Paper presented in the 15th conference of the Soil Science Society of East Africa (SSSEA) held in 1996 at Nanyuki, Kenya.

Wangare, N. L. 2004. Ex-ante evaluation of the economic potential of herbicide coated maize seed in the control of striga weed in Western Kenya. M.Sc. thesis, University of Nairobi. 72 p.

Warren, G. P. 1992. Fertilizer phosphorus: sorption and residual value in tropical African soils. NRI Bullettin 37, Chatham, U. K: Natural resources Institute, 89 p.

Wells, K. L., Murdock, L. W. and Miller, H. F. Urea as a source of fertilizer nitrogen for crops in Kentucky. AGR-69 (3-78), 5 p.

Whitbread, A. M., Jiri, O., Maasdorp, B. 2004. The effect of managing improved fallows of mucuna on maize production and soil carbon and N dynamics in sub-humid Zimbabwe. Nutrient cycling in agroecosystems, Volume 69, Number 1, pp. 59-71.

Wielemaker, W. G. and Boxem, H. W (eds.) 1982. Soils of Kisii, Kenya. 208 pp.

Williams, O. B. and Sedgley, R. H. 1965. A simplified filter paper method determining the 15-atmosphere percentage in soils. *Australian journal of Experimental agriculture and animal husbandry, 5*: 201-205.

Wortmann, C.S., Isabirye, M and in Musa, S. 1994. *Crotalaria Ochreleuca* as a green manure crop in Uganda. *African Crop Science Journal 2 (1)*: 55 -61.

Wortmann, C. S., Schnier, H. F. and Muriuki, A.W. 1996. Estimation of the fertilizer response of maize and bean intercropping using sole crop response equations. *African Crop Science Journal (4)1*:51-55.

Wong, M. T. F. and Nortcliff, S. 1995. Seasonal fluctuations of native available N and soil management implications. *Fertilizer Research 42*: 13-26.

Woomer, P. L., Martin, A., Albrecht, A, Resck, D. V. S. and Scharpenseel, H. W. 1994. The importance and management of soil organic matter in the tropics. In: Woomer, P. L., Swift, M. J. (Eds.), The Biological management of tropical soil fertility. Woomer, P. L. and Swift, M. J. (eds.), pp. 47-80. John Wiley and sons, Chichester, UK. pp. 47-80.

APPENDICES

Appendix 1. Long term rainfall data for Kisii district, southwest Kenya [•]
(Altitude 1766 m a. s. l[*], Kisii experimental Station Office; 64 years of record; Agro-ecological zone=Upper midlands one-UM_1).

Kind of record	Annual rainfall (mm)	Monthly rainfall (mm)											
		January	February	March	April	May	June	July	August	September	October	November	December
Average	1784	70	89	176	265	220	146	111	151	171	138	141	107
60% probability	1602	45	70	126	238	198	126	83	134	131	107	104	78

Lower midlands agro-ecological zones (Lower parts of Kisii where experimental site was located)

Kind of record	Altitude (m a.s. l)	Annual mean temperature (^{0}C)	60% reliability Rainfall (mm) Long rains	Rainfall (mm) Short rains	60% reliability Long rains (Number of days)	Short rains (Number of days)	Total in days
Lower midlands one (LM_1)	1440-1500	21-20.5	800-1000	500-700	180 or more	115-140	295-320
Lower midlands two (LM_2)	1400-1500	21-20.5	800-1000	800-1000	215 or more	About 150	295-320

[•] Jaetzold, R and Schmidt, H. 1982. Farm management handbook of Kenya, Volume II: Natural conditions and farm management information, Part A, West Kenya . Ministry of Agriculture/Germany Agency for Technical cooperation (GAT), pp. 81-122. ([*] Meters above sea level)

Appendix 2. Long term temperature data for Kisii district, southwest Kenya[♦]
(Altitude 1766 M a. s. l[*], Kisii experimental Station Office; 64 years of record; Agro-ecological zone=Upper midlands one-UM_1).

	Temperature (°C)											
Kind of record	January	February	March	April	May	June	July	August	September	October	November	December
Mean maximum	25.8	24.5	24.6	23.2	26.6	23.8	23.6	23.8	23.9	24.7	23.6	24.1
Mean temperature	20.5	19.6	19.8	19.0	19.2	19.0	18.5	18.8	18.9	19.5	18.9	19.2
Mean minimum	15.2	14.7	14.9	14.7	14.7	14.0	13.5	13.7	13.8	14.2	14.1	14.3
Absolute minimum	11.1	11.7	13.3	12.2	13.3	11.1	11.1	11.1	11.1	11.1	11.1	10.0

[♦] Jaetzold, R and Schmidt, H. 1982. Farm management handbook of Kenya, Volume II: Natural conditions and farm management information, Part A, West Kenya . Ministry of Agriculture/Germany Agency for Technical cooperation (GAT), pp. 81-122.