# INFLUENCE OF COVER CROPS ON NITROGEN AVAILABILITY, SOIL MOISTURE CONTENT AND MAIZE YIELD UNDER SUB HUMID CLIMATE OF MOROGORO, TANZANIA



BY

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A THESIS SUBMITTED IN FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY OF SOKOINE UNIVERSITY OF AGRICULTURE. MOROGORO, TANZANIA


2005

## ABSTRACT

A study was conducted in Morogoro Tanzania, for 3 consecutive years to evaluate the influence of cover crops planted in short rains on nitrogen (N) availability, soil moisture and grain yield of the subsequent maize crop planted in the long rains. The cover crops namely cowpea (*Vigna unguiculata* [L] Walp.), lablab (*Lablab purpureus,* L.), mucuna (*Mucuna pruriens*) and pumpkin (*Cucurbita maxima*) were evaluated against weed and bare fallows in Randomized Complete Block Design (RCBD) replicated three times. Cover crops residues had N content > 2%. Pumpkin, although not a legume, had high quality residues, having 2.1% N and higher P (0.25% P) and base content than other cover crops. Mucuna was the only cover crop that produced an average biomass above the threshold of 2 Mg DM $ha^{-1}$. Mucuna biomass was significantly higher ($P < 0.05$) than that of the other cover crops, ranging from 2.7 to 5.1 Mg DM $ha^{-1}$, with good short rains and accumulating 63 to 118 kg N $ha^{-1}$. At the end of the short rainy season, mineral N after mucuna increased by 2 to 30% and was significantly higher ($P < 0.05$) than after the other cover crops. Seventeen and 35% of N accumulated in pumpkin and cowpea residues was released in the first 7 days of incubation, respectively. These were significantly higher than the 4 and 6% accumulated N in lablab and mucuna residues, respectively. At 35 days of incubation, mineral N released from lablab, pumpkin and mucuna residues was 19, 34 and 31% of the applied amount, respectively. Mucuna and lablab significantly increased soil moisture reserve in the 40 – 60 cm soil layer ($P < 0.05$) by 9 mm in the short rainy season whereas pumpkin and weed fallow reduced it by 3 and 4 mm, respectively. In the long rainy seasons, mucuna and lablab reduced runoff from 30 – 45% to 6 – 15% of rainfall. Mucuna significantly increased the number of maize plant silking ($P < 0.05$) at 53 days after planting by 15 – 17% over weed fallow and maize grain yield by 3 – 4 fold in

seasons with insufficient long rains. It is recommended that in order to increase maize production in the sub humid area of Morogoro, mucuna should be planted in the short rains instead of leaving the land under weed fallow and supplemental mineral N fertilizer should be topdressed at 28 to 35 days after maize planting.

## DECLARATION

I, Matilda Charles Kalumuna, do declare to the Senate of Sokoine University of Agriculture that this thesis is my own original work and that it has not been submitted for a degree award in any other University.

Date...16/10/2005... Signature...M.C. Kalumuna...

## COPYRIGHT

# ACKNOWLEDGEMENTS

Thanks to Almighty God for the guidance and protection during the whole period of this study.

I am grateful to Tanzania Agricultural Research Project phase II for the financial support of this study. I sincerely thank my employer, the Ministry of Agriculture and Food Security, for granting me study leave, which gave me enough time to concentrate on my study.

Many thanks to my supervisors, Dr. P. W. Mtakwa and Prof. F. B. R. Rwehumbiza for their constant technical assistance, guidance and advises since the development of the proposal up to the completion of this study.

I am grateful to the Head, Department of Soil Science (DSS), for providing working facilities and to academic staff of the DSS, particularly Prof J. M. R. Semoka and Dr. J. P. Mrema, for their encouragement. I would like to extend my gratitude to the laboratory technicians of the DSS, especially Ms. E. Kafui, Mr. S. Marangi and Mrs. B. Nyange, for the commendable assistance in laboratory analysis they offered to me.

I am very thankful to the coordinator of Vlaamse Interuniversitaire Raad (VLIR) Programme, Dr. P.W. Mtakwa, for allowing me to use printing facilities of the Programme during writing up of this thesis. My sincere gratitude goes to the secretary of VLIR Coordination office, miss D. Mdegela, for accommodating me in her working environment during thesis writeup.

Special appreciation to my friends, Dr. S. T. Ikerra, Dr. Z. C. Mkangwa, Mr. A. Marandu, Mr. K. Masuki, Mr. E.M Marwa, Dr. A. Kaaya, Mr. A. Msolla, Mr. S. Noah and Mrs E. Mtengeti and Dr. D. N. Kimaro for their ideas and encouragement.

I am indebted to my sisters Flora and Godetha, my brothers Novatus, Renatus and Cletus, my brother in - law Method and my sisters in - law Evelyne and Christina for their moral and physical support during the period of undertaking this study. Prayers and good wishes from my father Charles Kalumuna and my son Innocent are very much acknowledged. This work would have not been possible without care rendered by Deus Steven and Zakayo William to my son Innocent. Their assistance is highly appreciated.

Many thanks are due to other parties who helped in one way or another in this study, as it is difficult to mention them all.

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## LIST OF ABBREVIATIONS AND SYMBOLS

| | |
|---|---|
| AAS | Atomic Absorption Spectrophotometer |
| AHI | African Highland Initiative |
| ATP | Adenosine Tri Phosphate |
| BS | Base saturation |
| C:N | Carbon to Nitrogen ratio |
| CC | Cover crop |
| CEC | Cation Exchange Capacity |
| Cmol(+) $kg^{-1}$ | Centimoles(+) per kilogram |
| RCBD | Randomized Complete Block Design |
| CRD | Completely Randomized Design |
| CV | Coefficient of Variation |
| DAPC | Days After Cover Crop Planting |
| DAPM | Days After Maize planting |
| DM | Dry Matter |
| DNMRT | Duncan's New Multiple Range Test |
| *et al.* | And others |
| FAO | Food and Agriculture Organisation of the United Nations |
| FYM | Farm Yard Manure |
| GURT | Government of the United Republic of Tanzania |
| $H_2O$ | Water |
| I | Infiltration |
| IITA | International Institute for Tropical Agriculture |
| ISRIC | International Soil Reference Information Centre |

| | |
|---|---|
| ISSS | International Society of Soil Sciences |
| K | Potassium |
| Lsd | Least significant difference |
| m.a.s.l. | meters above sea level |
| Mg $ha^{-1}$ | Megagrammes per hectare |
| mg $kg^{-1}$ | Milligrammes per kilogram |
| Mg $m^{-3}$ | Megagrammes per cubic meter |
| Mm | millimetre |
| mM | milliMole |
| Mo | Molybdenum |
| MWD | Mean Weight Diameter |
| N | Nitrogen |
| $N_2$ | Dinitrogen |
| n.a | Not applicable |
| $N_2O$ | Nitrous oxide |
| Ndfa | Nitrogen derived from atmospheric nitrogen fixation |
| $NH_3$ | Ammonia |
| $NH_4^+$ | Ammonium ion |
| NO | Nitrogen monoxide |
| $NO_2^-$ | Nitrite ion |
| $NO_3^-$ | Nitrate ion |
| n.s. | Not significant |
| $O_2$ | Oxygen |

# CHAPTER ONE

# INTRODUCTION

## 1.1 Problem overview

Sub humid zones are the second potential area of crop production after humid ones. They cover 38% of land in sub Saharan Africa (Mafongoya *et al.*, 2003), 30% of Tanzania [Soil Fertility Initiative (SFI), 2000] and 50% of the eastern Zone of Tanzania [Government of the United Republic of Tanzania (GURT), 1976]. Sub humid areas receive rainfall ranging from 750 to 1000 mm per annum and the rains are erratic in terms of onset, amount and distribution. In the eastern zone of Tanzania, the rainfall pattern is bimodal, characterized by short and long rains lasting from mid November to mid January and from mid March to mid May, respectively. The short rains are lighter and more erratic than the long rains and they do not produce sufficient moisture for successful maize production (Rwehumbiza, 2000). Due to rainfall inadequacy, farmers in sub humid areas in the eastern zone leave their fields under weed fallow during the short rainy season. The rainfall in the short and long rainy seasons is of high intensity particularly at the beginning of the season resulting into runoff of as high as 36% of the seasonal rains (Rwehumbiza, 2000; Bazugba, 2001) hence contributing to moisture inadequacy in the soil.

The soils in sub humid areas of Tanzania are mainly kaolinitic, low in organic matter, nitrogen (N), and water holding capacity and are prone to surface sealing (Ley *et al.*, 2002). Various crops are grown on these soils. Maize is a major crop grown, as it is the main staple food. In the Eastern Zone of Tanzania maize

constitutes 55 – 60% of crops grown in the area (GURT, 1976). Crop production is mainly under rainfed agriculture, hence rainfall and soil moisture conservation are important determinants of water available for crop production. Most of farmers in the Eastern Zone are smallholder, depending mainly on locally available resources for crop production. Maize grain yield in farmers' field ranges between 0.6 to 1.5 Mg $ha^{-1}$ (SFI, 2000) and the average national yield is 1.3 Mg $ha^{-1}$ (Shao, 1996). This yield level is 25 to 50 % of 2.4 to 5.2 Mg $ha^{-1}$ yield of maize under recommended technologies (Quinones *et al.*, 1997). Many factors have contributed to low maize grain yield but decline in soil N (Smaling *et al.*, 1997) and inadequate moisture availability are among the major ones (Mitawa and Chilagane, 1986).

Nitrogen is the most limiting nutrient because it is depleted at the highest rate. The annual N depletion rate in Tanzania ranges from 20 to 40 kg N $ha^{-1}$ (Smaling *et al.*, 1997). This decline is attributed to transfer through crop harvests, erosion and leaching. Mineral N fertilizers and organic materials such as farm yard manure (FYM), compost and green manure can be used to increase soil N status. Application rates recommended depend on the agro - ecological zone and crop requirements, but they range from 50 to 80 kg N $ha^{-1}$ (Mowo *et al.*, 1993). However, application of mineral fertilizers is constrained by unfavourable value/ cost ratio for most crops and limited availability (Nyaki and Mawenya, 1999). Organic fertilizers are characterized by low nutrient content, which necessitates higher application rates, with resultant higher transport and labour costs (Palm *et al.*, 1997). These limitations vary from one location to another depending on the availability of labour, cash and livestock. The use of cover crops is another technology that has been reported to increase soil N

status by increasing soil organic matter, reducing leaching (Biederbeck and Bouman, 1994; Zobisch *et al.*, 1995; Wyland *et al.*, 1996), runoff and losses of nutrients (Abdin *et al.*, 1998; Unger *et al.*, 1998). Legume cover crops improve soil N also by fixing atmospheric nitrogen (MacColl, 1989; Sanginga *et al.*, 1996b; Carsky *et al.*, 1998). Cover crops have the advantage over FYM of being easily established *in situ* thereby eliminating transport costs. Cover crops have been reported to increase soil fertility in West Africa (Sanginga *et al.*, 1996a; Buckles *et al.*, 1998; Carsky *et al.*, 1998) and Uganda in East Africa (Wortmann *et al.*, 1994). Work done in highland and humid areas of Uganda and Kenya identified mucuna, lablab, crotalaria and canavalia as the most outstanding cover crops in terms of biomass production and nodulation (Gachene *et al.*, 2000). In Tanzania, information on the use of cover crops is scanty. Existing information include work done by Temu and Aune (1995) in the southern highlands and by Kullaya *et al.* (1995) in the northern highlands. Other information relies on experiences of Rupper (1984) in Peramiho and Assmo and Eriksson (1994) in Usambara Mountains. These studies evaluated the effect of *Crotalaria spp* on maize grain yield in high altitude zones in the humid climate with no limitation of amount and distribution of rainfall.

Inadequate soil moisture is another factor which limits crop production in the sub humid areas. The erratic rainfall distribution has been the main cause of inadequate soil moisture during the cropping season and, consequently, causing low crop yields in the sub humid areas. High runoff losses and low water holding capacity of the soils in sub humid areas further aggravate the inadequacy of soil moisture to plants. Besides the direct effect on crop growth, inadequate moisture indirectly limits

nutrient availability by either reducing nutrient mobility to and within the plant and the rate of N mineralization or retarding root growth. The problem of moisture inadequacy to plants may be effectively solved by irrigation but the practice is not feasible in many parts of the country due to limited water sources and the high initial cost (Hatibu *et al.*, 1991). Tillage practices such as deep tillage, open and tied ridges have been reported to be effective in soil water conservation in some cases (Macartney *et al.*,1971; Huxley, 1979) and ineffective in other cases (Antapa, 1990; Hatibu *et al.*, 1991; Saether *et al.*, 1997) depending on soil texture and amount of rainfall received. However, the above-mentioned practices do not add nutrients in the soil system but rather improve infiltration of water into the soil.

The use of cover crops is another strategy that can increase soil moisture in the subsequent season. Work done in Canada and the United State of America, in the temperate environment has shown that cover crops increase soil water retention (Keisling *et al.*, 1994), infiltration (Gulick *et al.*, 1994), decrease surface strength (Folorunso *et al.*, 1992; Bauer and Busscher, 1996) and stabilize soil aggregates (Jordahl and Karlen, 1993; Hermawan and Bomke, 1997). During their growing period, cover crops deplete water from the soil but after they are terminated they produce mulch, which conserves soil moisture (Unger and Vigil, 1998). Cover crops can also influence soil moisture content indirectly by suppressing weeds (Versteeg *et al.*, 1998; Vissoh *et al.*, 1998; Udensi *et al.*, 1999; Chikoye and Ekeleme, 2000). Cover crops can also be used to increase soil N and to conserve soil moisture.

Performance of cover crops varies with species and elevation (Gachene *et al.*, 1997; Maobe *et al.*, 1998). Studies conducted in Kenya indicated that most cover crop species perform well in the upper midland zones (1300 - 1800 m.a.s.l.), followed by lower highlands (1800 - 2300 m.a.s.l.) and lower mid zones (800 - 1300 m.a.s.l.). These studies did not evaluate the influence of cover crops on nutrient and moisture availability to the succeeding cereal crop like maize. Work done on cover crops in Tanzania concentrated on the effect of *Crotalaria ochroleuca* on maize yield but did not assess their effect on N and moisture availability.

The limitations mentioned earlier in the use of mineral fertilizers, FYM and irrigation faced by small scale farmers in Tanzania indicate that there is need to explore the possibility of tapping the advantages of cover crops in crop production. The potentials of cover crops in zones which are relatively drier like the sub humid areas of Morogoro have not been fully explored. Kalumuna *et al.* (1999) summarized work done on the use of organic fertilizers in Tanzania and revealed that little work has been done on cover crops in relatively drier areas. The findings showed that the effect of *Crotalaria* on inter-cropped and on subsequent maize grain yield was very variable, ranging from zero to 1.07 Mg ha $^{-1}$ indicating that *Crotalaria* may not be the appropriate cover crop for these sub humid areas.

Herbaceous and grain legumes like mucuna, lablab and cowpea which are known to be relatively drought tolerant (Gachene *et al.*, 2000), may be potential cover crops in these sub humid areas. There are other non-leguminous crops grown in the area like pumpkin that have extensive vegetative growth and substantial ground cover, which

## 1.2 General objective

To determine the effectiveness of cover crops on soil N availability, soil moisture conservation and maize grain yield in the sub humid environment of Morogoro.

## 1.3 Specific objectives

1. To evaluate the performance of cover crops grown in the short rains under the sub humid environment.
2. To assess the influence of cover crops on N availability in the subsequent maize crop.
3. To evaluate the effects of cover crops on soil moisture content.
4. To assess the effect of cover crops on some soil characteristics that influence soil moisture status.
5. To evaluate the effects of cover crops on maize grain yield.

# CHAPTER TWO

# LITERATURE REVIEW

## 2.1 Soil nitrogen

Nitrogen is a plant nutrient that is needed in larger quantities than others. In Tanzania, N taken out of the soil through crop harvest annually has been estimated to range from 20 to 40 kg $ha^{-1}$ whereas removal of K and P ranges from 16.6 to 33.2 and 3.5 to 6.6 kg $ha^{-1}$, respectively (Smaling *et al.*, 1997). Nitrogen is, therefore, a major limiting nutrient particularly in cereal production (Tisdale *et al.*, 1990; Sanchez *et al.*, 1997) and its deficiency is common all over Tanzania (Samki, 1989). This is reflected in crop yield responses to different rates of N fertilizer obtained on different soils (Mowo *et al.*, 1993).

### 2.1.1 Sources of soil nitrogen

There are two major sources of soil N, namely organic and inorganic N. Organic N is contained in soil organic matter whereas inorganic N is contained in soil solution and on soil exchange sites. Organic N constitutes between 95 and 99% of soil N whereas inorganic N accounts for only 1 to 5% (Brady and Weil, 2000). Inorganic N is the form that is taken by plants (Warren *et al.*, 1997). Organic N may be transformed to inorganic N and *vice versa* depending on soil pH, water, oxygen, and temperature. This indicates that both forms are important for plant N uptake. Organic matter plays a major role as N source because most of the soil N is derived from its biological decomposition (Zech *et al.*, 1997).

Nitrogen may be added to the soil from external sources through industrial fertilizers, organic inputs, biological $N_2$ fixation and atmospheric N deposition (Brady and Weil,

2000). Atmospheric deposition has little contribution, amounting to ≤ 10 kg N $ha^{-1}$ $year^{-1}$ (Mengel and Kirkby, 1987). Organic inputs include farmyard manure (FYM), compost manure, green manure and plant residues. The amount of N added to the soil by the organic input depends on the quantity and N content of the added material. Nitrogen content of FYM is low and variable ranging between 0.58 and 0.74% (Kasembe *et al.*, 1983). Therefore, large quantities are needed to meet crop N requirement. Likewise, N content of compost manure is also low and variable, depending on the chemical composition of the materials used for its preparation and its management. Compost preparation is labour intensive. The high labour demand associated with preparation and transportation is a major bottleneck to wide use of FYM and compost manure.

Agroforestry (Kwesiga *et al.*, 1999; Ikerra *et al.*, 2001) and the use of legume cover crops (Lal, 1990; Sanchez and Jama, 2002) are among the technologies that can generate high *in situ* plant biomass thereby increasing soil N content through biological N fixation at relatively lower labour costs.

### 2.1.2 Biological $N_2$ fixation

Biological N fixation is a process whereby atmospheric N may be converted to soil N. Various microorganisms including specific cyanobacteria, actinomycetes and bacteria mediate this process. *Rhizobia* are the predominant group of the $N_2$ fixing organisms (Giller and Wilson, 1991). These are symbiotically associated with legume roots through nodules. In the root nodules, the rhizobia reduce atmospheric $N_2$ to $NH_4^+$. The amount of $N_2$ fixed in this process depends on the characteristics of the host legume and soil properties.

### 2.1.2.1 Effect of host plant characteristics on $N_2$ fixation

The characteristics of the host plant affecting $N_2$ fixation include vigour and life span of the plant and nodules. The host plant should be able to generate sufficient photosynthates for its metabolism and energy supply for rhizobia. Rhizobia require 28 moles of Adenosine Tri Phosphate (ATP) from the plant, which costs about 33% of plant photosynthates for each mole of $N_2$ fixed (Michin *et al.*, 1981; Saari and Ludden, 1986). This implies that weak plants that are unable to generate adequate photosynthetes may attain little $N_2$ fixation. MacColl (1989) reported that more $N_2$ was fixed in legumes with higher than with lower vegetative growth. According to Humphreys (1995), 15 to 40 kg N is fixed for each 1000 kg dry matter of the legume shoots, indicating that the legumes have to produce high biomass in order to fix considerable amount of $N_2$.

The life span of the host plant and nodules also influence the amount of $N_2$ fixed. The longer the life span of the legume and nodule the higher the amount of $N_2$ fixed. Giller and Wilson (1991) reported that *Desmodium ovalifolium* grown for 17 and 52 weeks fixed 25 and 61 - 110 kg N $ha^{-1}$, respectively. However, the peak N fixation is attained at flowering stage (Palm *et al.*, 2001; Cheruiyot *et al.*, 2001), hence extending cover crop growth beyond this stage results to low amount of $N_2$ fixed in the soil as most of N is translocated to the seeds.

### 2.1.2.2 Effect of soil properties on $N_2$ fixation

Soil properties that influence $N_2$ fixation include soil pH, P, Mo, $O_2$, $NO_3^-$ and water availability. Nitrogen fixation is retarded under acidic (pH < 6.5) soil conditions, limited P (P < 15 mg $kg^{-1}$), low Mo (< 0.1 mg $kg^{-1}$), low water (water potential < -50 kPa) and limited $O_2$ (Mengel and Kirkby, 1987). Soil acidity and inadequate Mo limit the formation

of root nodules, whereas acidic soils, low P and anaerobic conditions reduce the growth of the host plant. Nitrate promotes early growth and extensive root system of the host plant, hence hastening $N_2$ fixation (Section 2.1.2.1). However, high levels of soil $NO_3^-$ retard $N_2$ fixation process (Harper and Gibson, 1984; Armstrong *et al.*, 1999) by depressing nodule formation and inhibiting nitrogenase activities of mature nodules (Giller and Wilson, 1991). Armstrong *et al.* (1999) reported that nitrogen derived from atmospheric fixation (Ndfa) was reduced by 50% when soil $NO_3^-$ increased from 20 to 40 kg $ha^{-1}$ and was reduced to < 20% when soil $NO_3^-$ exceeded 40 kg $ha^{-1}$. The critical value for $NO_3^-$ varies with legume species, but it generally ranges between 2 and 20 mM (Harper and Gibson, 1984).

### 2.1.3 Mineralization of organic N

Mineralization is an enzymatic process that converts amino compounds (organic N form) to mineral N (Brady and Weil, 2000). The N contained in soil organic matter has to decompose and undergo mineralization before it is taken up by plants (Mengel and Kirkby, 1987; Piccolo *et al.*, 1994). Mineralization of organic N involves two biological processes, namely, ammonification and nitrification. Ammonification is a process mediated by heterotrophs that reduces amino N to ammonium N, whereas nitrification is an autotroph - mediated process that oxidises ammonium N to $NO_2^-$ and $NO_3^-$ forms. The process of mineralization is summarized in Equation 1.

$$R\text{-}NH_2 \overset{a}{\rightleftharpoons} OH^- + R\text{-}OH + NH_4^+ \overset{b}{\rightleftharpoons} 4H^+ + \text{energy} + NO_2^- \overset{c}{\rightleftharpoons} \text{energy} + NO_3^- \quad \text{.....[1]}$$

Where: a = 1mol $H_2O$ is used

b = 0.5 mol $O_2$ is used

c = 1.5 mol $O_2$ are used

Mineralization takes place when the reaction goes to the right and immobilization takes place when the reaction goes to the left. The direction of this equation is determined by soil moisture status, $O_2$ supply, soil pH, temperature and activities of soil microorganisms mediating the processes.

### 2.1.3.1 The effect of soil moisture on N mineralization

Soil moisture governs N mineralization by influencing microbial activities involved in this process. Low soil moisture condition < -1500 kPa restricts the activities of bacteria involved in nitrification, consequently slowing down the rate of N mineralization. Nitrification is more sensitive to moisture stress than ammonification. Thus, more $NH_4^+$ accumulates in the dry season than does $NO_3^-$ (Mengel and Kirkby, 1987). Ammonification was reported to take place even at water potential as low as –1.5 MPa (Robinson, 1957). Robinson (1957) observed that nitrification stopped completely at potential of -1.5 MPa, while ammonification was still taking place.

The rate of nitrification increases with adequate soil moisture. Re-wetting of dry soil by the first rains following a dry period results into a sharp increase in soil $NO_3^-$ levels referred to as nitrate flush (Warren *et al.*, 1997; Ikerra *et al.*, 1999). The optimum moisture for nitrification is 80% of the soil's field capacity (Scholes *et al.*, 1994). Under excess soil moisture conditions, when water fills more than 90% of soil pore space, mineralization processes cease and denitrification processes dominate, resulting to conversion of $NO_3^-$

and $NO_2^-$ to nitrogenous gases (NO, $N_2O$ and $N_2$). These gases are eventually lost into the atmosphere (Aulakh *et al.*, 1991). This condition normally occurs when the field is water logged (Mengel and Kirkby, 1987), but may also occur after heavy rains due to temporal anaerobic soil conditions (Blevins and Frye, 1993; Warren *et al.*, 1997; Brady and Weil, 2000).

### 2.1.3.2 The effect of soil oxygen on N mineralization

Oxygen is required to oxidize $NH_4^+$ to $NO_3^-$ in the nitrification process and for respiration of soil microorganisms. Inadequate $O_2$ supply limits N mineralization and favours denitrification. The condition of inadequate $O_2$ supply occurs when the soil is water logged or when there is high microbial population (Myers *et al.*, 1994; Warren *et al.*, 1997).

#### 2.1.3.3 The effect of soil texture and structure on N mineralization

Soil texture and structure have indirect effects on the mineralization process because they control pore size distribution and continuity. The pore size distribution and continuity influence soil water availability, gas diffusion and the movement of soil organisms, all of which influence decomposition of soil organic matter and N mineralization. The pore size of 0.75 – 6 μm is considered favourable for N mineralization because it makes SOM more accessible to bacteria responsible for mineralization. This size fraction decreases exponentially with increasing clay content (Mtambanegwe *et al.*, 2004). Weber *et al.* (1995) reported higher mineralization rates in loamy sands than in sandy loam, with peak N release between day 7 and 14 and day 14 to 35 days of incubation, respectively.

### 2.1.3.4 The effect of soil pH on N mineralization

Soil pH affects N mineralization indirectly as it controls the activities of bacteria responsible in mineralization processes. The optimum soil pH for nitrifiers is 6.5 to 7.0 (Mengel and Kirkby, 1987). The activities of nitrifiers is reduced under low soil pH (soil acidity) hence causing the reaction in Equation 1 to shift to the left and hence reducing nitrification rate. The effect of soil pH on N mineralization was elaborated by Mengel and Kirkby (1987) where 20 mg $NH_4^+$ incubated for 35 days was nitrified to 47.2 mg $NO_3^-$ $kg^{-1}$ when soils pH was 4.4 but it was nitrified to 214 mg $NO_3^-$ $kg^{-1}$ when soil pH was 6.0.

At soil pH > 6.0 ammonium is converted to ammonia and lost through volatilazation as shown in the following equation

$$NH_4^+ \rightleftharpoons NH_3\uparrow + H^+ \quad \text{.....[2].}$$

As soil pH increases, $H^+$ ions in solution are reduced, hence shifting the reaction in Equation 2 to the right by converting more $NH_4^+$ to $NH_3$, reducing the concentration of $NH_4^+$. Reduction in concentration of $NH_4^+$, shifts the reaction in Equation 1 to the left by converting $NO_3^-$ to $NH_4^+$, hence retarding ammonification and nitrification processes and favouring denitrification process (Brady and Weil, 2000).

### 2.1.3.5 The effect of soil temperature on N mineralization

Soil temperature controls the activities of nitrifiers and ammonifiers and hence influencing nitrification and ammonification processes. Both ammonification and nitrification processes increase with soil temperature, but nitrification attains its optimum at relatively lower temperatures (Azam *et al.*, 1993; Brady and Weil, 2000).

The optimum temperatures are 26°C and 50°C for nitrification and ammonification, respectively (Azam *et al.*, 1993). This suggests that there are higher levels of $NH_4^+$ than $NO_3^-$ in the soil under high temperature conditions. High soil temperature (> 40°C) has been reported to increase the rate of denitrification (Brady and Weil, 2000). Low temperatures (< 10°C) reduce soil biological activities hence retarding ammonification and nitrification processes (Mengel and Kirkby, 1987; Scholes *et al.*, 1994).

### 2.1.4 Nitrogen dynamics in the soil

Nitrogen dynamics refer to nitrogen changes with respect to forms, time and soil depth. Nitrogen dynamics is governed by soil moisture, pH and temperature. Soil moisture has more influence on N dynamics than pH and soil temperature. On rainfed agriculture, soil moisture depends on rainfall hence amount and distribution of rainfall play a major role in determining N dynamics. Most of soil N is in the topsoil, the layer which has higher organic matter input as compared to the subsoil. Powlson *et al.* (1992) reported that 84 - 88% of soil N is within the top 23 cm of the soil. But higher levels may be found in subsurface horizons following leaching of $NO_3^-$ accumulated in the surface horizon by high rainfall.

Highest levels of $NO_3^-$ in the topsoil are obtained at pre - season, a few days following the first rains but drop sharply later resulting to increased N levels in the subsoil (Hagedorn *et al.*, 1997; Warren *et al.*, 1997; Ikerra *et al.*, 1999; Whitbread *et al.*, 2002). Hagedorn *et al.* (1997) reported nitrate flush amounting to 14.8 mg N $kg^{-1}$ soil in the first 5 days following 3 months of dry period in Rwanda. In Kenya, $NO_3^-$ flush ranging from 10 to 14 mg N $kg^{-1}$ was reported by Warren *et al.* (1997). In Malawi, $NO_3^-$ flush in the topsoil amounted to

15.1 kg N $ha^{-1}$ in sole maize and 59.3 kg N $ha^{-1}$ soil in gliricidia treatments (Ikerra *et al.*, 1999).

Mineral N in the topsoil decreases rapidly after the first rains, due to leaching (Ikerra *et al.*, 1999; Whitbread *et al.*, 2002) and denitrification (Janzen and McGinn, 1991; Brady and Weil, 2000). Ikerra *et al.* (1999) observed that in 5 weeks after the first rains, mineral N decreased from 21 and 69 kg N $ha^{-1}$ to < 10 kg N $ha^{-1}$ in sole maize and gliricidia treatments, respectively, leading to corresponding increases in the subsoil. Work by Whitbread *et al.* (2002) in Zimbabwe on a sandy soil showed that pre - season $NO_3^-$ in the top 0 - 15 cm was 7 mg $kg^{-1}$ following weed fallow and 30 mg $kg^{-1}$ following mucuna but at planting after 32 mm rainfall, $NO_3^-$ in mucuna treatment declined from 30 to 11 mg $kg^{-1}$ with corresponding increase in the 15 - 30 cm soil depth. At 2 weeks after planting, following 111 mm rainfall, $NO_3^-$ levels in the 0 - 15 cm soil layer declined to 2 mg $kg^{-1}$ and $NO_3^-$ bulge was formed at 15 – 30 cm soil layer. Thereafter, $NO_3^-$ levels were < 4 mg $kg^{-1}$ in all soil layers, indicating the possibility of leaching losses. Warren *et al.* (1997) reported that between 6 and 48 days after the onset of rainfall, $NO_3^-$ in the topsoil in Mutuobare, Kenya, decreased by 96 kg $NO_3^-$ $ha^{-1}$. In the dry season $NH_4^+$ was reported to increase whereas the levels of $NO_3^-$ were low and constant. Reduced plant uptake and lack of nitrification in the dry period explained the accumulation of $NH_4^+$ - N observed in the dry period.

### 2.1.5 Soil nitrogen losses

Nitrogen can be lost from the root zone in various ways including denitrification (Brady and Weil, 2000), leaching (Ikerra *et al.*, 1999; Whitbread *et al.*, 2002), nutrient transfer by crop harvest (Stoorvogel *et al.*, 1993) and erosion (Ngatunga, 1984). Depending on soil

pH, moisture and temperature of the soil, gaseous nitrogen in the form of NO, $N_2O$, $NO_2$ and $N_2$ are prone to losses ranging between 5 and 50% of the N applied (Mengel and Kirkby, 1987). Nitrogen in form of $NO_3$ may be lost through leaching under high rainfall conditions especially in soils with low water holding capacity and low anion exchange capacity (Scholes *et al.*, 1994).

Leaching losses vary between crops depending on root vigour and depth (Pieri, 1995). Losses ranging from 0.3 to 7.1 kg N $ha^{-1}$ were reported under cereals and as high as 25 kg N $ha^{-1}$ under groundnuts in West Africa with annual rainfall of 507 - 705 mm (Pieri, 1995). There was no mention whether these crops were fertilized with N fertilizer indicating that N leached came from mineralized soil organic matter. Leaching on coarse textured soils is higher than on clays. Leaching loss as high as 40 kg N $ha^{-1}$ $y^{-1}$ was reported on sandy soils in Sweden and Denmark (Hansen and Djurhuus, 1997). Studies have shown that erosion losses through sediment transport can account for > 95% of N losses (Brurwell *et al.*, 1975). In Minnesota, erosion losses amounting to 50 - 110 kg N $ha^{-1}$ $y^{-1}$ have been reported (Power, 1983). Soil N is also lost through crop harvests that are not returned to the field. According to Stoovogel *et al.* (1993) this loss ranges from 20 to 40 kg N $ha^{-1}$ $yr^{-1}$ in Tanzania. Due to these losses and the dynamic nature of N, management of this nutrient needs much attention in order to optimize its availability to crops.

### 2.1.6 Nitrogen management strategies

Two strategies, namely reducing N losses in the root zone and improving N uptake by crops may be used in management of soil N.

### 2.1.6.1 Reducing N losses in the root zone

Soil N may be prevented from leaching losses through several management options including recycling, early sowing and by multiple cropping (Woomer and Swift, 1994; Hartemink *et al.*, 1996; Mekonnen *et al.*, 1997). Nitrogen recycling can be achieved by planting deep - rooted trees or shrubs that extract leached N from the subsurface horizons and return them to the soil surface upon the decomposition of leaf litter and roots. Mekonnen *et al.* (1997) found that subsoil $NO_3^-$ was lowered by 64 kg N $ha^{-1}$ under one year sesbania fallow and was increased under maize by 44 kg N $ha^{-1}$ indicating the ability of sesbania to capture and recycle subsoil $NO_3^-$. Apart from trees, weeds and shrubs have been reported to recycle soil N. Mekonnen *et al.* (1997) reported that $NO_3^-$ in lower horizon down to 2 m depth was reduced by 107 kg N $ha^{-1}$ under 1 year un managed weed fallow whereas under maize it increased by 44 kg N $ha^{-1}$. This shows the ability of weed fallow to extract soil N from deeper horizons than maize, hence reducing leaching losses.

Planting at the right time and at proper spacing are among crop husbandry practices that reduce N losses by leaching, erosion and denitrification of soil N. Early sowing ensures that crops use most of available N produced from $NO_3^-$ flush, hence minimizing leaching losses of N. Multiple cropping, on the other hand, promotes maximum N uptake from the soil thereby reducing the extent of N leaching. Use of organic inputs also reduces leaching of soil N by increasing the soil water holding capacity and anion exchange capacity.

Physical barriers, biological control measures, appropriate crop rotation and cover crops control soil erosion and reduce N that would otherwise be lost through sediment transport (Lal, 1989; Blevins and Frye, 1993). Nitrogen loss by erosion was reduced from 55% to 22% by changing from continuous maize to maize-wheat-clover rotation (Blevins and

Frye, 1993). The practices that ensure good soil aeration, such as proper soil drainage, may reduce denitrification and hence reduces N losses. According to Brady and Weil (2000), the soil should have 10 - 20% of its pore space empty for aeration in order to reduce the rate of denitrification.

### 2.1.6.2 Improving crop N uptake

Improved crop N uptake can be achieved by creating favourable conditions of soil pH and supply of water and other nutrients especially P (Mengel and Kirkby, 1987). Improving soil physical characteristics such as soil bulk density, soil porosity and soil aggregate stability increase crop N uptake. Hulugalle and Lal (1986) observed that pigeon pea in rotation with maize under zero tillage reduced bulk density by 0.05 Mg $m^{-3}$ and increased maize roots penetrating 20 - 30 cm layer by 82.7% as compared to continuous maize. The improvement in bulk density and root penetration increased maize N uptake.

## 2.2 Soil moisture

Soil moisture is the most important soil characteristic determining crop production. Soil moisture is required by plants for cell turgidity and photosynthesis and it acts as a medium for translocation of nutrients to and within the plant (Mengel and Kirkby, 1987). Soil moisture controls the rates of soil biological processes such as $N_2$ fixation, OM decomposition, mineralization, denitrification and leaching as outlined in sections 2.1.2.2 and 2.1.3.1. It also controls soil aeration, which influences biological reactions in the soil (See sections 2.1.3.1 and 2.1.3.2).

### 2.2.1 Factors influencing soil moisture

Soil moisture (soil water content) at any particular time is determined by water balance as expressed in Equation 3.

Soil water = R + I + ST – RO – E – D – U .....[3].

Where: R = rainfall (mm)

I = irrigation (mm)

ST = storage (mm)

RO = runoff (mm)

E = Evaporation (mm)

D = drainage (mm) and U = plant uptake

#### 2.2.1.1 Rainfall

Rainfall is a major source of soil water particularly in rain-fed agriculture. The amount and rate (intensity) of rainfall play a big role in regulating soil water. Rainfall amount determines the amount of water available to replenish the soil moisture whereas rainfall intensity influences the amount of rain entering the soil (effective rainfall). Rainfall intensity and the rate at which rainwater enters the soil (infiltration rate) determine the amount of effective rainfall and runoff. When rainfall intensity exceeds infiltration rate, the excess water is lost as surface runoff (Lal, 1990).

Rainfall affects water infiltration through raindrop impact on the soil surface. The impact of raindrops detaches soil particles, which may lead to surface sealing or blockage of the pore spaces in the soil profile, consequently reducing infiltration rate (Douglas and Goss, 1982; Lal *et al.*, 1989). Rainfall also influences activities of soil organisms that play a

major role in soil aggregation and creation of soil biopores, ultimately influencing the infiltration rate (Douglas and Goss, 1982; Lal *et al.*, 1989). Rainfall also indirectly affects soil moisture by influencing organic matter production, which is crucial in soil aggregation and water holding capacity (Woomer *et al.*, 1994). Amount and frequency of rainfall affect soil wetness indirectly influencing infiltration rate and runoff of the subsequent rainfall (Littleboy *et al.*, 1996; Rao *et al.*, 1998). Work by Rao *et al.* (1998) showed that the rainfall characteristic that had greatest influence on runoff depended on the wetness of the soil and ground cover. They reported that the amount of rainfall had more influence on runoff on dry soil with limited ground cover (<30%) than on wet soil with high ground cover (>30%). The product of the amount and intensity of rainfall has more influence on runoff than the amount of rainfall alone on wet soil or on dry soil with high ground cover.

### 2.2.1.2 Water infiltration and runoff

Infiltration is defined as the rate at which water percolates into the soil through its soil–atmosphere interface (Ghildyal and Tripathi, 1987). Infiltration is influenced by soil total porosity, pore size distribution and continuity of soil pores. These factors are determined by the soil texture and structure. However, they can also be influenced by external factors such as rainfall, human and animal activities (FAO, 1978).

Surface sealing caused by raindrop impact and soil compaction by animal or machinery may clog soil pores thereby reducing infiltration rate (Dabney, 1998). Surface sealing can reduce infiltration even on sandy soil as reported by Valentin (1981) in Niger and by Hoogmoed and Stroosnijder (1984) in Mali. Casenave and Valentin (1989) reported that infiltration rate in soils with surface sealing can range between 0 and 2.5 cm $h^{-1}$.

Cultivation of the soil breaks the surface seal and compacted layer, leading to increased infiltration rate. Willcocks (1984) in Sebele, Botswana, reported that cultivating a sandy loam increased soil porosity from 32 to 45% and infiltration rate by 24 cm $h^{-1}$ (< 12 to 36 cm $h^{-1}$). Blevins and Frye (1993), on the other hand, reported that cultivation reduced water stability of soil aggregates and subjected them to erosion and surface sealing.

The amount of rainwater that enters the soil depends on rainfall amount, intensity, initial soil moisture content and ground cover (Littleboy *et al.*, 1996; Rao *et al.*, 1998). Littleboy *et al.* (1996) identified wetness of the surface soil and ground cover as the most important factors in predicting the amount of rainfall that is lost through runoff.

Infiltration rate is governed by matric potential and gravitational force (Ghildyal and Tripathi, 1987), expressed by the following Philips model:

$I = St^{0.5} + At$ .....[4].

Where: I is cumulative infiltration

S is sorptivity. It is a term that is dependent on soil matric potential.

A is a constant = 0.333 * Saturated hydraulic conductivity. It is a term that is controlled by gravitational force.

t is time in seconds.

Early infiltration stages are mainly governed by matric potential but as the soil moisture in the profile increases matric potential diminishes making gravitational force play the major

role at the later stages (Ghildyal and Tripathi, 1987). Initial soil moisture content influences early infiltration rate because it is negatively related to the matric potential, but it has no influence on later infiltration stages. Apart from affecting soil matric potential, the initial soil moisture content influences infiltration rate through its effect on aggregate breakdown (Truman and Bradford, 1990; Le Bissonnais *et al.*, 1992). Increasing initial soil moisture content may result into increased aggregate breakdown, surface sealing and runoff because wet soils are more susceptible to rain drop impact as they have lower shear strength than dry soils (Le Bissonnais *et al.*, 1992). In cases where slaking is more important than rain drop impact, increasing initial soil moisture content from air dry to near field capacity may lead to reduced aggregate breakdown and runoff. Le Bissonnais *et al.* (1992) reported that 25 mm of rain caused runoff of 25 mm $h^{-1}$ on dry soil while it caused no runoff on pre – wetted soil. In the absence of soil aggregate degradation, when the soil is covered by vegetation or by a well - formed crust, higher runoff occurs on initially wet soil than on a dry soil (Le Bissonnais *et al.*, 1992; Littleboy *et al.*, 1996; Rao *et al.*, 1998).

The time available for infiltration also influences amount of water that enters the soil (Blevins and Frye, 1993). This in turn is affected by the land slope, soil surface characteristics and presence of vegetative cover on the soil surface (FAO, 1978; Rao *et al.*, 1998). The slope of the land controls the speed of water movement on the soil surface hence determining the time available for infiltration. Increased slope steepness results into rapid water movement on the soil surface and reduced time for infiltration (FAO, 1978). Rough soil surfaces create micro-basins that hold water longer than smooth surfaces, thereby availing more time for infiltration (Blevins and Frye, 1993; Okwach, 2000). Vegetative materials that cover the soil surface also retard the speed of water, increasing

time for infiltration and reducing amount of runoff (Wall *et al.*, 1991; Dabney, 1998). In their study, Wall *et al.* (1991) observed that increased residue cover led to increased time for infiltration and reduced runoff ultimately increasing infiltration. Dabney (1998) reported that the presence of *Lespedeza stipulaceae* or *Poa pratensis* as cover crops decreased runoff velocity 10 - fold relative to smooth surface and 5 - fold relative to bare soil surface. Increased infiltration may lead to increased leaching losses of soluble plant nutrients in sandy soils and in wet climatic zones (Blevins and Frye, 1993).

2.2.1.3 Soil aggregate stability

Soil aggregate stability in water is used as an index of soil resistance to dispersion and compaction (Kang *et al.*, 1991). It influences soil porosity and ultimately water infiltration and runoff. Soil porosity and infiltration are reduced when soil particles block water - conducting pores. This occurs when soil aggregates break down into small aggregates by dispersion due to rain - drop impact or by slaking due to rapid wetting of soil aggregates (Ghildyal and Tripathi, 1987). These small aggregates may form a crust on the soil surface or enter the profile and block water transmission pores and ultimately reducing the amount of water entering the soil profile (FAO, 1978).

Tisdall and Oades (1982) reported that persistent and decomposable binding agents are involved in soil aggregation. Persistent binding agents include clays and the oxides of iron and aluminium and decomposable binding agents involve microbial biomass and microbial by - products. Elliott (1986) reported that plant roots and the associated mycorrhiza are also involved in soil aggregation. Persistent binding agents bind micro – aggregates (< 250 μm) whereas decomposable binding agents and plant roots and mycorrhiza bind macro – aggregates (> 250 μm). Due to the decomposable nature of the

binding agent, macro – aggregates are more affected by soil management than micro – aggregates (Haynes and Swift, 1990).

Other studies have shown that cultivation practices and cropping systems affect the level of water stable soil aggregates (Aina, 1979; Yaacob and Blair, 1981; Mc Vay *et al.*, 1989; Kandeler and Murer, 1993; Blair and Crocker, 2000). Ploughing and conventional tillage lower water stable soil aggregates because they subject SOM to rapid decomposition (Aina, 1979; Bruce, 1991; Kandeler and Murer, 1993). Aina (1979) reported that ploughed land had lower water stable soil aggregates (23%) than uncultivated land (79%). Cropping systems that were reported to increase soil aggregate stability included permanent grassland (Kandeler and Murer, 1993) and legume cover crops (Yaacob and Blair, 1981; Mc Vay *et al.*, 1989).

### 2.2.4 Management of soil water

Addition of organic materials, mulching and use of cover crops are among the management practices that could be used to conserve soil moisture (Lal, 1990; Mahoo, *et al.*, 1996; Rasse *et al.*, 2000; Ghuman and Sur, 2001). Mulch conserves soil moisture by reducing runoff loss of rainwater (Lal, 1976; Ngatunga *et al.*, 1984; Freebrairn and Boughton, 1985; Okwach, 2000), increasing water infiltration rate (Rasse *et al.*, 2000; Ghuman and Sur, 2001) and improving soil aggregation (Cannell and Hawes, 1994; Børrsen, 1997; Rasse *et al.*, 2000). Ngatunga *et al.* (1984) observed that application of mulch at 6 Mg $ha^{-1}$ reduced runoff by 21 and 53 mm on a slope of 10 and 22%, respectively. In Machakos, Kenya, application of 50% of stover obtained from the previous maize crop was reported to reduce runoff by 42% compared to bare fallow (Okwach, 2000). Freebrairn and Boughton (1985) reported that stubble mulch increased

infiltration rate by 100% and reduced runoff by 40% over stubble incorporation resulting to 25 mm more water storage. Ghuman and Sur (2001) reported that initial infiltration of minimum tilled soil, infiltration rate and cumulative infiltration were increased by 1.6, 0.2 and 1.9 cm $h^{-1}$, respectively by surface applied crop residue after 5 rotation cycles. Alfalfa mulch improved water infiltration and increased moisture content in the Ap horizon by 12.6% after 50 mm of rainfall whereas bare fallow increased it by 7.2%.

The amount of soil moisture may be improved by reducing runoff losses through increasing the quantity of cover crop residues on the soil surface. Singer and Blackard (1978) observed that runoff velocity was reduced by 50% following increased surface residues from 0 to 2 Mg DM $ha^{-1}$. Also, mulch improves soil moisture content through improving water stability of soil aggregates (Section 2.2.1.3). Rasse *et al.* (2000) obtained an increase in mean weight diameter (MWD) of 0.81 mm over bare fallow by applying alfalfa mulch at the rate of 16.4 Mg dry matter $ha^{-1}$ for 2 years.

However, use of mulch is limited by inadequate supply of mulching material particularly in dry seasons. There is, therefore, a need to identify cropping systems that will enable *in situ* generation of residue mulch. Studies have shown that cover crops when properly incorporated in the cropping systems can generate *in situ* biomass, which can serve as mulching material (Unger and Vigil, 1998). Studies have shown that the performance of cover crops varied with species and climate (Zhu *et al.*, 1991; Unger and Vigil, 1998; Gachene *et al.*, 2000).

## 2.3 Cover crops

Cover crops are leguminous or non-leguminous plants that cover the soil and protect it against the impact of raindrops and soil erosion by water or by wind (Dabney, 1998). Lal *et al.* (1991) defined cover crops as plants grown specifically to protect the soil against erosion, ameliorate soil structure, enhance soil fertility and suppress weeds, insects and pathogens. From this definition, cover crops encompass a wide range of vegetation including grain legumes, green manure, pastures and vegetation planted as grass strips. However, the effectiveness of these vegetation as cover crops vary depending on their growth habit, soil and climatic conditions. Cover crops have the advantage of producing mulch materials in situ consequently eliminating transport costs.

Research work done in the temperate countries (Jordahl and Karlen, 1993; Gulick *et al.*, 1994; Hermawan and Bomke, 1997; Unger and Vigil, 1998) and in humid climates in Africa (MacColl, 1989; Sanginga *et al.*, 1996a; Carsky *et al.*, 1998; Fischler and Wortmann, 1999) have demonstrated the potential of cover crops on plant nutrients supply, soil moisture conservation and on yield increase of crops grown in the subsequent season.

### 2.3.1 Use of cover crops for soil fertility improvement

Cover crops improve soil fertility by reducing nutrient losses through soil erosion and leaching, by adding nutrients through decomposition of organic matter to the soil and by fixing atmospheric $N_2$ in case of leguminous crops (Unger and Vigil, 1998). Importance of incorporating legume cover crops in cropping systems is due to their role in $N_2$ fixation and to high N content in their residues, for uptake by succeeding crops. According to Giller and Wilson (1991) about ≥40% of N in the legume leaf biomass is released in less

than 2 weeks after application. Cover crops control soil erosion, thus reducing N and other nutrients like P and K from being lost. Zobisch *et al.* (1995) studied the influence of plant cover on nutrient losses by erosion in Kenya and found that P losses were reduced by 75.8 under maize, 84.7 under beans and 90.7% under maize - bean intercropping. Losses of K were reduced by 71.7, 84.6 and 89.3% under maize, beans and maize - bean intercropping, respectively.

Uptake of water and nutrients by cover crops reduce deep percolation of water, thereby reducing leaching of nutrients (Biederbeck and Bouman, 1994). Agamuthu and Broughton (1985) reported that legume cover lowered leaching losses of N by 63 kg $ha^{-1}$ $y^{-1}$ as compared to natural re-growth. *Phacelia tanacetifolia* and *Secale cereale* planted in autum reduced leaching losses of $NO_3^-$ during winter by 65 - 70% of that under fallow (Wyland *et al.*, 1996).

### 2.3.1.1 Cover crop biomass production

Cover crops can generate above ground biomass ranging from 4 to 15 Mg DM $ha^{-1}y^{-1}$ in wet areas and 1 - 8 Mg DM $ha^{-1}y^{-1}$ in drier areas (Szott *et al.*, 1999). Galiba (1994) reported dry matter production of between 7 and 9 Mg DM $ha^{-1}$ for mucuna in bimodal rainfall zone of West Africa. In Nigeria, *Lablab purpureus*, *Mucuna pruriens* and *Crotalaria ochroleuca* produced biomass of 3.6, 3.2, and 3.7 Mg DM $ha^{-1}$ at 16 weeks after planting (WAP), respectively (Salako and Tian, 2003). Fischler and Wortmann (1999) obtained higher biomass production from cover crops in Uganda than those by Salako and Tian (2003) at 10 months after planting cover crops. The dry matter production was 8.0, 7.9 and 6.3 Mg DM $ha^{-1}$ for *L. purpureus*, *M. pruriens* and *C. ochroleuca*,

respectively. This shows that the amount of biomass that can be generated by cover crops varies with locations and duration of growth of the cover crop.

### 2.3.1.2 Nitrogen content of cover crop residues

Nitrogen content reported for some of the cover crops ranges between 3.04 - 5.77% for *Lablab purpureus* and 2.5 - 5.54% for *Mucuna pruriens* (Palm *et al.*, 1997). From the biomass production levels in section 2.3.1.1 and N contents, lablab and mucuna accumulated N ranging between 147.6 - 328 kg N $ha^{-1}$ and 112 - 276 kg N $ha^{-1}$, respectively. The contribution of roots to organic matter input is lower than the above ground vegetation. Mekonnen *et al.* (1997) reported that root biomass of *Sesbania sesban* and that of 19 month old weed fallow was 36 and 41% of the above ground biomass, respectively. The amount of N that can be accumulated by roots of cover crops ranges from 27 to 40% of the total N fixed (Armstrong *et al.*, 1999).

### 2.3.1.3 Effect of cover crops on soil pH, bases and temperature

Cover crops also influence soil properties such as pH and soil temperature, consequently affecting soil biological activities (Bessho and Bell, 1992; Pocknee and Sumner, 1997; Mullen *et al.*, 1998). The influence on soil pH depends on the chemical composition of the cover crop residues added to the soil. The amount of bases in the organic material relative to N content is among the factors that influence the final soil pH (Bessho and Bell, 1992). Pocknee and Sumner (1997) evaluated the effect of organic materials of various levels of bases on soil pH and found that the amount of bases correlated well with soil pH. The cover crop residues when surface applied moderate soil temperature. Cover crop residues may reduce soil temperature by 2 - 5 °C under high temperatures and increase it by 1 °C under low temperatures (IPM, 2004).

### 2.3.1.4 Biological $N_2$ fixation and N accumulated by cover crops

Leguminous cover crops have additional advantage of fixing atmospheric $N_2$. The fixed $N_2$ becomes available upon decomposition of roots, nodules and leaves (Palm *et al.*, 1997; Hoefsloot *et al.*, 1993). Leguminous cover crops, through biological processes can fix N ranging from 25 to 115 kg $ha^{-1}$ (Giller and Wilson, 1991). The above ground biomass contains 85% whereas the roots contains 15% of the $N_2$ fixed (Hoefsloot *et al.*, 1993), indicating that above ground biomass of legumes has higher contribution to soil N than the roots. The amount of N added to the soil by legume cover crops varies among crops depending on quality and amount of generated biomass. Non - edible legumes like *Mucuna* have higher N turnover than edible legume cover crops because in the latter some N is taken out of the field via harvestable grain and leaves (Giller *et al.*, 1997). Datt and Bhardwaj (1995) found that sunnhemp and sesbania grown for 55 days accumulated 103 and 84 kg N $ha^{-1}$, respectively, whereas cowpea grown for the same duration accumulated 67 kg N $ha^{-1}$. *Lablab purpureus* has relatively higher vegetative growth and lower grain yield and, as a result, it has relatively higher N turnover than groundnuts, soybean or pigeonpea (MacColl, 1989).

The amount of N input by the cover crop residues is also influenced by the stage of harvesting (Palm *et al.*, 1997; Cheruiyot *et al.*, 2001). Cover crops have been reported to accumulate higher levels of N at flowering stages than at seed formation (Palm *et al.*, 1997). Cheruiyot *et al.* (2001) indicated that cover crops slashed at early vegetative stage or at maturity had relatively lower N content in their residues than those slashed at flowering stage. The reason for higher N content in residues slashed at flowering stage than those slashed at early vegetative or at maturity stage is that maximum N uptake is

attained at flowering stage. At maturity stage a large portion of N taken by the cover crop is translocated to seeds which normally are not left in the field.

Soil and environmental conditions also determine the amount of N accumulated by the legumes as they affect $N_2$ fixation (Section 2.1.2) and biomass production. Higher accumulation is obtained under condition of adequate soil moisture of - 20 kPa to - 50 kPa (Mengel and Kirkby, 1987), soil pH of between 6.5 and 7.0 (Brady and Weil, 2000) and soil $NO_3^-$ of < 40 kg N $ha^{-1}$ (Armstrong *et al.*, 1999). Under adverse conditions of water stress or low soil pH, the capacity of the legume to fix atmospheric $N_2$ is appreciably reduced. Water stress depresses $O_2$ uptake and reduces the supply of metabolites required in legume nodules for $N_2$ fixation, leading to low N accumulation. The supply of plants with N from cover crop residues depends on N release pattern and recovery of the accumulated N.

### 2.3.1.5 Nitrogen release from cover crop residues

Nitrogen release from cover crop residues through net N mineralization depends on C:N ratio and residue degradability (Smith and Elliot, 1990). Decomposition of residues takes place in two phases, the first is rapid and the second is relatively slower (Jama and Nair, 1996). The first phase is controlled by the C:N ratio whereas the second phase is determined by the degradability of the residue which is controlled by the lignin and polyphenol content of the residue (Jama and Nair, 1996). The rate of first phase - decomposition is accelerated by high contents of soluble N in the residue. Critical levels of N below which the rate of decomposition is retarded are 18 to 22 mg $g^{-1}$ (Palm *et al.*, 1997). Studies on the relationship between N release and C:N ratio showed that net N

mineralization occurs when the applied residue has C:N ratio < 25 (Smith and Elliot, 1990; Myers *et al.*, 1994).

High lignin and polyphenol content of the residue retard the rate of second phase decomposition and eventually net N mineralization. Mellilo *et al.* (1982) reported that high lignin content of residues reduced N mineralization and enhanced N immobilization. The levels of 15 and 4% have been suggested as critical above which decomposition is reduced for lignin and polyphenol contents, respectively (Palm and Rowland, 1997; Palm *et al.*, 2001). Other workers have obtained good correlation between N release from residues and polyphenol:N ratio than with individual component (Palm and Sanchez, 1991; Oglesby and Fownes, 1992). Palm and Sanchez (1991) reported that net mineralization took place when the polyphenol:N ratio exceeded 0.5.

High quality residues decompose faster and release N earlier before the peak demand of N by cereal crops like maize. According to Karlen *et al.*, (1988) the peak demand of N by maize occurs between 6 and 9 weeks after planting (WAP) whereas most of high quality residues release most of N within four weeks after their application (Myres *et al.*, 1994; Ikerra *et al.*, 1999). This shows that there is lack of synchrony between N release by high quality residues and peak N demand of the subsequent cereal crop.

**2.3.1.6 Recovery of N accumulated in cover crop residues**

Only a small part of N accumulated by legumes becomes available to the succeeding main crop. For example, in temperate countries crops absorb only 10 – 30% of the accumulated N and the remaining is immobilized (Myres *et al.*, 1994) or get lost through leaching and denitrification (Smyth *et al.*, 1991). According to Ladd *et al.* (1983) and Janzen *et al.*

(1990), the N contribution from residues applied to a subsequent crop ranged from 1 to 4% of the N content of the material applied. Myres *et al.* (1994) reported that N recovered by the succeeding crop accounts for 15% of the amount accumulated in leguminous residues. Danso and Papastylianou (1992) reported that only 17% of the total N accumulated in barley was derived from $N_2$ fixed by vetch that was grown in previous two seasons. Haggar *et al.* (1993) and Sidhu and Sur (1993) reported that under tropical conditions N recovery ranged from 10 to 28%. This shows that only little benefit is obtained from leguminous cover crops as regards to N availability to a subsequent crop. However, increases in yields of cereal following legumes have been reported widely (Suwanarit *et al.*, 1986; Bruulsema and Christie, 1987; Bagayoko *et al.*, 1996) suggesting that there are other attributes of legumes that contribute to yield increases of the subsequent cereal crop. The increases in yields of subsequent crops are attributed also to N sparing effects, improved nutrient availability, improved soil physical characteristics and reduced pests and diseases (Wani *et al.*, 1995).

### 2.3.2 Effect of cover crops on soil moisture conservation

#### 2.3.2.1 Effect of cover crops on runoff

The effect of cover crops on soil moisture conservation is through the cover provided by canopy and residues of cover crops. Cover crops and their residues provide mulch to the soil surface that absorbs rain drop energy, leading to reduction in dispersion of the soil aggregates which would otherwise result to surface sealing and eventually runoff losses. The residues increase time of infiltration and reduce runoff velocity (Trojan and Linden, 1998). These effects increase the amount of rainwater that infiltrates the soil (Lal *et al.*, 1979; Lal, 1984; Wall *et al.*, 1991; Zougmore *et al.*, 1998). Zougmore *et al.* (1998) found that sorghum - cowpea intercropping system in Burkina Faso reduced runoff by 20 - 30%

compared to sole sorghum and 5 - 10% compared to sole cowpea. In Canada, red clover cover crop intercropped with maize reduced runoff by 45 to 87% relative to sole maize (Wall *et al.*, 1991).

Runoff is appreciably reduced when the ground covered by vegetation exceeds 30% (Elwell and Stocking, 1976). Ground cover varies between species depending on growth characteristics such as plant height and growth rate. Cover crops with fast growth rate produce high vegetative cover and attain the 30% ground cover earlier. For example, velvet bean planted during the short rains in Kenya recorded 85% ground cover in 8 weeks, whereas cowpea and pigeon peas recorded 22 and 13%, respectively (Gachene and Makau, 1997). Because most of the runoff losses are obtained early in the growing season, fast growing cover crops may be more efficient in reducing these losses hence increasing the amount of water infiltrating into the soil (Lal *et al.*, 1991).

Cover crops rotated with cereals may generate residues that when surface applied, provide ground cover/mulch at the beginning of the following rainy season, when the main crop is still young. This period is normally characterized by highest runoff and soil losses. The work of Bazugba (2001) has shown that runoff and soil losses that occur at the beginning of the long rainy season (March – April) under sub humid climate in Morogoro, Tanzania was respectively 85 and 74% of the seasonal losses. Khisa *et al.* (2002) also reported high soil losses at the beginning of the rainy season in the central highlands of Kenya. They reported that 81% of the total soil loss occurred in the first 3 weeks after onset of the rainfall. The use of cover crops might bring down these losses, but the amount of mulch that can be generated by cover crops under sub humid climate and their effectiveness in reducing runoff are not well known.

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The mulches obtained from cover crops alter net radiation, vapour pressure deficit and surface temperature (Dabney, 1998), consequently, cover crops reduce evaporation and conserve soil moisture.

### 2.3.2.2 Effect of cover crops on soil aggregation

Organic matter obtained from leaf - litter and senescent roots of cover crops enhance biological activities and improve soil aggregation (Angers and Caron, 1998). Root activities of cover crops and associated fungal hyphae also promote soil aggregation by enmeshing of soil aggregates (Dabney, 1998; Rasse *et al.*, 2000). Soil cracks created as a result of wetting and drying cycles caused by water absorption by cover crop roots, also improve soil aggregation (Rasse *et al.*, 2000). Improved soil aggregation and biopores created by decomposing roots, soil cracks and soil macro - organisms increase soil porosity, ultimately enhancing infiltration rate of rainwater (Lal *et al.*, 1979; Trojan and Linden, 1998).

The effects of cover crops on soil aggregation vary with crop species depending on ground cover and the amount of above and below ground biomass produced. Unger *et al.* (1998) compared the effects of wheat and sorghum residues on soil aggregation and observed slightly higher aggregate stability with wheat (67.6%) than with sorghum (63.6%). This difference was attributed to the variations in extent of ground cover from the residues of the two crops. The effect of rapidly decomposing organic materials such as green manure on aggregate stability is short lived, lasting 4 - 6 weeks (FAO, 1978). This indicates that the improvement in soil aggregate stability is obtained in the early part of the subsequent season. Still this effect could reduce surface sealing due to heavy rains received at the

beginning of the season, increase soil permeability to water and air and improve soil rootability by plants grown in the subsequent season.

### 2.3.3 Other benefits of cover crops

Cover crops suppress weeds (Coultas *et al.*, 1996; Semere and Williams, 1997; Carsky *et al.*, 1998; Fischler and Wortmann, 1999) and reduce crop pests (Skovgard and Pats, 1996; 1997). Carsky *et al.* (1998) reviewed research done on velvet bean in West Africa and reported that velvet bean reduced population of nut grass (*Cyperus rotundus*) and cogon grass (*Imperata cylindrica*). Skovgard and Pats (1996, 1997) reported that intercropping maize with cowpea in Kenya reduced stem - borer (*Chilo spp* and *Sesamia calamistis*) incidences by 15 - 25% compared to sole maize. This resulted from increased parasitism of eggs of stem-borer by the *Hymenoptera* parasite whose population was increased by 80% after intercropping maize with cowpea.

However, when not properly incorporated in the farming system, cover crops may compete with the main crop for land, water, light and nutrients. Also cover crops may harbour pests (Riekert and Henshaw, 1998). All these may negatively affect the yield of the main crop.

### 2.3.4 Potential niches for cover crop use

#### 2.3.4.1 Intercropping

Intercropping refers to a cropping system where more than one crop are grown together on the same piece of land in a specific pattern. It is an efficient use of limited land and is a way of spreading risks. It therefore stabilizes crop production and increases rainfall use efficiency (Morris and Garrit, 1993; Virmani, 1993).

Planting cover crops together with the main crop at the start of the growing season provides greater canopy cover early in the season. This protects soil surface from impact of raindrop, improves infiltration rate and reduces runoff losses, hence increasing available water in the soil (Lal *et al.*, 1991; Zougmore *et al.*, 1998). In the Central plateau of Burkina Faso, planting cowpea and sorghum simultaneously reduced runoff by 20 - 30% and 5 - 10% more than that of sole sorghum and cowpea, respectively (Zougmore *et al.*, 1998).

However, cover crops planted at the same time with the main crop may compete for moisture, particularly at early growth stages and reduce the yields of the main crop. For example Nordquist and Wicks (1974) observed maize yield reduction of 20 - 50% when maize was planted at the same time with alfalfa. In Ghana, maize grain yield was reduced by 1 Mg $ha^{-1}$ when velvet bean was planted simultaneously with maize (Osei - Bonsu and Buckles, 1993).

Delaying planting of the cover crop was suggested as a mean to reduce competition for moisture between cover crops and the main crop and, hence, maintain yields of the latter (Scott *et al.*, 1987; Abdin *et al.*, 1998). Scott *et al.* (1987) observed that when cover crop planting was delayed until when maize was 15 to 30 cm high, maize grain yield was not affected. In Ghana, mucuna intercropped 45 days after maize sowing had no effect on maize grain yield in the first season but increased yields in the second season. The overall yield increase due to maize – mucuna intercropping for the two seasons was 1.9 Mg $ha^{-1}$ (Carsky *et al.*, 1998). Debele (1996) obtained highest maize grain yield by intercropping haricot bean (*Phaseolus vulgaris*) at 75% of the recommended plant density, 37 days after sowing maize. Abdin *et al.* (1998) evaluated the effect of cover crops planted 10 and 20

days after maize germination on maize yield and observed no significant difference between the tested planting dates. A study by Coultas *et al.* (1996) in northern Belize showed that mucuna intercropped two weeks after maize planting did not affect maize yield. Fischler and Wortmann (1999) reported contradicting results in Uganda, where velvet bean and lablab intercropped three weeks after sowing maize, reduced maize grain yield by 24 and 28%, respectively.

These studies show that timing of cover crops planting under intercropping system influences yields of the intercropped cereal crop, possibly due to competition between cover crops and cereal crop for soil moisture. Delaying planting of cover crop may reduce competition for moisture with the main crop. However, this also depends on the ability of the cover crop to survive on the limited soil moisture that is usually experienced towards the end of the cropping season.

Leguminous cover crops under intercropping systems fix less atmospheric $N_2$ than its sole crop (Nambiar *et al.*, 1983; El - Swaify, 1988). Intercropped pigeonpea may add amounts equivalent to 15 kg N $ha^{-1}$ of mineral fertilizers whereas when sole cropped pigeon pea may add twice as much (El - Swaify, 1988). Reduction in amount of fixed $N_2$ under intercropping systems may be associated with reduced nodulation and fixation due to competition for water, nutrients and light between companion crops.

Plants under intercropping system extract more water than their sole crops (Reddy and Willey, 1981; Govindarajan *et al.*, 1996). This behaviour may have a positive attribute as it reduces leaching losses of nutrient particularly $NO_3^-$ - N and increases $NO_3^-$ – N use efficiency. From the preceding it is clear that cover crops under intercropping system

have little benefit in relation to N – supply, water conservation and yield of the companion crop.

### 2.3.2.2 Rotation

Cover crops may be rotated with the main crop thereby acting as an improved fallow. Fallowing is resting of land from cropping for one or more growing seasons to allow the land to be colonized by secondary vegetation that may be grazed or left unused (Rocheleau *et. al.*, 1988). When a cover crop is planted as a fallow crop it produces large quantities of biomass that improves soil organic matter content, protects the soil against erosion and increases water infiltration. Fallow cover crops also absorb $NO_3^-$ - N, preventing it from being leached out of the root zone.

The effects of cover crops on soil moisture conservation to subsequent crop depend on several aspects including the onset and amount of precipitation, amount of water infiltrating the soil, evaporation and transpiration of the cover crop. The amount, quality and management of the harvested cover crop residues, also greatly influence soil moisture.

Cover crops planted as fallow winter crops in USA and Canada reduced the amount of soil moisture leading to moisture inadequacy to the subsequent crops except in years with early onset of rains (Badaruddin and Meyer, 1989; Schlegel and Havlin, 1997; McGuire *et al.*, 1998). Biederbeck and Bouman (1994) observed that cover crops improved infiltration, resulting in higher subsoil water gain at the depth below 60 cm than continuous wheat in seasons with early onset of rains. Termination time of cover crops greatly influence soil moisture status in the temperate climate (Clark *et al.*, 1997).

The amount of biomass applied and the ground cover provided by residues influence the extent of soil water conservation. An application of 2, 4 and 6 Mg $ha^{-1}$ of mulch reduced runoff in Nigeria by 61, 84 and 98%, respectively (Lal, 1977), implying that the higher the biomass, the more runoff is controlled. Interaction exists between the amount of residues and soil cover on soil water conservation. For example, the same quantity of 0.5 Mg $ha^{-1}$ of maize and wheat residues applied as mulch generates variable ground covers, that of wheat being higher (FAO, 2000). Due to its relatively low ground cover, maize residues resulted into higher erosion losses, consequently reducing rainwater infiltrating the soil. Residues that offer good soil cover also reduce evaporation losses by reducing soil temperature (FAO, 2000). Apart from the quantity of residue biomass applied, quality of the residues plays a major role on the performance of the main crop by influencing nutrient availability and soil physical characteristics.

The amount of residues produced by cover crops and spread on the soil surface, maintains or increases soil organic matter. Havlin *et al.* (1990) observed that organic C and N were higher in crop rotation involving sorghum than soybean and were directly related to the quantity of the residue produced. The amount of surface applied crop residue influences its decomposition. The study by Dahiya *et al.* (2001) showed that the decomposition rate of surface applied residue declined as the amount of residue increased. This reduced decomposition implies that nutrient release is slower and mulching effect is longer with high than low amount of surface applied residues.

The yield benefits subsequent to fallows depend on the fallow properties and the nature of crop limitations (Szott *et al.*, 1999). Some studies have reported high yields subsequent to none N – fixing cover crop fallows (Szott *et al.*, 1999) while others reported higher yields

with legume fallows (Cheruiyot *et al.*, 2001). A study by Cheruiyot *et al.* (2001) in Kenya showed that despite their low biomass production, legume fallows increased maize grain yield of the succeeding crop by 39% over that of weed fallow and continuous maize. This indicates that in the situation where Cheruiyot *et al.* (2001) worked, residue quality was more important than biomass quantity *per se*. In some cases, rotations involving legumes have been reported to increase pests to the subsequent cereal crop. For example, Riekert and Henshaw (1998) reported significant increase of root – knot nematode (*Meloidogyne javanica* and *Meloidogyne incognita*) infestation on maize succeeding soybean or cowpea.

### 2.3.5 Potentials of selected cover crops

#### 2.3.5.1 Cowpea (*Vigna unguiculata*)

Cowpea is a grain legume, commonly grown in the lowlands of Tanzania, and second most important grain legume after field bean (*Phaseolus vulgaris*). It controls maize stalk borer when planted together with maize (Skovgard and Pats, 1997). Clement *et al.* (1998) reported that the leaves of *V. unguiculata* are composed of 33.7 – 42.1% C, 3.0 – 3.2% N, 5.6 – 7.2% lignin, 23.9 – 24.7% cellulose, 1.3 – 1.9% polyphenol and 0.16 – 0.27 % tannins. Cowpea produces 1 to 4 Mg DM $ha^{-1}$ above ground biomass and from 0.5 to 2 Mg DM $ha^{-1}$ below ground biomass (Carsky *et al.*, 2005).

#### 2.3.5.2 Lablab (*Lablab purpureus*)

Lablab also known as dolichos, is a herbaceous legume adapted to altitudes ranging from 0 to 1 900 metres above sea level (m a.s.l.). It has fast growth rate, producing a lot of biomass containing 41 kg N $Mg^{-1}$ dry matter (Palm *et al.*, 1997). Biomass production ranging between 3.4 and 7.4 Mg $ha^{-1}$ has been reported in Kitale, Kenya (Gachene *et al.*, 2000). However, high rainfall after planting considerably retards its growth rate. Studies

conducted in East Africa have shown that lablab leaves contain 3.04 – 5.77% N, 0.10 – 0.28% P, 4.18 – 7.9% lignin, and 1.57 – 3.26% soluble polyphenols. The leaves and beans of lablab are edible and may be used as animal feed, and have medicinal effects against blood pressure, diabetes and wounds (Palm *et al.*, 1997). The plant has medium to deep rooting system that enables it to survive dry spells. However, the potentials of lablab are limited by high susceptibility to pest and diseases.

### 2.3.5.3 Mucuna (*Mucuna pruriens*)

Mucuna also known as velvet bean, is a leguminous crop that grows better at altitudes ranging from 0 to 1900 m a.s.l. It is reported to produce a lot of biomass and suppress weed and root knot nematodes (Coultas *et al.*, 1996; Palm *et al.*, 1997). Biomass production at 3 months after planting ranging between 4 and 7 Mg $ha^{-1}$ has been reported in Kenya (Gachene *et al.*, 2000). Mucuna has been reported to produce root biomass ranging between 100 and 400 kg $ha^{-1}$ in the top 0 – 20 cm soil at the age of 4 months in Benin (Carsky and Etèka, 2000).

Analytical results of mucuna leaves from various locations of East Africa have shown that the material have N content ranging between 2.50 and 5.54%, phosphorus content between 0.09 and 0.24%, lignin content between 6.04 and 10.94% and soluble polyphenol between 0.46 and 4.73%. Generally, mucuna has low lignin and polyphenol contents and narrow C/N ratio hence has high decomposition rate (Tian *et al.*, 1992). On average, mucuna has a potential of supplying 35 kg N $Mg^{-1}$ dry matter (Palm *et al.*, 1997). Its leaves, seeds and roots contain a toxic chemical known as L - 3, 4 - dihydroxyphenylalanine (L-DOPA), which suppresses broad-leaved plants including cucumbers and lettuce (Fujii *et al.*, 1992). The presence of L-DOPA also limits the use of mucuna as food. Processing of mucuna

seeds, including boiling of seeds and discarding water together with seed coat is necessary to bring down levels of L-DOPA before mucuna is used for human consumption (Vissoh *et al.*, 1998). The potentials of mucuna may be limitation by risk of damage of maize by rodents because rodents prefer to build their nests in the litter layer (Buckles and Triomple, 1999).

#### 2.3.5.4 Pumpkin (*Cucurbita maxima*)

Pumpkin is a non - leguminous crop with prostrate growth behaviour. It grows well at temperature between 18 and 30°C and soil pH of 6.5 – 7.5. It is grown in the lowlands of the eastern Tanzania for provision of leaves and fruits that are used as food. It may also be planted to provide live mulch. The plant has large leaves that make it require large amounts of water. Its water requirement per growth cycle ranges between 500 and 900 mm (Rubatzky and Yamaguchi, 1997).

# CHAPTER THREE

# MATERIALS AND METHODS

## 3.1 Study area

### 3.1.1 Location

The experiment was conducted at SUA farm, Morogoro, Tanzania. The farm is 1.5 km west of Morogoro town, along Morogoro – Mzinga road. It is bordered by the Uluguru Mountains to the south - east, Mindu Mountains to the west and Lugala Hills to the north - west. The experimental site is situated at 6°29' S, 37°39' E, at an altitude of 526 m a.s.l. and on a land with a straight slope of 4 – 5%.

### 3.1.2 Geology and soils

The soils originate from colluvial materials derived from hornblende, pyroxene, granulites and micaceous gneiss. They are deep to very deep, well drained, reddish brown to dark red, clays with weak to moderate structure development. (Msanya et al., 1999). The soils have a bulk density ranging from 1.21 to 1.59 Mg $m^{-3}$ in topsoil with total porosity ranging from 40 to 54% and low available water capacity (AWC) ranging from 3.46 to 23.0% (Kaaya, 1989; Mdemu, 2002). The soil is hard setting which is conducive to runoff. About 36% of rainfall is lost as runoff on these soils (Rwehumbiza, 2000 and Bazugba, 2001).

### 3.1.3 Climate

SUA farm has sub humid tropical type of climate (Sharma, 1987). The rainfall pattern is bimodal with a lighter and short rainy season lasting from mid November to mid January and heavier long rains from mid March to mid May. The beginning and the end of these

rainy seasons vary from year to year and the rains are also irregular and unreliable. The short rains are normally less than potential evaporation and insufficient for maize production while the long rains exceed potential evaporation for 60 days starting from mid March (Rwehumbiza, 2000). Potential evaporation (ETo Penman) ranges from 2.69 to 6.89 mm $day^{-1}$, being lowest in April and May and highest in November to January. Mean daily temperature ranges from 21.3 to 26.6 °C. The temperatures are low in June and July and high in November to February.

### 3.2 Soil characterization

Soil characterization involved analysis of physical and chemical characteristics of composite samples collected from the top 0 – 20 cm and genetic horizons of the soil profile. Soil physical characteristics analysed included soil particle distribution, soil bulk density and soil moisture characteristics. The chemical characteristics included pH, OC, TN, available P, CEC and exchangeable Ca, Mg and K. These were obtained from laboratory analysis, following internationally accepted procedures and were used to classify the soil. The soil was classified according to World Reference Base for Resources (FAO *et al.*, 1998) and Soil Taxonomy (Soil Survey Staff, 1998) classification systems.

### 3.3 Characterization of cover crops

Characteristics of cover crops that may influence soil moisture and nitrogen availability were evaluated. These characteristics included biomass production, chemical composition and mineralization behaviour of their residues. For biomass production, total biomass and the proportion of each plant component were determined. Biomass production was determined in both pot and field studies. Chemical composition of the cover crop residues

obtained in the first season of field study was determined by chemical analysis. Mineralization behaviour was studied in the laboratory under an incubation study.

### 3.3.1 Determination of biomass production by cover crops in the pot study

Pots containing 4 kg of air dried soil were irrigated to 80% field capacity (Klute, 1986) and 4 seeds of each cover crop sown. One week later the plants were thinned to three per pot. The pots were irrigated by distilled water to maintain moisture content to 80% field capacity. The plants were harvested at 45 days after planting. The leaves, stems and roots were separated, oven dried at 64 °C to constant weight and weighed to obtain oven dry weight.

#### 3.3.1.1 Root biomass and nodulation

The soil and roots were removed from the pot and separated by immersing in water over night followed by gently shaking in order to detach soil particles from roots. The roots and nodules were recovered from the soil using 1 mm sieve. The roots were washed and nodules counted and separated from the roots.

#### 3.3.1.2 Total and proportions of biomass components

The above ground biomass was washed and rinsed with distilled water. The leaves were separated from stem and each of these plant parts oven dried at 64°C to constant weight. The total biomass was obtained by summation of oven dry weights of leaves, stems and roots. The proportion of each plant component was expressed as a percentage of total biomass.

### 3.3.2 Mineralization of the cover crop residues in the incubation study

The topsoil (0 - 20 cm) samples were collected outside the experimental plots and used for the incubation study. The samples were air dried and screened through 2 mm sieve. Samples of cover crop residues obtained in field experiment after first season (2000/01) were ground to the size of 0.5 mm. The ground plant materials weighing 2.27 g of each cover crop were mixed with 200 g soil resulting to plant material:soil ratio of 1:88. The mixture was moistened to 60% of soil field capacity and incubated at room temperature of 25°C ± 1 for 35 days. The containers were covered with perforated polythene papers to reduce evaporation. Soil moisture was maintained at 60% of soil field capacity by intermittent weighing of the containers and making up the weight loss with distilled water. Soil samples were taken at 0, 7, 14 and 35 days of incubation for the determination of mineral N ($NH_4^+ + NO_3^-$) - N).

## 3.4 Evaluation of cover crops in the field

### 3.4.1 Experimental layout and treatments

The effect of cover crops on soil moisture, mineral nitrogen and yield of a subsequent maize crop were tested for three years under rotational system. The treatments consisted of

Cowpea

Lablab

Mucuna

Pumpkin

Weed fallow

Bare fallow

The cover crops were planted as sole crops in short rains and in long rains the plots were planted with maize. The cover crop treatments were tested in a randomized complete block design (RCBD) and they were replicated three times. *Fahari* and *TMV-1* varieties were used for cowpea and maize, respectively. Locally available seeds of lablab, mucuna and pumpkin were used because there were no released improved varieties of these crops. In the long rains of 2001/02, short maturing maize variety, *kito* was planted instead of *TMV1* because maize was planted one month after the season had started. Weed fallow species composed mainly of *cynodon dactylon*, others included *Urochloa panicoides*, *Bothriochloa insculpta*, *Launaea cornuta*, *Trichodesma zeylanicum*, *Boerhavia diffusa*, *Achyranthea aspera* and *Cyperus rotundus*. The plot gross size was 5 m x 10 m and net size was 6.75 x 2.4 m (9 central rows with 8 plants each). A one-meter path separated the plots.

The experiment commenced in mid November 2000. Vegetation was slashed and the land ploughed using a tractor. Harrowing was done using a hand hoe and plots were demarcated. Land preparation in the 2001/02 and 2002/03 seasons was done by the hand hoe. Cover crops were planted at the onset of the short rains of 2000/01, 2001/02 and 2002/03 seasons. The sowing dates were 7 December, 28 December and 24 October in 2000, 2001 and 2002, respectively.

All cover crops were planted at a spacing of 75 x 30 cm. For each cover crop, two seeds were sown per hole and one week after germination the plants were thinned to one per hill, making a total of 44 444 plants $ha^{-1}$. Cover crops were harvested at the time of land preparation for the long rains crop and the residues left as surface mulch.

In the long rains, the plots that were used during the short rains were minimum - tilled by a hand hoe and the respective cover crop residues evenly spread on the surface of the entire plot. A basal application of 80 kg P $ha^{-1}$ as triple super phosphate (TSP) was banded at maize planting to all plots. Maize was sown at the onset of the long rains. Maize was sown on 13 March 2001, 5 April 2002 and on 13 March 2003 in 2000/01, 2001/02 and 2002/03 seasons, respectively. Two maize seeds were sown per hole between rows of the previous cover crops at a spacing of 75 x 30 cm. Gap filling was done one week after emergence and plants were thinned to one plant per hill two weeks after emergence.

The parameters that were assessed included cover crop ground cover, amount of above ground biomass, chemical composition of cover crop residues and mineralization behaviour of cover crop residues. The study also assessed the effects of cover crops on soil physical properties that could influence soil moisture and N availability. These included soil bulk density, aggregate stability, infiltration and soil moisture content. Other parameters assessed were runoff, soil mineral nitrogen, N, P and K uptake by maize and maize grain yield.

### 3.4.2 Management of the crops

Cover crops plots were weeded once at 2 weeks after planting whereas weed fallow plots were not weeded in order to allow the growth of native weeds. Bare plots were kept free of weeds by hand pulling of weeds throughout the short rains. Cowpea, lablab and pumpkin were sprayed with the insecticide Thionex at 4 and 6 weeks after planting to control thrips, aphids and hoppers.

The short rains of 2001/02 season started late and were inadequate. In order to maintain the cover crops, plots were irrigated daily by 115 litres of water per plot (equivalent to 2.3 mm day-1) in the first two weeks of February 2002. Harvesting date of cover crops varied between seasons depending on the onset of the long rains. Harvesting dates for the cover crops were 5 March 2001, 2 April 2002 and 13 February 2003. The delayed harvesting in 2001/02 season was due to the late onset and inadequate short rains in this season.

The cover crop biomass assessed did not include pods and fruits. The cover crop stems were cut at 2 cm from the ground level and the above ground biomass was weighed, sub sampled and oven dried at 64 °C to constant weight. The oven dry weight was used to convert the fresh biomass yield to dry yield on per ha basis.

In the long rains, maize crop was weeded at 2, 5 and 9 weeks after planting. Rat poison "Kerat" was spread around the field and between the plots to control rodent attack on seeds and seedlings in the first week of maize planting in 2000/01. In order to control maize stalkborer in the three seasons, "Thionex" was sprayed once at 5 weeks after planting. The long rains of 2001/2002 ceased 30 days after maize planting when plants were approaching tasseling stage, leading to moisture stress to the crop. To rescue this situation, all plots were irrigated three times per week by 216 litres (4 mm) per plot for 45 days starting in mid May 2002.

### 3.4.3 Data collection

#### 3.4.3.1 Assessment of ground cover provided by cover crops

Ground cover generated by the cover crops during the short rains was assessed using a sighting frame as described by Elwell and Wendelaar (1977). Data were taken from

randomly selected four stations in each of the net plots. Each station covered a surface area of 1 m x 1 m. At each station, the frame was laid along the plot between crop rows and the ground cover provided by the cover crops was assessed through openings present on the frame. Then the frame was moved ten times, each time moving 10 cm parallel to the previous position and assessment was repeated.

The score for surface cover observed through an opening was considered as one when more than 50% was covered by vegetation or zero if otherwise. Each row had 10 openings and each station had 10 rows, therefore the percent cover at each station gave a total score for the 10 openings in 10 rows. The ground cover provided by the cover crop in a plot was obtained as the average of the 4 stations. Ground cover provided by the cover crops was measured 7 times at 14 days intervals in the 2001/02. Basing on small changes in the ground cover obtained between records in 2001/02 season, the sampling intervals was increased to 30 days in the 2002/03 season.

#### 3.4.3.2 Assessment of ground cover generated by the cover crop residues

The ground cover by vegetation generated by the crop residues was determined at 28 days after planting maize (DAPM) before the first weeding in the third season to quantify the extent of mulching offered by different cover crop residues. The ground cover was determined using line transect method (Wollenhaupt, 1993) with some modifications in order to accommodate maize plants that were in the field. A rope with short length intervals was inorder to collect adequate data from the plot size. Measurements were done in straight line between maize rows instead of diagonal transect in order to avoid the interference of maize plants.

A rope was marked at 10 cm intervals for the length of 2.4 m, laid down between maize rows and the number of times the residues intercepted the mark counted. The percentage of the total mark that was intercepted by residues was calculated. The assessment was repeated in all the 9 rows of the net plot and the mean percentage of marks intercepted by residues gave a value of the ground cover.

### 3.4.3.3 Soil bulk density and porosity

Soil bulk density was determined at the beginning of the experiment in November 2000 and at the end of the short rains of 2001/02 and 2002/03 seasons. Four cores of undisturbed sample were collected from the top soil of each plot, oven dried, weighed and the bulk density calculated as a ratio of oven dry soil to core volume as described by Landon (1991). Soil porosity was derived from the bulk density using the relationship:

$$\text{Porosity} = (1-\rho b/\rho p)*100 \quad \ldots\ldots [5]$$

Where $\rho b$ = soil bulk density

$\rho p$ = particle density (2.65 Mg $m^{-3}$)

### 3.4.3.4 Soil aggregate stability

Soil aggregate stability was measured at the beginning of the experiment and after cover crops had been grown for 3 seasons. Three core samples (10 cm long and 6.5 cm diameter) were taken randomly between rows of cover crops from 0 - 10 cm layer and bulked. The soil was screened using 6 mm sieve. The sieves with sizes of 53, 250 and 2000 µm were used for wet sieving. Soil weighing 100 g was wet sieved as described by Garcia - Oliva *et*

*al.* (1999). In order to avoid soil particle from passing through the sieves while still dry, the soil was put on filter paper, which was placed on the largest sieve of the nest of sieves.

The nest of sieves was immersed in water in such a way that water level touched the largest sieve to facilitate capillary wetting of the soil. The soil was capillary wetted to reduce slaking and in order to properly detect biologically enhanced soil aggregation due to the different cover crops (Beare and Bruce, 1993; Linteau, 2004). The soils were capillary wetted for 10 minutes, the filter paper was gently removed and rinsed with water to ensure that all soil particles were recovered by the nest of sieves. After capillary wetting, the soil samples were wet sieved for 20 minutes. The soil particles recovered by each sieve were oven dried and weighed. The weight of soils that went through the smallest sieve was obtained by subtracting the weight of soils recovered on sieves from the initial weight of 100 g. The weights obtained were used to quantify the fractions of the large (> 2000 μm) and small (250 - 2000 μm) macro - aggregates and coarse (53 - 250 μm) and fine (<53 μm) micro aggregate in the soil.

### 3.4.3.5 Water infiltration capacity

Water infiltration capacity of the soil at the beginning of the experiment, and after harvesting of the third year cover crop was measured using a CSIRO disc permeameter (CSIRO, 1988). The reading was taken from three randomly selected stations in each plot. The land was cleared of plant debris and a one - cm thick sand layer was placed on top of the soil surface to provide smooth, levelled surface that gave good contact with the permeameter membrane. The permeameter was placed on the sand layer and water intake (cumulative infiltration) at a constant supply tension of 10 cm was recorded at five minutes intervals until constant intake was attained. The cumulative infiltration and time

were used to calculate sorptivity and basic infiltration rate. The sorptivity and basic infiltration rate of the soils were obtained as slopes of the linear parts of the first part of cumulative infiltration against square root of time and last part of the cumulative infiltration versus time graphs, respectively.

### 3.4.3.6 Collection and measurement of runoff

The amount of rain lost as surface runoff from each plot was collected and measured for each rainfall event. To ensure that all runoff leaving the plot was collected, the plots were surrounded by metal sheet and the water leaving a plot as runoff was channelled to a collecting tank that was located at the lower end of each plot. The depth of runoff collected from each rainfall event in collection tanks was measured using a calibrated stick and thereafter the tanks were emptied ready for collection of subsequent runoff. The volume of runoff in each tank was obtained by multiplying the recorded water depth (mm) by the cross sectional area of the tank (1 m x 1 m). This volume was divided by the area of the plot (5 m x 10 m) to obtain the amount of runoff generated in mm.

### 3.4.3.7 Soil moisture content

Soil samples from the 0 - 20 cm depth between the rows from 5 randomly selected stations were taken. The soils were mixed, sub - sampled, packed in moisture boxes, sealed with masking tape and taken to the laboratory for weighing and oven drying. Soil sampling was intended to capture soil moisture content after rains and during dry spells. In the short rains, soil samples were taken at 0, 14, 43 and 75 days after cover crop planting (DAPC) in 2000/01 and at 0, 5, 15, 31, 41 and 52 DAPC in the 2001/02 season. Also soil samples from 0 - 5, 6 - 10, 11 - 20, 21 - 25, 26 - 30, 31 - 40 and 41 - 60 cm soil depths were taken at the beginning of the short rains and 45 days after planting of the cover crop in 2000/01

to determine the effect of cover crops on residual soil moisture. In the long rains, soils were sampled from 0 - 20 cm depth at 0, 21, 35 and 43 days after maize planting (DAPM) in 2000/01, at 7, 14, 21, 28 and 35 DAPM in 2001/02 and 0, 7, 21, 26, 37 and 47 DAPM in 2002/03 season.

Soil moisture content was determined gravimetrically by weighing soil when fresh and when oven dried at 105°C to constant weight. The moisture content was calculated as percent of moisture on oven dry soil basis.

### 3.4.3.8 Determination of mineral N

Soil samples from 0 - 20 cm depth were taken between the rows from 5 randomly selected points in each plot. The soils were bulked, packed in polythene bags and then kept in a cool box while in the field and during transportation to the laboratory in order to reduce evaporation and microbial activities. Soils were also sampled from 20 - 40 cm and 40 - 60 cm at the end of the long rains of 2001/02 and 2002/03 for determination of $NH_4^+$ and $NO_3^-$ - N to monitor the influence of the cover crop on mineral N movement in the profile.

In the short rains, soil samples for determination of mineral N were collected at 0 and 75 DAPC in 2000/2001 and 7 and 75 DAPC in 2002/03 season. In the long rain season, soil samples were taken at 0, 21 and 35 DAPM in 2000/01 and at 7, 14, 21 and 35 DAPM in 2001/02 and at 7, 21, 35 and 42 in 2002/03 season. Soil samples were extracted on the same day or stored in deep freezer and analyzed within 3 days of sampling.

### 3.4.3.9 Sampling of plants and leaves for determination of dry matter and nutrient content

In the 2000/01 season, four plants of each cover crop were randomly collected at harvesting for determinations of OC, TN and lignin contents. Likewise, cover crop samples were collected in the short rains of 2001/02 and 2002/03 for determination of N, P and K concentrations. In the long rains of the 2000/01 season, nine maize plants from the net plot, one from each row, were selected in a longitudinal transect. Ear leaves from these plants were sampled at silking stage for determination of N concentration.

In 2001/02 season maize plants were sampled at 17 DAPM for the determination of dry matter yield and N and P uptake in order to determine whether the differences in maize growth at early growth stages were caused by variations in uptake of these nutrients. Six maize plants were randomly sampled from each row making a total of 72 plants per plot. The samples were then washed with deionized water and oven dried at 64°C to constant weight. The oven dried plant materials were weighed, ground to pass through a 0.5 mm sieve and used for determinations of N and P concentration. In 2002/03, five plants at 45 days after planting were sampled from each plot for determinations of dry matter yield and N, P and K concentrations. In 2001/02 and 2002/03 seasons the ear leaves were not sampled, because there were inconsistency in ear formation due to moisture stress that was experienced during the reproductive stage of maize.

### 3.4.3.10 Maize yield

Maize was harvested in the first week of July, the last week of June and in last week of July in the 2000/01, 2001/02 and 2002/03 growing season, respectively. The grain weight was based on 12% moisture content.

### 3.4.4 Laboratory analysis

The particle size distribution was determined by the hydrometer method as described by Gee and Bauder (1986). The bulk density of the soil was determined as described by Anderson and Ingram (1993) and water retention characteristic determined using pressure plate membrane as described by Klute (1986). Soil pH was determined electronically in the 1:2.5 soil: extractant ratio (McLean, 1982), organic carbon by wet digestion as described by Nelson and Sommer (1982) and total N by micro – Kjeldahl digestion method (Bremner and Mulvaney, 1982). Soil available P was determined by Bray 1 method as described by Okalebo (2002), using ascorbic acid for colour development (Murphy and Riley, 1962). Exchangeable bases were extracted with neutral ammonium acetate (Anderson and Ingram, 1993). Sodium and K in the extract were determined photometricaly and Ca and Mg were determined using an AAS as described by Thomas (1982). Cation exchange capacity was determined by the ammonium acetate saturation method as described by Anderson and Ingram (1993).

Ammonium N was obtained by steam distillation as explained by Okalebo (2002). Nitrate - N was determined using an ion selective electrode as described by Mørbeg (2000). Nitrogen content in plant materials was determined according to micro-Kjedah method as for soil analysis. Determinations of P, K, Ca and Mg in the plant samples involved dry ashing of the materials as described by IITA (1979) then followed by extraction with 6N HCl. Phosphorus in the extract was determined by ascorbic acid molybdate blue method (Murphy and Riley, 1962). Calcium and Mg were determined by atomic absorption spectrometry and K determined by flame photometer (Bremner and Mulvaney, 1982). Lignin was determined by the acid detergent fibre method (Goering and Van Soest, 1970) and polyphenol was determined by Folin Denis method (Waterman and Mole, 1994).

### 3.4.5 Analysis and interpretation of the data

Data on soil moisture and mineral N were sorted by sampling date and depth, prior to being subjected to analysis of variance. The sorted data were then analyzed for variance in the Randomized Complete Block Design as described by Montgomery (1991). The means that were significantly different were further separated by Duncan's New Multiple Range Test or orthogonal contrasts.

The data on changes in moisture content and mineral N were transformed by squaring before they were analyzed for variance. Regression analysis of the data was used to establish the relationships between parameters.

# CHAPTER FOUR

## RESULTS AND DISCUSSION

### 4.1 Soils

The soil is deep, well drained, sandy clay (49% sand, 12% silt and 39% clay) in the topsoil and clay (38% sand, 9% silt and 53% clay) in the subsoil. The soil is classified as Haplic Acrisol. The chemical and physical properties of the top and subsoil are shown in Table 1 and some selected soil properties down the soil profile are shown in Appendices 2 and 3. The soil has available water capacity (AWC) of 81.0 mm $m^{-1}$ (Appendix 3) of which 16.3 mm are for the surface horizon (0 – 20 cm), 16.0 mm for the subsurface horizon (20 – 45 cm) and 48.7 mm for the lower horizons (45 – 100 cm). The subsoil (20 - 45 cm) has higher bulk density than other horizons (1.36 against 1.19 Mg $m^{-3}$) (Table 1). The soil is slightly acidic in the top and subsoil with pH of 6.2 and 5.9, respectively. The topsoil has medium CEC but low available P, organic carbon and N content of 12.7 mmol(+) $kg^{-1}$, 5 mg $kg^{-1}$, 1.46% and 0.15%, respectively.

The soil has AWC < 120 mm $m^{-1}$, which according to Landon (1991) is classified as low. This implies that the soil cannot hold enough water to support plant growth for a long time. A soil with low AWC needs frequent wetting by rain or irrigation in order for it to supply sufficient water to crops. Under the condition of a long dry spell, soil water is likely to be depleted faster and the crops suffer moisture stress earlier than in those soils with high AWC. According to Sanchez (1976), Plants growing on soils similar to that used in the current study start showing signs of water stress after 5 days of a dry spell.

Table 1: Some selected properties of the soil used in the study

| Parameter | Soil depth (cm) | |
|---|---|---|
| | 0 – 20 | 20 - 45 |
| Sand (%) | 49 | 38 |
| Silt (%) | 12 | 9 |
| Clay (%) | 39 | 53 |
| Bulk density (Mg $m^{-3}$) | 1.19 | 1.36 |
| FC (%) | 24.0 | 26.0 |
| PWP (%) | 11.0 | 13.0 |
| AWC (mm) | 16.3 | 16.0 |
| pH | 6.2 | 5.9 |
| OC (%) | 1.46 | 0.97 |
| TN (%) | 0.15 | 0.08 |
| Av. P (mg $kg^{-1}$) | 5 | 1 |
| CEC ( mmol(+) $kg^{-1}$) | 12.7 | 18 |
| Ca ( mmol(+) $kg^{-1}$) | 5.94 | 5.08 |
| Mg ( mmol(+) $kg^{-1}$) | 2.08 | 1.41 |
| K ( mmol(+) $kg^{-1}$) | 1.31 | 0.93 |

The higher bulk density observed in the subsoil (20 – 45 cm) relative to the other horizons may be attributed to clay accumulation in this horizon as shown in Appendix 2. The bulk density of the subsoil observed in this study is lower than 1.6 Mg $m^{-3}$, which was reported to restrict root growth (Spoor and Berry, 1990; Landon, 1991) suggesting that the soil has no major limitation on root penetration. However, root penetration and water infiltration in this soil layer may be relatively lower than in the other soil layers.

The relatively higher OC and pH, and more favourable bulk density in the top 0 – 20 cm soil layer, may result into high concentration of roots in this layer especially to shallow rooted crops. This may cause crops growing on this soil to suffer moisture stress after a short dry spell as the topsoil dries. The soil characteristics suggest the need of soil management that will increase N content, and the water holding capacity in order for the soil to produce adequate crop yield.

## 4.2 Weather

### 4.2.1 Rainfall and evaporation

The daily rainfall distribution during the experimental period is shown in Figure 1. The short rainy season in 2000/01 started in early December 2000 and ended in February 2001. In 2001/02, the short rains started at the end of December 2001, but were received for only two days. Thereafter, there was a long dry spell of 1 month up to early February 2002 when the rains resumed. In 2002/03, the short rains started in late October 2002, which was earlier than those in 2000/01 and 2001/02. The rains were interrupted by 2 long dry spells of 12 days (1 – 12 November 2002) and 17 days (7 – 23 December 2002). Good rainfall distribution was obtained between the last week of December 2002 and the first week of January 2003. The total amount of rainfall received in the short rains of 2000/01, 2001/02 and 2002/03 was 410, 298 and 340 mm, respectively (Fig. 1).

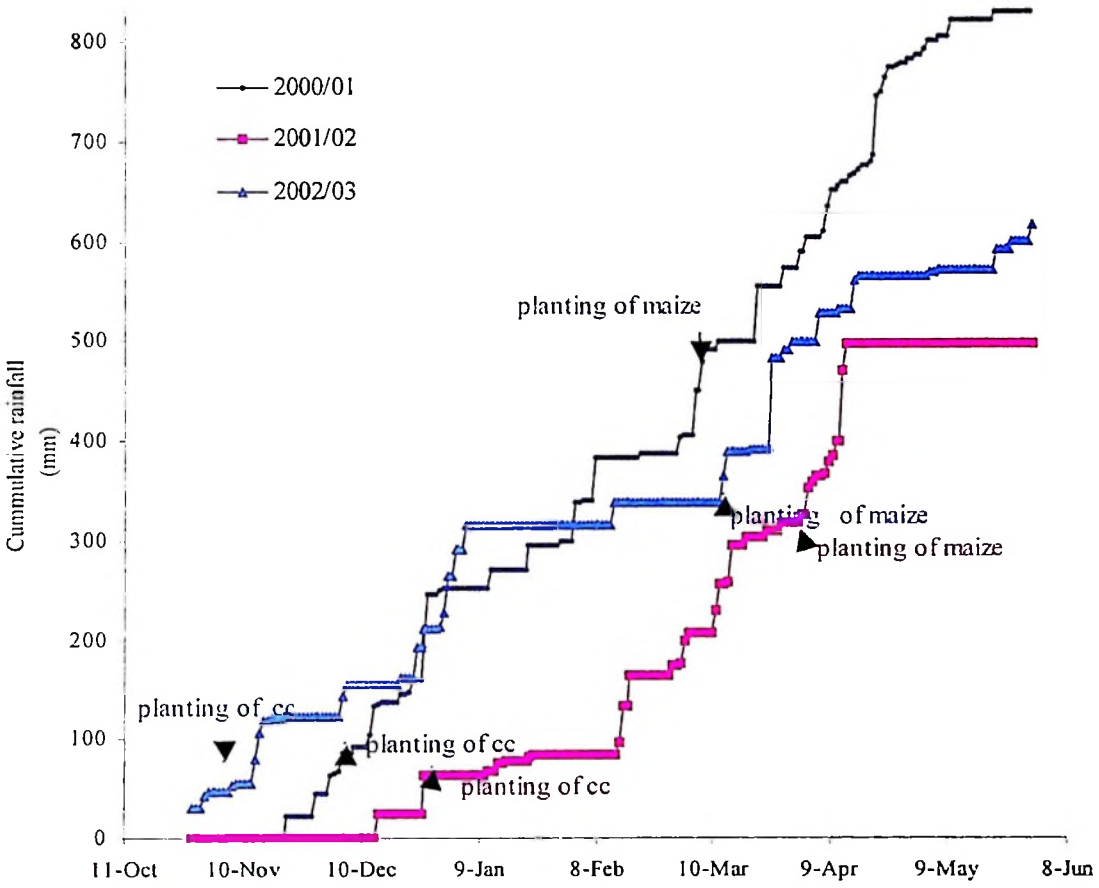


Figure 1: Rainfall distribution pattern in the 3 years of the experiment

The amount of short rains received in 2000/01 and 2002/03 was above the long term mean of 327 mm but the rains were poorly distributed in 2002/03. The short rains of 2000/01 growing season were the highest and best distributed of the three seasons of the experiment whereas that of 2001/02 season was the lowest of the 3 years of study and were not adequate for cover crop growth.

The monthly rainfall distributions with the corresponding potential evapotranspiration for the short and long rains during the experimental period are shown in Figures 2 and 3, respectively. In the 2000/01 season, the short rains exceeded 0.5 potential evapotranspiration only in December and in February. The short rains in 2001/02 season were lower than 0.5 potential evapotranspiration in all months except February. In 2002/03 season, the short rains were higher than 0.5 potential evapotranspiration for three months consecutively, November, December and January (Fig. 2). The growing season starts when the amount of rainfall exceeds 0.5 potential evapotranspiration. These results indicate that the growing season began in November and December in 2002/03 and 2000/01, respectively.

The short rains in 2001/02 season were not adequate for a growing season. The variations in the beginning of the growing season resulted to differences in the duration at which the cover crop were grown in the 3 seasons of experimentation. The cover crops grew for 95, 98 and 112 days in 2000/01, 2001/02 and 2002/03, respectively.

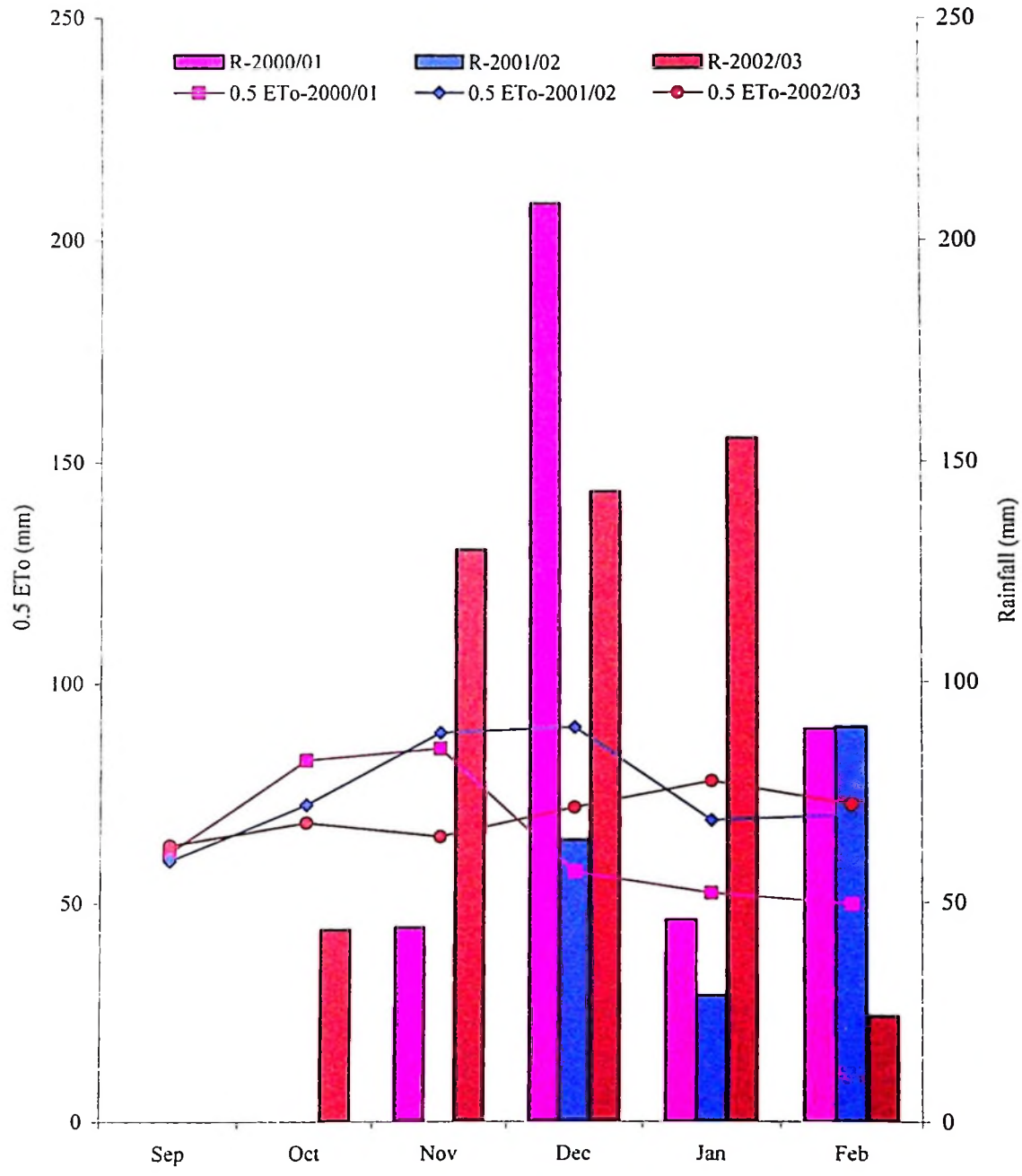


Figure 2: Monthly rainfall and potential evaporation in the shortrains of 2000/01 – 2002/03

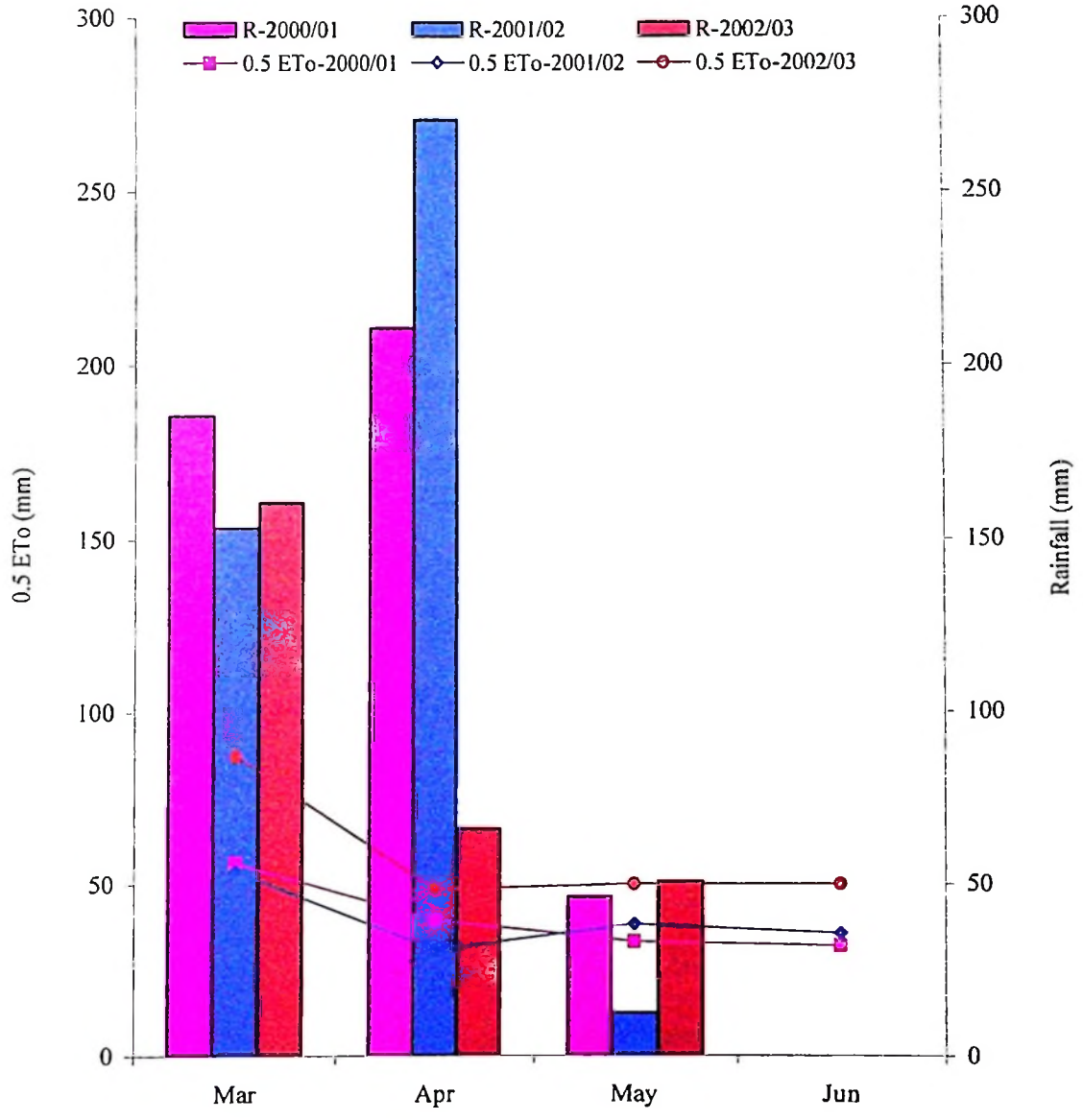


Figure 3: Monthly rainfall and potential evaporation in the longrains of 2000/01 – 2002/03

The long rains of 2000/01 started in the first week of March 2001 and ended at the end of May 2001. Its distribution was poor particularly at the beginning of the season (Fig. 1). In 2001/02, the long rains started in the third week of March and ended at the end of April 2002. The onset of long rains in the 2002/03 season was in mid March 2003 and ended in mid April 2003. The season was interrupted by a dry spell of 7 days after the onset (Fig. 1), which adversely affected maize germination. The rains amounted to 443 mm, 530 and 277.3 mm in the 2000/01, 2001/02 and 2002/03 season, respectively.

The long rains in 2001/02 and 2002/03 ceased earlier than expected (Fig. 1). According to Kassase *et al.* (1993), the long rainy season is expected at the probability of 50 to 80 percent, to end in the last week of May. Cessation of the long rains in April negatively affected cob formation and reduced grain filling and maize grain yields because the tasselling stages coincided with the dry periods. The long rainy season in the 2002/03 was the shortest of the three years of experimentation.

The long rains exceeded 0.5 potential evapotranspiration in March and April in all three seasons of the experiment but were higher than 0.5 potential evapotranspiration in May in the 2000/01 season only (Fig. 3). In 2002/03, the long rains were equal to 0.5 potential evapotranspiration in May and could indicate that the growing season ended in May. However, due to irregular distribution and a long dry spell preceding the rains that were received in the last week of May (Fig. 1), the growing season was shorter than indicated in Figure 3 suggesting that monthly rainfall data can be less useful in predicting the length of growing season in areas with erratic rainfall distribution like that of the study area. The rainfall data indicated that the growing seasons in the long rains lasted from March to May only in the 2000/01 season and for the other two seasons it lasted from March to April.

### 4.2.2 Temperature

The mean daily temperature in the 3 years of experimentation is shown in Table 2. The daily temperature ranged from 23.5 to 28.0 °C in the short rains and from 21.2 to 27.9 °C during the long rains. The period between December and February in the short rainy season of the 2000/01 was relatively cooler than in the 2001/02 and 2002/03 seasons whereas that of 2001/02 was the hottest of all seasons. During the long rains, temperatures in March and April were relatively higher in 2002/03 than during the other two seasons. The temperatures obtained in the short seasons are within favourable range of the cover crops, which is 12.5 – 27.8 °C for cowpea (Velenzuela and Smith, 2002) and 18 – 30 °C for pumpkin (Rubatzky and Yamaguchi, 1997) while in the long rainy season they were within the optimum range for maize of 22.5 – 27 °C (Commuri and Jones, 2001).

Table 2: Mean daily air temperature during the experimental period

| Seazone | Sep | Oct | Nov | Dec | Jan | Feb |
|---|---|---|---|---|---|---|
| | Air temperature (°C) | | | | | |
| **Short rains** | | | | | | |
| 2000/01 | 23.5 | 25.5 | 27.2 | 26.3 | 26.1 | 26.1 |
| 2001/02 | 23.6 | 25.1 | 27.0 | 28.0 | 27.3 | 26.9 |
| 2002/03 | 24.1 | 25.3 | 26.2 | 27.2 | 26.8 | 28.0 |
| **Long rains** | | | | | | |
| Year/Month | Mar | Apr | May | Jun | Jul | Aug |
| 2000/01 | 26.4 | 25.3 | 24.4 | 22.5 | 21.2 | 22.2 |
| 2001/02 | 26.2 | 24.8 | 23.9 | 21.7 | 22.6 | 22.7 |
| 2002/03 | 27.9 | 26.0 | | | | |

Source: SUA agrometeorological station

## 4.3 Characteristics of the cover crops

### 4.3.1 Biomass production of the cover crops

The performance of the cover crops in terms of biomass production, proportions of each plant part and nodule production are shown in Table 3. The leaf biomass produced by cover crops ranged from 7.4 to 14.2 g $pot^{-1}$ whereas stem biomass ranged from 3.1 to 6.2 g $pot^{-1}$. Mucuna had significantly higher ($P < 0.05$) leaf biomass than the other cover crops. Pumpkin and lablab had similar but significantly higher ($P < 0.05$) leaf biomass than that of cowpeas. Significantly higher ($P < 0.05$) stem biomass was produced by lablab. Total above ground biomass (leaves + stems) ranged from 10.5 to 18.6 g $pot^{-1}$. Cowpea had significantly lower above ground biomass than other cover crops.

Table 3: Cover crop biomass production at 45 DAP

| | Cover crops | | | |
|---|---|---|---|---|
| Plant parameter | Cowpea | Lablab | Mucuna | Pumpkin |
| Leaves (g/pot) | 7.42c | 11.18b | 14.17a | 11.06b |
| Stems (g/pot) | 3.11c | 6.18a | 4.45b | 3.88bc |
| Above ground biomass (g/pot) | 10.53b | 17.37a | 18.62a | 14.94a |
| Roots (g/pot) | 3.82a | 4.09a | 4.63a | 3.92a |
| Nodule (no./pot) | 111a | 136a | 11b | n.a |
| Nodule wt (g/pot) | 0.11c | 0.26b | 0.38a | n.a |
| Nodule wt (mg/nodule) | 1.0b | 1.9b | 34.4a | n.a |
| $Leaf_{AGB}$ (%) | 71b | 64c | 76a | 74a |
| $Leaf_{TB}$ (%) | 52b | 52b | 61a | 59a |
| $Root_{TB}$ (%) | 27a | 19a | 20a | 21a |
| $Stem_{TB}$ (%) | 21b | 29a | 19c | 20bc |

Means in a row followed by the same letter are not significantly different at P = 0.05 using DNMRT.

n.a = not applicable

AGB = Above ground biomass

TB = Total biomass

Mucuna, lablab and pumpkin produced statistically similar above ground biomass. The above ground biomass of mucuna and pumpkin had the highest proportion of leaves (76 and 74%, respectively), whereas that of lablab had highest proportion of stems (29%).

Studies have indicated that leafy biomass is higher in N and lower in lignin contents than stems (Palm *et al.*, 2001). Lower proportions of leaf biomass in above ground biomass of the cover crop might imply low N content and high lignin content which, in turn, might retard the rate of mineralization of cover crop biomass (Myers *et al.*, 1994). This suggests that mucuna and pumpkin have higher mineralization rates than lablab and cowpea. The root biomass ranged from 3.8 to 4.6 g $pot^{-1}$ and was not statistically different between the cover crops. The cover crops had nodules ranging from 11 to 136 per pot and the fresh of the nodules were pink in colour, indicating that they were effective in $N_2$ fixation. Mean nodule weights varied between the cover crops, ranging from 1.0 to 34.5 mg $nodule^{-1}$. Mucuna had significantly less ($P < 0.05$) but heavier nodules than cowpea and lablab. The number and size of nodules have been reported to reflect nitrogen fixation ability of legumes. According to Alexander (1983), greater number of small sized nodules suggests lower effectiveness in fixing $N_2$ than large few nodules. The results of the current study may indicate that mucuna is the most effective in $N_2$ fixation of the tested cover crops and would therefore, be a better N source than cowpea and lablab.

### 4.3.2 Chemical composition of cover crop residues

Chemical composition of cover crop residues at slashing is shown in Table 4. The residue of cover crops tested had N content ranging from 2.14 to 2.30%. These values were higher than in the weed fallow treatment which had 1.37% N, indicating high quality of cover crop residues compared to weed residue.

Table 4: Some chemical composition of the cover crop residues

| | OC | N | C:N | P | Ca | Mg | K | Lignin | Polyphenol |
|---|---|---|---|---|---|---|---|---|---|
| CC type | .....%..... | | | .....%..... | | | | | |
| Cowpea | 44.4 | 2.14 | 21 | 0.10 | 0.40 | 0.16 | 2.75 | 9.4 | 2.76 |
| Lablab | 48.3 | 2.19 | 21 | 0.19 | 0.39 | 0.10 | 2.12 | 10.7 | 5.30 |
| Mucuna | 42.5 | 2.30 | 18 | 0.13 | 0.43 | 0.15 | 2.15 | 12.2 | 23.50 |
| Pumpkin | 48.3 | 2.21 | 22 | 0.25 | 1.33 | 0.51 | 3.13 | 7.4 | n.d |
| Weed fallow | 50.2 | 1.37 | 37 | 0.09 | 0.18 | 0.11 | 2.75 | 6.5 | n.d |

The values are from composite samples for each treatment
n.d. = not determined
CC = cover crop

Pumpkin and mucuna residues had N content > 2.2%. The cover crops had C:N ratios < 30 and lignin content < 15%, suggesting that they would lead to net N mineralization and high decomposition rate (Palm *et al.*, 2001). The weed fallow biomass had lignin content < 15% but had C:N ratio > 30, indicating that this would lead to net N immobilization during the initial stages of decomposition, thereby creating N deficiency to subsequent maize plants at the early growth stages. Cowpea residues had lower N concentration and higher lignin and polyphenol contents than those reported by Clement *et al.* (1998) of 3.0, 7.2 and 1.86%, respectively. This suggests that cowpea residues in the current study may have slower decomposition and N mineralization rates than those used by Clement *et al.* (1998). The differences in N concentrations in cowpeas residues obtained in current study and by Clement *et al.* (1998) was accounted for by the differences in growth stages at which cowpea was harvested. In the current study cowpea was harvested at maturity whereas in the work by Clement *et al.* (1998) was harvested at reproductive stage (having green pods). Cover crop residue at vegetative stage is known to have higher N content than at maturity (Palm *et al.*, 1997; Cheruiyot *et al.*, 2001).

The quality of lablab was relatively lower than that reported by Palm *et al.* (1997) for lablab from other parts of East Africa which had N, lignin and polyphenol contents > 3.0, < 7.9 and < 3.26%, respectively. Mucuna residues had lower N content and higher lignin and polyphenol contents than those reported from other parts of East Africa of 2.5 - 5.5, 6.0 - 10.9 and 0.46 - 4.73%, respectively. The difference in the qualities of the cover crop residues in this study and those reported by Palm *et al.* (1997) could be due to difference in plant parts of the cover crops analyzed. The contents reported were of leaves whereas in the current study the concentrations were obtained from a mixture of leaves and stems. Leaves contain more N and less lignin than stems (Palm *et al.*, 2001), suggesting that the

mixture of leaves and stems would lead to lower N concentration than that of leaves alone. The normal and practical way by which farmers apply crop residues in their fields is slashing and applying both leaves and stems as surface mulch. Therefore the composition of the mixture of leaves and stems gives a better impression on the quality of the applied residues than that of leaves alone.

Except for pumpkin, the other cover crop residues had P contents lower than the critical value for P mineralization of 0.25% (Palm *et al.*, 2001). Weed fallow had the lowest P value. In view of the low levels of soil available P (Table 1), these cover crops and weed residues cannot supply sufficient P to the subsequent maize crop hence there is a need for supplemental P from external P sources. Pumpkin had the highest base content implying that its biomass could be a potential source of bases in the soils.

### 4.3.3 Mineralization pattern of the cover crop residues

Mineralization patterns of cover crop residues when applied in equal amounts of biomass at 60% field capacity and in the absence of a growing plant are shown in Figure 4 and Appendix 4 and 5. At the beginning of incubation (day 0), mineral N in the tested treatments ranged from 8.9 to 17.5 mg $kg^{-1}$ (Fig. 4). Mineral N was significantly higher ($P < 0.001$) in lablab, mucuna and pumpkin than in control and cowpea treatments. Mineral N obtained at day 0, could be from water soluble organic N from cover crop materials. The results suggest that lablab, mucuna and pumpkin residues have higher soluble organic N than those of cowpea and weed fallow.

After 7 days of incubation mineral N levels increased to values ranging from 22.3 to 37.9 mg $kg^{-1}$. The increase in relation to the initial levels (day 0) were 42, 80, 141,

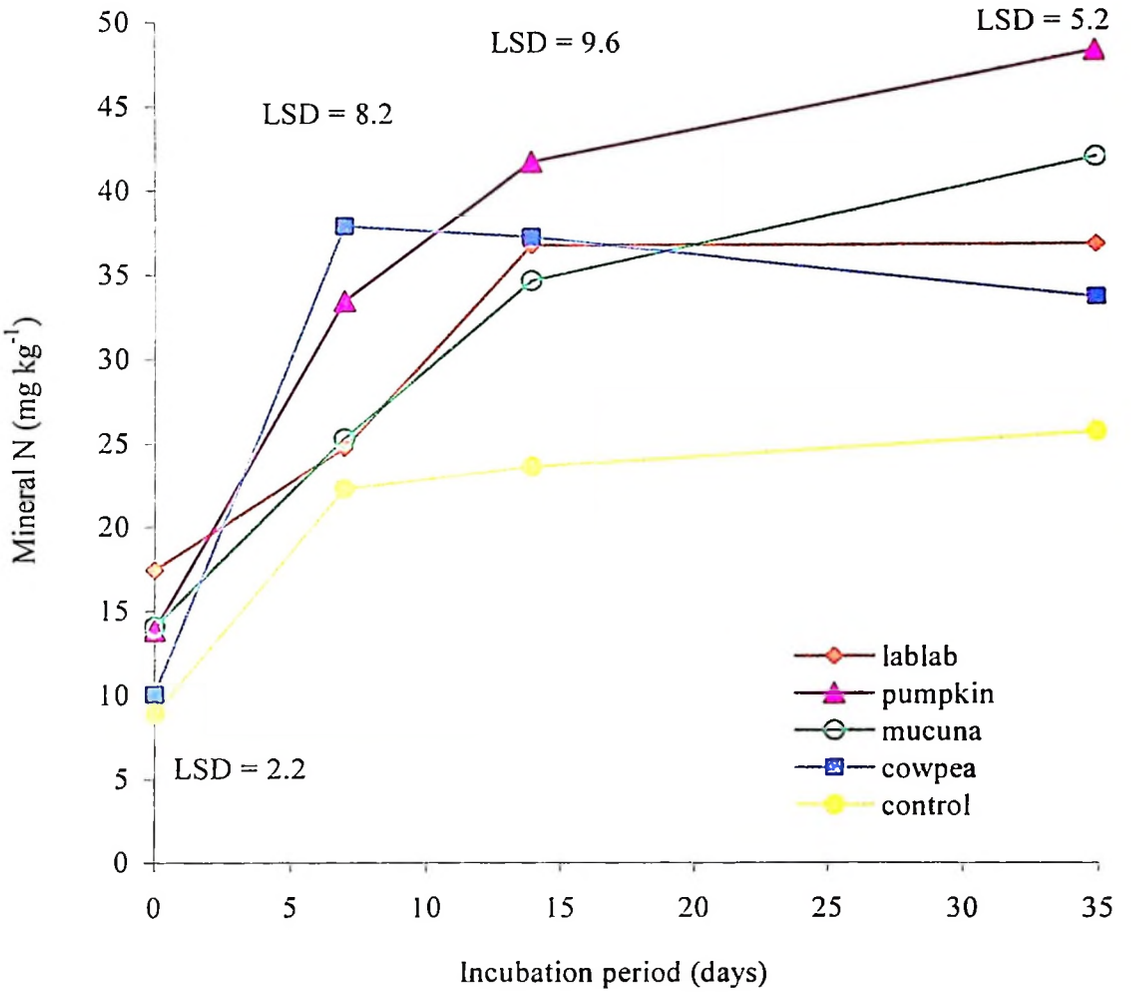


Figure 4: Nitrogen mineralization pattern of the above ground biomass of the cover crops

150 and 276% in lablab, mucuna, pumpkin, control and cowpea, respectively (Appendix 5). At day 7, cowpea and pumpkin treatments had similar but significantly higher ($P < 0.01$) mineral N than lablab and mucuna residues.

Mineral N concentrations in mucuna and lablab plots were statistically equal to those in the control treatment but those in pumpkin and cowpea were 50 and 70% higher (Appendix 5). The results suggest that residues of pumpkin and cowpea mineralize much faster than that of lablab, and mucuna. This may be explained by the slight difference in lignin content of residues of these cover crops (Table 4). Pumpkin and cowpea residues had relatively lower lignin content than lablab and mucuna, which could have resulted into relatively rapid initial mineralization in pumpkin and cowpea.

At day 14, the rate of mineralization ranged from < 1% in cowpea treatment to 48% in lablab. Mineral N concentration in cowpea was equal to that of mucuna and lablab but was higher than that of the control. Mineralization rates at day 35 were in the order mucuna > pumpkin > control > lablab > weed fallow > cowpea and were lower than that of the first 14 days (Appendix 5). Total amount of N mineralized after 35 days of incubation in control was 26 mg $kg^{-1}$ soil. The amount of N mineralised in control in this study was higher than those obtained by Singh and Kumar (1996). Singh and Kumar (1996) obtained mineral N values ranging from 22 to 40 mg $kg^{-1}$ soil from control after 56 days of incubation and about 18 mg $kg^{-1}$ after incubating for 35 days. The difference may be attributed to the higher OC content in soil (1.46%) in the current study than in soils used by Singh and Kumar (1996) which ranged from 0.56 to 0.62%. The OC of the soil is an index of organic matter content, which is a substrate for N mineralization (Equation 1).

The mineralization rate of soil organic matter increases with increasing the OC levels. In their field study, Hartemink *et al.* (1996) also reported higher mineral N release in soils with higher soil OC (OC = 1.5%) at Ochinga than at Muange (OC = 0.8%) in Kenya.

Mineral N levels at day 35 in cowpea, lablab, mucuna and pumpkin treated soils were 31, 43, 63 and 88% higher than those in the control, respectively (Appendix 5). The amounts of mineral N in pumpkin and mucuna treatments were significantly higher ($P < 0.001$) than those in lablab and cowpea and those of pumpkin were significantly higher ($P < 0.05$) than in mucuna treatment (Appendix 4). The difference in amount of mineral N between cover crop residues could be due to differences in their chemical composition. The residues had N content ranging from 1.93% to 2.91 indicating that the total amount of N added to the soil by the same amount of biomass of cover crop residues was variable. The amounts of N added to the soil, obtained by multiplying the amount of material added by the N concentration were 67, 57, 53 and 44 mg N $kg^{-1}$ soil for pumpkin, lablab, mucuna and cowpea treatments, respectively. When compared with the amount of N added at the beginning of incubation, mineral N at 35 days of incubation ranged from 18 to 34% of the N added by cover crop residues in the order pumpkin > mucuna > lablab > cowpea (Appendix 4). This indicated that 18 to 34% of the N added by cover crop residues had mineralised within 35 days of incubation. These values are within the mineralization range of 10 - 60% observed on green manure of tropical leguminous trees by Oglesby and Fownes (1992) at 8 weeks (56 days) of incubation.

The highest rate of N release was obtained in the first 7 days of incubation for cowpea residues and in the first 14 days of incubation for pumpkin, lablab and mucuna residues (Fig. 4 and Appendix 5). These N release patterns agree with the peak range of 7 to 14

reported by Beri *et al.* (1989) for the legume cover crops. This release pattern might not synchronize with maize requirement for N because this period coincides with maize germination and early vegetative growth stage when N requirement is still very low. N release from pumpkin and mucuna was fast in the first 14 days of incubation and it was gradual in the rest period of incubation to day 35. This would imply that pumpkin and mucuna had a potential to supply N to maize for longer duration than cowpea and lablab.

## 4.4 Performance of the cover crops in the field

### 4.4.1 Ground cover

The ground cover for the different cover crops in the short rains of 2001/02 is shown in Figure 5. More details are given in Appendix 6. The ground cover was negatively affected by drought resulting from erratic rainfall distribution. After sowing of cover crops there was a drought of 14 days (Fig. 1). This had a negative effect on seed germination, particularly of mucuna and lablab and early establishment of all cover crops and eventually resulting to low ground cover. The ground cover generated by the cover crops at the end of January, at 28 DAPC, ranged from 9.5 to 21%. Irrigation that was done in the second and third weeks of February helped to keep the cover crops alive but the ground cover by the cover crops was not improved much.

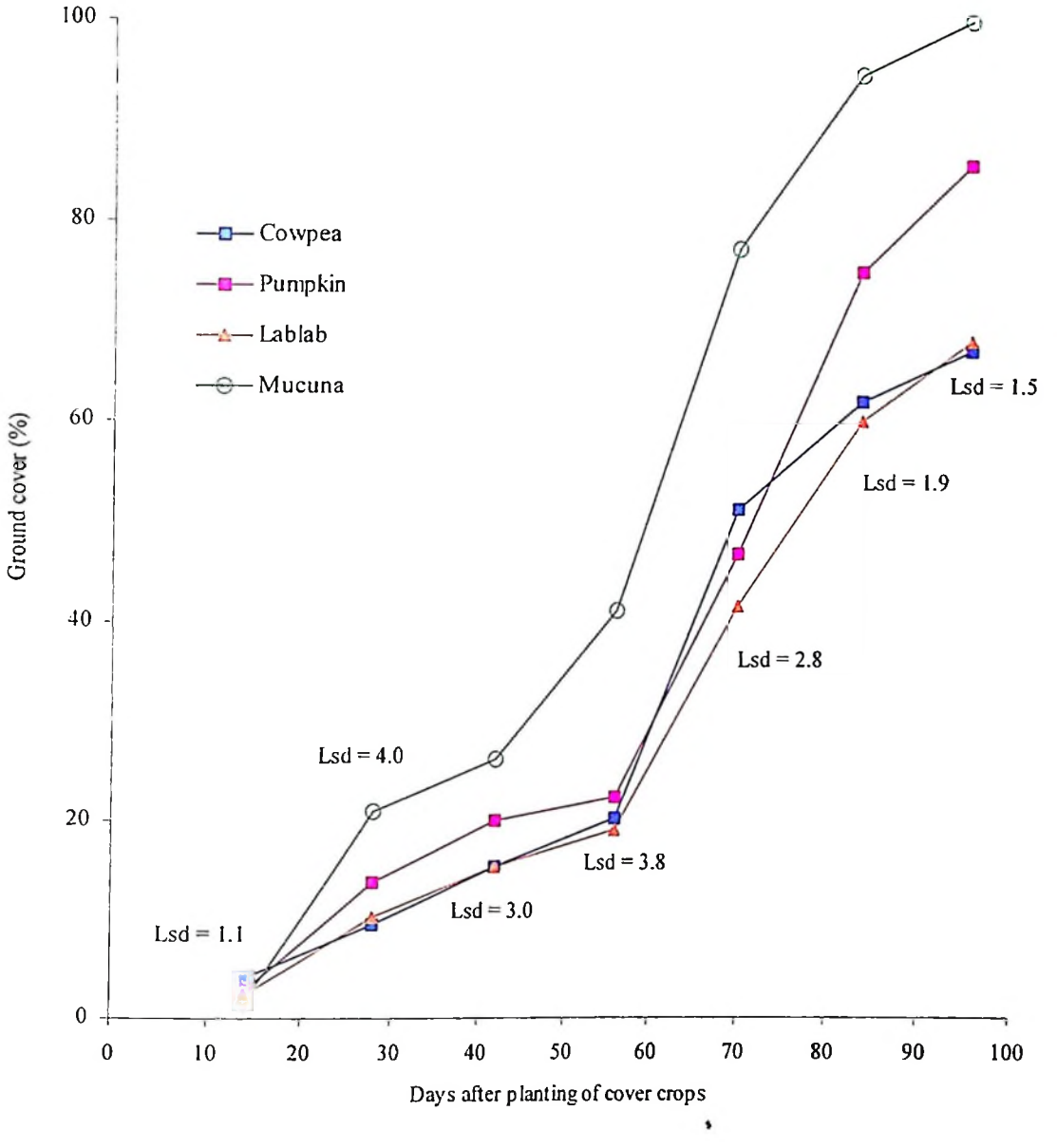


Figure 5: Ground cover by the cover crops in the short rains of 2001/02 season.

For instance, at 42 DAPC (8 February) the ground cover ranged from 15.3 to 26.3 percent (Figure 5). Generally, the ground cover generated by the cover crops in the first 49 DAPC before the rains that were received in mid – February, was very little and was not significantly different between the cover crops. The rains that were received from the last half of February to the end of March 2002 increased the ground cover. At 56 DAPC (22 February), ground cover ranged from 19.0 to 41% and 14 days later (8 March) it increased to between 41.5 and 77.3%. At harvest, 14 weeks after planting (3 April), the ground cover increased to between 67 and 100%. Mucuna generated significantly greater ground cover than did the other cover crops (Fig. 5). At harvest mucuna had already attained 100% ground cover whereas cowpea and lablab attained only 67 and 68%, respectively.

Ground cover for the 2002/03 season is shown in Figure 6 and Appendix 7. Unlike in the short rains of 2001/02, the ground cover in the short rain of 2002/03 season increased rapidly after germination. At 30 DAPC, ground cover ranged from 27.9 to 93.9% and was significantly higher in weed fallow than in cover crop treatments. Ground cover at 30 DAPC was not significantly different but cowpea and mucuna generated comparatively higher ground cover than lablab and pumpkin in the later days. At 60 DAPC, the ground cover generated was 52, 53, 68 and 71% for lablab, pumpkin, mucuna and cowpea, respectively. Ground cover generated by cowpea and mucuna at 60 DAPC was 33% higher than that by pumpkin and lablab. The cover crops recorded lower ground cover than the weed fallow in the first 60 days. Figure 6 shows that the rate of ground cover increase in weed fallow plots was highest in the first 30 days, and thereafter it was almost constant.

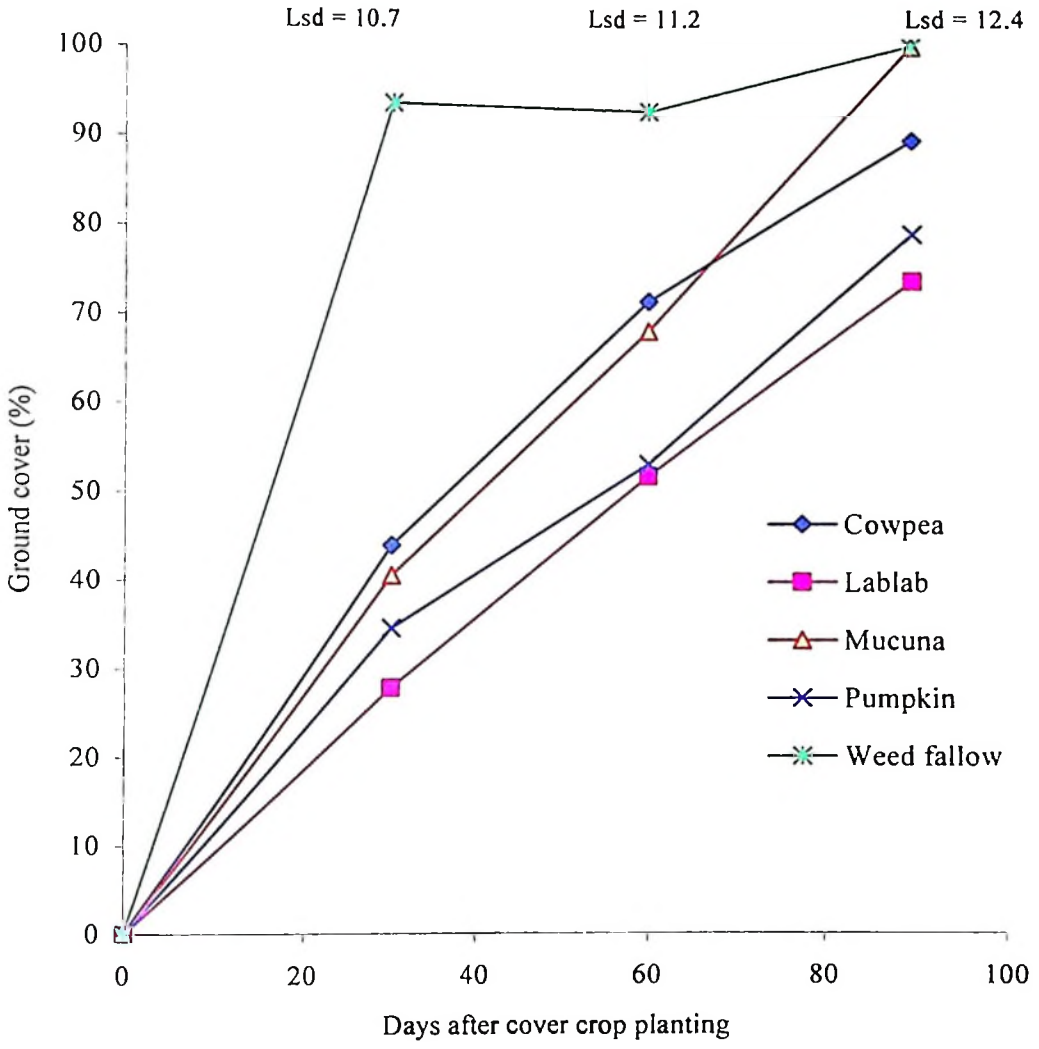


Figure 6: Ground cover generated by cover crops in the short rainy season of 2002/03

After 60 DAPC, the ground cover afforded by mucuna and lablab increased at an increasing rate whereas that of cowpea increased at a decreasing rate. The ground cover by cowpea increased at the decreasing rate compared to those of mucuna and lablab because the vegetative growth period of cowpea was 30 days shorter than that of the other two cover crops. At 60 DAPC cowpea had shed most of its leaves but mucuna and lablab were still growing vegetatively. The ground cover obtained at 90 DAPC ranged from 74 to 100% and was in the order weed fallow = mucuna > cowpea > pumpkin > lablab.

The results of this study are similar to those obtained by Kamidi *et al.* (2003) in that mucuna provided the highest ground cover. However, ground cover from three months old cover crops was higher than that reported in Kenya by Kamidi *et al.* (2003) of 72, 52 and 38% for 4 months old mucuna, lablab and cowpea, respectively. The difference in ground cover obtained might be explained by the difference in the cropping system used in the two studies whereby cover crops were grown in pure stand in the current study but they were intercropped with maize in the work reported by Kamidi *et al.* (2003). The ground cover obtained in the current study in a season with good distributed short rains of 2002/03 was similar to that reported by Abayomi *et al.* (2001) in Nigeria but was lower in seasons with inadequate erratic short rains in 2001/02. Abayomi *et al.* (2001) reported that mucuna and lablab generated 100 and 84% ground cover, respectively at 12 weeks after planting. These results show that cover crops generate adequate ground cover in seasons with adequate well distributed rains.

### 4.4.2 Biomass production

Biomass produced by the cover crops during the experimental period is shown in Table 5. The biomass generated by cover crops ranged from 1.1 to 3.0 Mg DM $ha^{-1}$. In this study

the biomass generated by cover crops was significantly lower than that of weed fallow. Among the cover crops, mucuna generated consistently higher biomass in the 3 seasons of experimentation. High biomass obtained in weed fallow treatment was due to high plant population and its adaptability to the soils and climatic conditions of the study area. Weeds are normally more adapted to the soil and climatic environment where they are growing than crops and this adaptability makes weeds grow faster than crops, generating high biomass.

Table 5: Biomass produced by the cover crops for the three short rainy seasons

| Cover crop Type | Year | | | Mean |
|---|---|---|---|---|
| | 2000/01 | 2001/02 | 2002/03 | |
| | ..... Mg ha$^{-1}$ ..... | | | |
| Cowpea | 2.2b | 0.8b | 1.2c | 1.4c |
| Lablab | 1.6b | 0.9b | 3.9b | 2.1bc |
| Mucuna | 2.7b | 1.3a | 5.1a | 3.0b |
| Pumpkin | 1.8b | 0.5b | 1.1c | 1.1c |
| Weed fallow | 4.6a | 1.4a | 4.9a | 3.6a |
| Rainfall (mm) | 410 | 298 | 340 | 349 |
| Duration of rainy period (day) | 95 | 98 | 112 | 103 |

Values in a column followed by the same letter are not significantly different at P = 0.05 using DNMRT.

The high biomass accumulated by mucuna relative to other cover crops is attributed to its high potential in biomass production (Buckles and Trimple, 1999; Gachene *et al.*, 2000; Kamidi *et al.*, 2000; Wortmann *et al.*, 2000; Abayomi *et al.*, 2001) and its tolerance to drought (Gachene *et al.*, 1997). Work in Northern Honduras (Buckles and Trimple, 1999), West Africa (Abayomi *et al.*, 2001), Uganda (Wortmann *et al.*, 2000) and Kenya (Kamidi

*et al.*, 2000; Gachene *et al.*, 2000) has shown that mucuna accumulates high biomass when compared with other cover crop species. Mucuna was reported to have a potential to extract water from down to a depth of 60 cm (Gachene *et al.*, 2000) and this enabled it to survive during long dry spells. The amount of biomass produced by cover crops in this study is lower than that reported elsewhere.

In Nigeria, Iwuafor and Odunze (2000) reported biomass production of up to 10.9 Mg DM $ha^{-1}$ from lablab grown as sole cover crop in an area with an annual rainfall of 600 – 700 mm. The biomass obtained in Burkina Faso (annual rainfall of 800 mm), ranged from 5.2 to 10.2 Mg DM $ha^{-1}$ for mucuna and 2.6 Mg DM $ha^{-1}$ for lablab (Zougmore, 2000). Unreliable onset and poor distribution of rainfall in the short rains (Fig. 1) caused the low biomass production observed in this study. Late onset of short rains shortened the growing period of cover crops and, consequently, led to low biomass production. In addition to late onset, poor distribution of rainfall during the short rains resulted into reduced growth rate of cover crops that resulted into low biomass.

The biomass produced by mucuna was more than 2 Mg DM $ha^{-1}$ in 2 out of 3 short rainy seasons while that in lablab and cowpea treatments was higher than 2 Mg DM $ha^{-1}$ only in one season (Table 5). The biomass generated by pumpkin was < 2 Mg DM $ha^{-1}$ throughout the 3 short rainy seasons tested. The above ground biomass production of at least 2 Mg DM $ha^{-1}$, according to Marilla *et al.* (1992), is a threshold value for a legume cover crop to have significant effect on a subsequent cereal crop. The biomass production levels in this study (Table 5) indicated that the short rains in the subhumid climate of Morogoro may not be sufficient for generation of adequate biomass of pumpkin, cowpea and lablab.

### 4.4.3 Nutrients accumulated in the cover crop biomass

Nitrogen concentration and total amount accumulated in the cover crop biomass are shown in Table 6. Nitrogen concentration of cover crop residues ranged from 1.51 to 2.91%. Except for cowpea, higher concentrations were obtained in the 2000/01 and 2002/03 than in the 2001/02 growing season. The difference in concentration between seasons may be explained by the variation in amounts of rainfall. Unlike in 2000/01 and 2002/03, the 2001/02 short rains were erratic and inadequate, resulting to poor growth of cover crops. This may explain the observed low N concentrations.

The concentration of N in pumpkin and lablab was more affected by drought than that of mucuna and cowpea (Table 6). The drought tolerance of mucuna and cowpea (Gachene *et al.*, 2000) may explain why N concentrations in the residues of these cover crops were less affected in 2001/02. The higher N concentration in cowpea residues in 2001/02 than in 2000/01 and 2002/03 would be due to variation in growth stages at harvest, which was at maturity stage in 2000/01 and 2002/03 as opposed to reproduction stage in 2001/02 season. Higher levels of N are accumulated in vegetative parts at flowering than at maturity stage (Palm *et al.*, 1997; Cheruiyot *et al.*, 2001). Cover crop residues had higher N concentration than weed fallow in all three seasons. This may be attributed to the fact that weed fallow consisted of non - $N_2$ fixing species. High N content in pumpkin residues indicates that the crop takes a lot of N from the soil. The average N concentration in residues for the three seasons was in the order mucuna > pumpkin > lablab > cowpea > weed fallow.

Table 6: Nitrogen concentration and accumulation in the cover crop residues at harvest

| | N concentration | | | | N accumulation | | | |
|---|---|---|---|---|---|---|---|---|
| | 2000/01 | 2001/02 | 2002/03 | mean | 2000/01 | 2001/02 | 2002/03 | mean |
| Cover crop | .....% | | | | .....kg N $ha^{-1}$ | | | |
| Cowpea | 1.93c | 2.34a | 2.14a | 2.14 | 42b | 19b | 26c | 31 |
| Lablab | 2.52b | 1.86ab | 2.19a | 2.19 | 40b | 17b | 86ab | 48 |
| Mucuna | 2.35bc | 2.24a | 2.30a | 2.30 | 63ab | 29a | 118a | 69 |
| Pumpkin | 2.91a | 1.51bc | 2.21a | 2.21 | 52b | 8c | 25c | 22 |
| Weed fallow | 1.58c | 1.26c | 1.26b | 1.37 | 73a | 18b | 61bc | 47 |

Values in a column followed by the same letter are not significantly different at P = 0.05 using DNMRT

The amount of nutrients accumulated in the cover crop residues varied between seasons depending on the amount and distribution of rainfall during the growing period of the cover crops and on the growth stage of cover crop at slashing. The total amount of rains received during the growth period of the cover crops was 410, 298 and 340 mm for 2000/01, 2001/02 and 2002/03, respectively (Table 5). The rainfall was highest and well distributed in 2000/01 and lowest and poorly distributed in 2001/02 (Figure 1). Duration of cover crop growth from planting to harvest (slashing) at the end of the short rainy season was 95, 98 and 112 days in 2000/01, 2001/02 and 2002/03, respectively depending on the length of the short rainy season. Except for pumpkin and cowpeas, highest accumulation was obtained in the 2002/03 season suggesting that the growth duration was the major determinant of N accumulation. This observation is in agreement with that reported by Giller and Wilson (1991), who indicated that the amount of N fixed by the cover crop increases with its life span. In the study by Giller and Wilson (1991),

*Desmodium ovalifolium* fixed 25 kg N $ha^{-1}$ in 17 weeks and 61 – 110 kg N $ha^{-1}$ in 52 weeks.

The amount of N accumulated in the biomass also varied between cover crops (Table 6). On average, N accumulation ranged from 22 to 69 kg $ha^{-1}$. The N accumulated by cover crops in this study are within the range of 14 – 240 kg N $ha^{-1}$ obtained by Tian *et al.* (2000) on cover crops grown for 4.5 months. The highest accumulation was obtained in mucuna (69 kg $ha^{-1}$) and the lowest from pumpkin (22 kg $ha^{-1}$). The N accumulated by mucuna was above the recommended rate for maize of 60 kg N $ha^{-1}$ whereas lablab, cowpea, pumpkin and weed fallow accumulated N levels below the recommended N rate for maize. Cowpea and pumpkin accumulated the lowest amount of N. This low accumulation is accounted for by the low total biomass produced by these two cover crops (Table 5).

Other research findings indicated that not all amounts of N accumulated in the cover crop biomass become available to the succeeding maize crop (Ladd *et al.*, 1983; Janzen *et al.*, 1990; Giller and Wilson, 1991; Haggar *et al.*, 1993; Sidhu and Sur, 1993; Myres *et al.*, 1994). The N recovery reported by these workers ranged from 1% to 50% of N in the legume biomass. The amount of N recovered by the subsequent cereal crop is influenced by the chemical composition of the residues, soil moisture content and soil pH (Giller and Wilson, 1991; Blevins and Frye, 1993; Warren *et al.*, 1997: Brady and Weil, 2000).

The chemical composition of the residues influences the rate of N release (Tian *et al.*, 1992; Warren *et al.*, 1997) whereas soil moisture content influences biological activities that are involved in N release, denitrification and leaching (Mengel and Kirkby, 1987;

Ikerra *et al.*, 1999; Whitbread *et al.*, 2002). Based on the N recovery reported, the cover crops were expected to supply to the subsequent maize with 0.7 – 35, 0.5 – 24, 0.3 – 15, 0.2 to 11 and 0.5 to 23 kg N $ha^{-1}$ for mucuna, lablab, cowpea, pumpkin and weed fallow, respectively. It was observed in the incubation experiment that most of N accumulated in cowpea residues (35%) was released 7 days earlier than that for lablab and mucuna (Fig. 4). This release occurred at the early maize growth stage when N requirement was still low indicating that most of N released by cowpea residues was not taken up by maize crop because N requirement by maize at 7 DAPM was still low.

In the field, the rate of mineralization may be slower than under incubation due to fluctuations in soil moisture content and temperature, hence prolonging N release and extending the period of N supply to maize. Apart from N, cover crops accumulated other macro – nutrients as shown in Table 7.

Table 7: Amount of P and K accumulated by the cover crops at the end of the short rainy seasons

| Nutrient Type | Season | Cowpea | Lablab | Mucuna | Pumpkin | Weed Fallow |
|---|---|---|---|---|---|---|
| | | ..... kg $ha^{-1}$ ..... | | | | |
| P | 2001/02 | 0.8 | 1.8 | 1.3 | 1.3 | 0.8 |
| | 2002/03 | 1.2 | 7.5 | 6.5 | 2.9 | 2.9 |
| | Mean | 1.0 | 4.6 | 3.9 | 2.1 | 1.9 |
| K | 2001/02 | 22.0 | 18.5 | 28.0 | 15.7 | 38.5 |
| | 2002/03 | 39.0 | 93.0 | 162.0 | 84.0 | 214.0 |
| | Mean | 30.5 | 55.8 | 95.0 | 49.8 | 126.3 |

The values are from the composite of each treatment.

The cover crops accumulated P ranging from 0.8 to 4.6 kg P $ha^{-1}$. As for N, the amount accumulated in 2001/02 season was lower than that in the 2002/03 season. Inadequate rainfall received in 2001/02 may be the reason for this low amount of P. The amount of P accumulated by all cover crops even in seasons of good rains (2002/03) was still lower than the recommended application rate of 20 kg P $ha^{-1}$ (Mowo *et al.*, 1993). This indicated that the tested cover crops were unable to supply adequate amounts of P to subsequent maize crop and hence there is a need for application of P from external sources. The cover crops accumulated 16 to 214 kg K $ha^{-1}$, an amount which is higher than the recommended 15 kg K $ha^{-1}$ (Mowo *et al.*, 1993). Mucuna and weed fallow accumulated higher K than cowpea, lablab and pumpkin hence can be used as a source of K to crops.

### 4.4.4 The effect of the cover crop residues on ground cover

Ground cover recorded from cover crop's residues at 28 DAP of maize in the long rains is shown in Figure 7. The ground cover attained by cover crop residues ranged from 16 to 71%. The ground cover was in the following order: weed fallow = mucuna > lablab > cowpea > pumpkin. Weed fallow and mucuna residues had significantly higher ($P < 0.05$) ground cover than cowpea and pumpkin residues by 1.5 and 3.4 fold, respectively. Both the quantity and decomposition rate of the cover crop residues determined the extent of surface covered. Mucuna and weed fallow for example, generated 5.1 and 4.8 Mg $ha^{-1}$ of biomass, respectively at the end of short rains of the 2002/03 season (Table 3) and this biomass provided considerable ground cover in the long rains (Fig. 7). For instance, at 28 DAPM the residues of mucuna, weed fallow and lablab provided more than 50% ground cover whereas the other cover crops provided very little cover. The extent of ground covered by residues of cowpea and lablab was intermediate, whereas that of pumpkin was the lowest (Fig. 7).

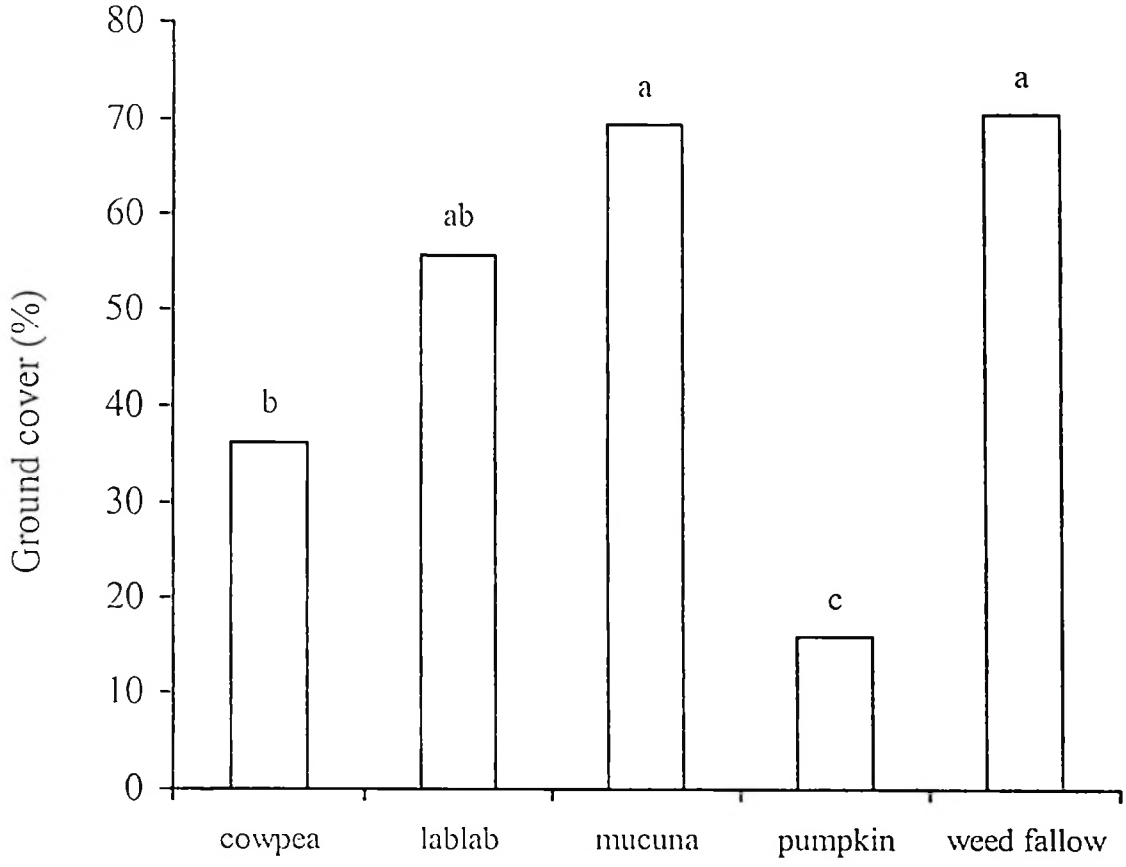


Figure 7: Ground cover by cover crop's residues at 28 DAPM

Cowpea residues generated significantly higher ground cover than pumpkin residues although its biomass at the end of the short rains was similar to that of pumpkin. This may indicate that the decomposition rate of pumpkin residues in the field was higher than that of cowpeas. In the incubation study, residues of the two cover crops had similar mineralization rate during the first 7 days. Thereafter, mineralization of pumpkin residues was higher than that of cowpea (Fig. 4). Higher N and P and lower lignin content of pumpkin than that of cowpeas residues could further explain this difference in mineralization rate and ground cover (Table 4). The ground cover in the long rains gives an indication of the mulching ability of the residues generated by cover crops. In this study weed fallow and mucuna generated significantly higher ($P < 0.05$) residue biomass, offered significantly higher ground cover and were therefore expected to have higher mulching effect than the other cover crops.

### 4.5 Effect of the cover crops on soil aggregate stability

The proportion of water stable aggregates at the beginning and at the end of the experiment is shown in Table 8. At the beginning of the experiment, the soil contained 2.7- 3.7% water stable soil aggregates of size < 53 μm, 23.5 - 34.2% of 53 - 250 μm, 46.1 - 61.5% of 250-2000 μm and 12.3 - 16.7% of > 2000 μm. The total micro – aggregates (< 250 μm) were lower than macro – aggregates (> 250 μm) and ranged from 26.2 to 37.2%. After planting cover crops for 3 consecutive short rain seasons, the water stable soil micro - aggregates ranged from 25.7 to 39.7%, being lowest in bare fallow and highest in pumpkin plots. The aggregates size fraction of <53 μm were 2.9 - 3.9% and 53-250 μm were 21.8 - 36.8%.

Table 8: Aggregate size fractions (%) after wet sieving at the beginning and at the end of the experiment

| Cover Crop | Aggregate size (µm) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Micro – aggregates | | | | | | Macro - aggregates | | | | | |
| | < 53 | | 53 - 250 | | Total | | 250 – 2000 | | > 2000 | | Total | |
| | Start | End | Start | End | Start | End | Start | End | Start | End | Start | End |
| Cowpea | 3.3a | 3.4a | 33.9a | 31.5a | 37.2a | 34.9a | 46.1b | 44.2b | 16.7a | 20.9a | 62.8a | 65.1a |
| Lablab | 3.6a | 3.9a | 26.9a | 28.6a | 30.5a | 32.5a | 52.9ab | 49.7b | 16.6a | 17.8a | 69.5a | 67.5a |
| Mucuna | 3.1a | 3.2a | 29.4a | 30.9a | 32.5a | 34.1a | 51.7b | 49.4b | 15.8a | 16.5a | 67.5a | 65.9a |
| Pumpkin | 2.7a | 2.9a | 34.2a | 36.8a | 36.9a | 39.7a | 50.5b | 46.6b | 12.6a | 13.7a | 63.1a | 60.3a |
| Weed Fallow | 2.7a | 2.9a | 23.5a | 25.5a | 26.2a | 28.4a | 61.5a | 58.9a | 12.3a | 12.7a | 73.8a | 71.6a |
| Bare Fallow | 3.7a | 3.9a | 27.8a | 21.8a | 31.5a | 25.7a | 55.5ab | 61.2a | 13.0a | 13.1a | 68.5a | 74.3a |

Values in a column followed by the same letter are not significantly different at P = 0.05 using DNMRT

The micro - aggregates in cover crops, weed and bare fallow treatments were statistically similar. The macro - aggregates (> 250 μm) constituted 60.3 to 74.3%, small macro - aggregates (250 - 2000 μm) 46.2 to 61.2% and large macro - aggregates (>2000 μm) 12.7 to 20.9% of the soil. The small macro – aggregates were significantly higher in bare fallow than in the other treatments. The higher level of this fraction in bare fallow observed at the start and at the end of the experiment indicates that it was inherent. The aggregate of size 250 - 2000 μm was the only fraction that showed differences between treatments indicating that this size fraction is affected most by cropping on the study soils. Changes in water stable soil aggregate fractions after 3 seasons of using cover crops are shown in Table 9.

The aggregate size fraction of 250 - 2000 μm was significantly decreased in cover crops and weed fallow whereas in bare fallow it was increased. With the exception of cowpea, the reverse trend was observed for the aggregate size fraction of 53 - 250 μm in which the increase of 1.5 - 2.6% was observed for the cover crops and 2.0 for weed fallow. A decrease in this fraction of 2.4 and 6.0% was observed in cowpea and bare fallow treatments, respectively. The other fractions were not significantly affected by any of the treatment. In the current study the use of cover crop decreased soil macro - aggregates by 1.9 - 3.9% as compared to the values at the beginning of the experiment. The decrease in soil macro - aggregates indicates deterioration in water stable aggregates (Haynes and Swift, 1990; Bear and Bruce, 1993). The deterioration in water stable aggregates may imply that the use of cover crops on the study area may result to reduced soil macro – porosity and water infiltration.

Table 9: Changes in aggregate size fraction due to the use of cover crops for three short rain seasons

| Cover crop | Aggregate size fraction (%) | | | |
|---|---|---|---|---|
| | <53 µm | 53-250 µm | 250-2000 µm | >2000 µm |
| Cowpea | 0.1a | -2.4a | -1.9b | 4.2a |
| Lablab | 0.3a | 1.7a | -3.2b | 1.2a |
| Mucuna | 0.1a | 1.5a | -2.3b | 0.7a |
| Pumpkin | 0.2a | 2.6a | -3.9b | 1.1a |
| Weed fallow | 0.2a | 2.0a | -2.6b | 0.4a |
| Bare fallow | 0.2a | -6.0b | 5.7a | 0.1a |

Values in a column followed by the same letter are not significantly different at P = 0.05 under DNMRT.

The differences between the effects of cover crops and bare fallow on soil aggregate stability could be due to variations in tillage operations during the short rains. In the short rains, cover crops were weeded using hand hoe whereas bare fallow was kept clean by hand pulling of weeds, which might have caused minimum soil disturbance in bare fallow.

Blair and Crocker (2000) observed a decrease in water stable soil aggregates following cropping and cultivation on vertisols. The use of cover crops in the current study had no improvement in water stable aggregates relative to bare fallow. This is contrary to observations by Rasse *et al.* (2000) and Mc Vay *et al.* (1989). Rasse *et al.* (2000) reported increased soil water aggregate stability (an increase of 20 and 13% in MWD) in the duration of 2 years due to shoot mulch and root turnover of alfalfa, respectively. It is not clear whether these differences in aggregate stability are associated with variation in the

amount of biomass produced or rainfall distribution, because in the study by Rasse *et al.* (2000) these parameters were not specified. In a long term study by Blair and Crocker (2000), higher aggregate > 250 μm following the use of lucerne (62.2%) and clover (63.5%) than that from long fallow (46.2%) was reported. Mc Vay *et al.* (1989) reported higher aggregate stability with legume cover crops than with non legumes in 3 years of experimentation. They attributed the higher soil aggregate stability to higher biomass produced by legume cover crops. The amount of soil organic matter, soil moisture content and soil biological activities are major determining factors in formation of soil macro-aggregates (Giller and Wilson, 1991; Sarig and Steinberger, 1993).

Lack of effect of cover crops on soil aggregation in the current study may be attributed to low biomass produced and applied to the soil (section 4.2.2) and droughts experienced in the short rains of 2001/02 and the long rains of 2002/03 (Fig. 1). These droughts might have reduced soil biological activities, consequently reducing soil aggregation. Also, because the residue of the cover crops was surface applied there was a possibility of limited mixing with soil and hence little effect on soil aggregation. The duration of the study of 3 years was not long enough to allow significant change in soil aggregation.

### 4.6 Effect of the cover crops on soil bulk density and porosity

Soil bulk density and porosity during 3 seasons of experimentation are shown in Table 10. The soil bulk density at the start of the experiment ranged from 1.45 to 1.54 Mg $m^{-3}$, in the second year it ranged from 1.47 to 1.55 Mg $m^{-3}$ and at the end of the experiment from 1.42 to 1.51 Mg $m^{-3}$. According to Landon (1991), clay soils that have bulk density beyond 1.4 Mg $m^{-3}$ hinder root penetration. The bulk density of the soil used in this study is lower than this range, indicating that the soil had no hindrance to root penetration. At the end of

the experiment the bulk density of the soil was reduced by 0.03, 0.09, 0.06 and 0.02 Mg $m^{-3}$ in lablab, pumpkin, mucuna and cowpea plots, respectively (Table 10).

Table 10: Soil bulk density and porosity as influenced by different cover crops

| Cover crop | Bulk density | | Changes in bulk density | Porosity | |
|---|---|---|---|---|---|
| | 2000/01 | 2002/03 | | 2000/01 | 2002/03 |
| | .....Mg $m^{-3}$..... | | .....%..... | .....%..... | |
| Bare fallow | 1.45 | 1.51 | 4 | 45 | 43 |
| Weed fallow | 1.47 | 1.48 | 1 | 45 | 44 |
| Cowpea | 1.45 | 1.43 | -1 | 45 | 46 |
| Lablab | 1.45 | 1.42 | -2 | 45 | 46 |
| Mucuna | 1.52 | 1.46 | -4 | 43 | 45 |
| Pumpkin | 1.51 | 1.42 | -6 | 43 | 46 |
| LSD | 0.12 | 0.13 | | 4 | 6 |

The soil bulk density was 2, 6, 4 and 1% lower than that at the commencement of the experiment in lablab, pumpkin, mucuna and cowpea plots, respectively. Weed and bare fallows respectively increased the bulk density by 1 and 4% of that at the beginning of the experiment. The reduction in soil bulk density by cover crops would be due to the effect of residues added to the soil. Crop residues are known to reduce soil bulk density by adding organic matter to the soil and stimulating activities of soil macro - organisms, all of which reduce soil bulk density (Ghuman and Sur, 2001). Ghuman and Sur (2001) observed that surface applied residues reduced the bulk density of the surface 10 cm layer by 0.05 Mg $m^{-3}$ but had no effect on underlying soil layers. The bulk density changes in the current study were obtained in the top 5 cm after growing cover crops for 3 seasons as opposed to those of Ghuman and Sur (2001), which was in the top 10 cm after 5 seasons of wheat.

The porosity in the surface soil ranged from 43 to 45% at the beginning of the experiment and after 3 seasons it had not changed much, it ranged from 43 to 46% (Table 10). The cover crop treatments had statistically similar effect on soil porosity as the bare treatment indicating that the tested cover crops had no significant influence on soil porosity during 3 years of the experiment.

### 4.7 Effect of cover crops on soil water infiltration

Infiltration rate of the soil at the beginning of the experiment and after the use of cover crops for three short rains are shown in Table 11.

Table 11: Water basic infiltration rate and sorptivity at the beginning and at harvest of the third season cover crop

| Parameter | Time of Measurement | Bare | Cowpea | Lablab | Mucuna | Pumpkin | Weed fallow |
|---|---|---|---|---|---|---|---|
| Basic infiltration ($cm\ h^{-1}$) | Beginning | 4.8a | 5.2a | 3.6a | 3.6a | 4.8a | 3.9a |
| | End | 4.9 bc | 4.3c | 4.6bc | 5.6ab | 6.2a | 5.7ab |
| | Change | 0.1 | 0.9 | 1.0 | 2.0 | 1.4 | 1.8 |
| Sorptivity ($mm\ h^{-1/2}$) | Beginning | 29a | 32a | 22a | 29a | 30a | 32a |
| | End | 23a | 22a | 26a | 26a | 22a | 31a |
| | Change | -6 | -10 | 4 | -3 | -8 | -1 |

Values followed by same letters in the row are not statistically different at P= 0.05 using DNMRT.

Basic infiltration rates at the beginning of the experiment ranged from 3.6 to 5.2 cm $h^{-1}$ and were statistically similar. At harvest of the third season cover crop it ranged from 4.3 to 6.2 cm $h^{-1}$. These infiltration rate values except for pumpkin at harvest of the third cover

crop are within the range of 2 to 6 cm $h^{-1}$, which is rated by Landon (1991) as moderate. Infiltration rate obtained in pumpkin treatment at harvest of the third cover crop was moderately high (Landon, 1991). This indicated that there was no major limitation in water conductance in the soil profile. Basic infiltration rate at harvest of the third season cover crop in pumpkin plots was statistically similar to that in mucuna and weed fallow, but was significantly higher ($P < 0.05$), roughly 24% higher than that in bare fallow, lablab and cowpea plots. The basic infiltration rates in bare, cowpea and lablab plots were not significantly different. At the end of third year of growing season, infiltration rate increased from 3.6 to 5.6, 3.9 to 5.7 and 4.8 to 6.2 cm $h^{-1}$ in mucuna, weed fallow and pumpkin treatment respectively whereas in bare fallow was almost unchanged. The increase in infiltration rate after mucuna, pumpkin and weed fallow implied that these treatments increase soil water conductivity possibly by increasing soil water conducting pores than the bare fallow, cowpea and lablab plots.

Sorptivity of the soil ranged from 22 to 32 mm $h^{-1/2}$ at the beginning of the experiment and from 22 to 31 mm $h^{-1/2}$ at harvest of the third season cover crop. The effect of cover crops on sorptivity was similar and was not significantly different from that of weed and bare fallows. This shows that there was no significant difference in moisture storage capacity between cover crop treatments and that when lateral flow of water was prevented, the treatments had similar infiltration rate at initial stages of infiltration. Basic infiltration rate was not significantly related to level of soil macro - aggregates, bulk density or above ground biomass (Appendix 21). The lack of correlation between basic infiltration rate and the level of soil macro - aggregates could be explained by the presence of channels formed by soil macro - organisms and pores created after decomposition of roots (biopores) in a soil profile. Although not quantified in this study, water can infiltrate into

the soil through the biopores (Douglas and Goss, 1982; Lal *et al.*, 1989). Since these biopores are not necessarily related to the amount of soil aggregate size fraction, some water infiltrating into the soil may not be accounted for by pores formed due to soil aggregation, leading to a weak correlation between basic infiltration and the level of soil macro aggregates. The weak correlation between infiltration rate and soil bulk density obtained in this study is similar to results obtained by Stirzaker and White (1995). Stirzaker and White (1995), working on sandy loam soil reported the lack of correlation between soil bulk density and infiltration rate.

The results of the current study are contrary to report that infiltration rate increases as the soil bulk density decreases (Lal, 1990). The weak correlation between the above ground biomass of the cover crop and the basic infiltration rate indicated that the effect of the cover crop biomass had minimal effect on the basic infiltration rate. Sorptivity was significantly positively correlated with above ground biomass ($r = 0.634$, $P < 0.05$). This implies that the effects of cover crops on sorptivity may adequately be explained by the amount of biomass added to the soil.

### 4.8 Effect of the cover crops on runoff

The amount of rain - water lost as runoff for each rainfall event in the 2001/02 season is shown in Table 12. Six rain storms caused runoff losses during the long rains of 2001/02 season. The highest runoff loss was obtained at the beginning of the long rains following 75 mm of rains, which were received at 73 days after planting of cover crops (DAPC).

Table 12: Runoff losses under different surface cover treatments in the long rains of the 2001/02 season

| | DAPC | | | DAPM | | |
|---|---|---|---|---|---|---|
| | 73 | 77 | 98 | 8 | 10 | 14 |
| Surface cover | ..... mm ..... | | | | | |
| Bare fallow | 39.4 | 20.6 | 3.4 | 21.0 | 11.8 | 9.6 |
| Weed fallow | 28.2 | 18.0 | 0.8 | 5.2 | 1.8 | 4.2 |
| Cowpea | 30.0 | 13.0 | 1.6 | 6.6 | 2.4 | 4.4 |
| Lablab | 35.2 | 19.2 | 1.0 | 6.6 | 2.2 | 4.4 |
| Mucuna | 40.4 | 36.6 | 1.8 | 7.6 | 2.4 | 4.4 |
| Pumpkin | 41.4 | 29.8 | 1.8 | 6.0 | 2.4 | 7.6 |
| Rainfall (mm) | 75.0 | 38.0 | 26.0 | 72.0 | 22.0 | 44.0 |
| Orthogonal contrasts | | | | | | |
| Bare vs rest | P= 0.234 | Ns | 0.003 | 0.000 | 0.000 | 0.000 |
| Pumpkin vs other covers | P= 0.045 | 0.084 | 0.295 | ns | ns | 0.001 |
| Weed vs legumes | P= 0.079 | 0.287 | 0.282 | 0.277 | ns | ns |
| Mucuna vs lablab & cowpea | P= 0.064 | 0.001 | ns | ns | ns | ns |

DAPC = Days After Planting of cover crops

DAPM = Days After Planting of maize

At 73 DAPC runoff ranged from 28.2 to 41.4 mm and was not statistically different between bare, cover crops and in weed fallow plots. However, within the cover crops, pumpkin plots had significantly higher runoff ($P < 0.05$). Runoff that was caused by a 38 mm rain received at 77 DAPC ranged from 13 to 36.6 mm. The lowest runoff was from cowpea, and the highest from mucuna plots. Runoff amounted to 34 and 96% of rainfall received in cowpea and mucuna plots, respectively. Runoff from mucuna plots was significantly higher than that from other cover crop plots ($P < 0.01$). The runoff from plots under the other cover crops, weed fallow and bare plots were statistically similar.

The proportion of rainfall lost as runoff in pumpkin and mucuna at 77 DAPC from 38.0 mm rainfall was higher than that at 73 DAPC from 75 mm rainfall. Pumpkin and mucuna had higher ground cover at 77 DAPC than cowpea and lablab and might have conserved more moisture from rainstorm received at 73 DAPC than other cover crops. High moisture content in the soil prior to the rainstorm may explain higher runoff at low amount of rainfall in mucuna and pumpkin. High proportion of rainfall as runoff from light rainfall was also reported by Gebremedhin (1996) at the same site when the antecedent soil moisture was high. Gebremedhin (1996) reported that 77% of rainfall was lost as runoff when a 9.6 mm rainstorm was preceded by three consecutive heavy rainstorms.

Runoff losses obtained 1 day after slashing of cover crops at 98 DAPC from 26 mm of rain ranged from 0.8 to 3.4 mm in weed fallow and bare fallow treatments. These amounts of runoff were lower than those obtained when cover crops were still growing (Table 12). The residues that were left on the soil surface after slashing of cover crops provided mulch that reduced runoff. For example, only 7 to 11% of 72 mm of rains received at 8 DAPM were lost as runoff in weed fallow and cover crop plots, which was very low compared to

runoff recorded after a 38 mm rain at 77 DAPC. The runoff from bare plots was significantly ($P < 0.01$) higher than that from weed fallow and from cover crop plots. The runoff losses that were generated by 44 mm of rain at 14 DAPM ranged from 4.2 to 9.6 mm, accounting for 10 to 22% of rainfall received. The runoff from the bare plots was significantly higher than that from the other plots ($P < 0.001$). The runoff in pumpkin treatment was 16.4% of rainfall and was significantly ($P < 0.001$) higher than those in weed fallow and other cover crops which ranged from 9.5 to 10% of rainfall. High runoff in pumpkin treatment at 14 DAPM could be attributed to lower amount of mulch in this treatment than those in other cover crops treatments and hence least effective in reducing of runoff.

The amount of rains and water runoff obtained in 2002/03 season is shown in Figure 8 and the percentage of rainfall lost as runoff under different cover crops in Table 13. Eight out of 22 rainstorms and two out of 17 rainstorms caused runoff in the short rains and in the long rains, respectively. The amounts of runoff ranged from 2.8 to 40 mm per rainfall event depending on the amount of rains and type of cover crop.

In bare fallow plots runoff amounted to 10 mm or less when rainfall was 30 mm or less but with higher amount of rainfall runoff exceeded 10 mm. This showed that runoff increased as amount of rainfall increased. More runoff was obtained at the end of the short rains in late December 2002 and early January 2003 (63 – 72 DAPC) and at the beginning of the long rains in March 2003 (0 – 12 DAPM).

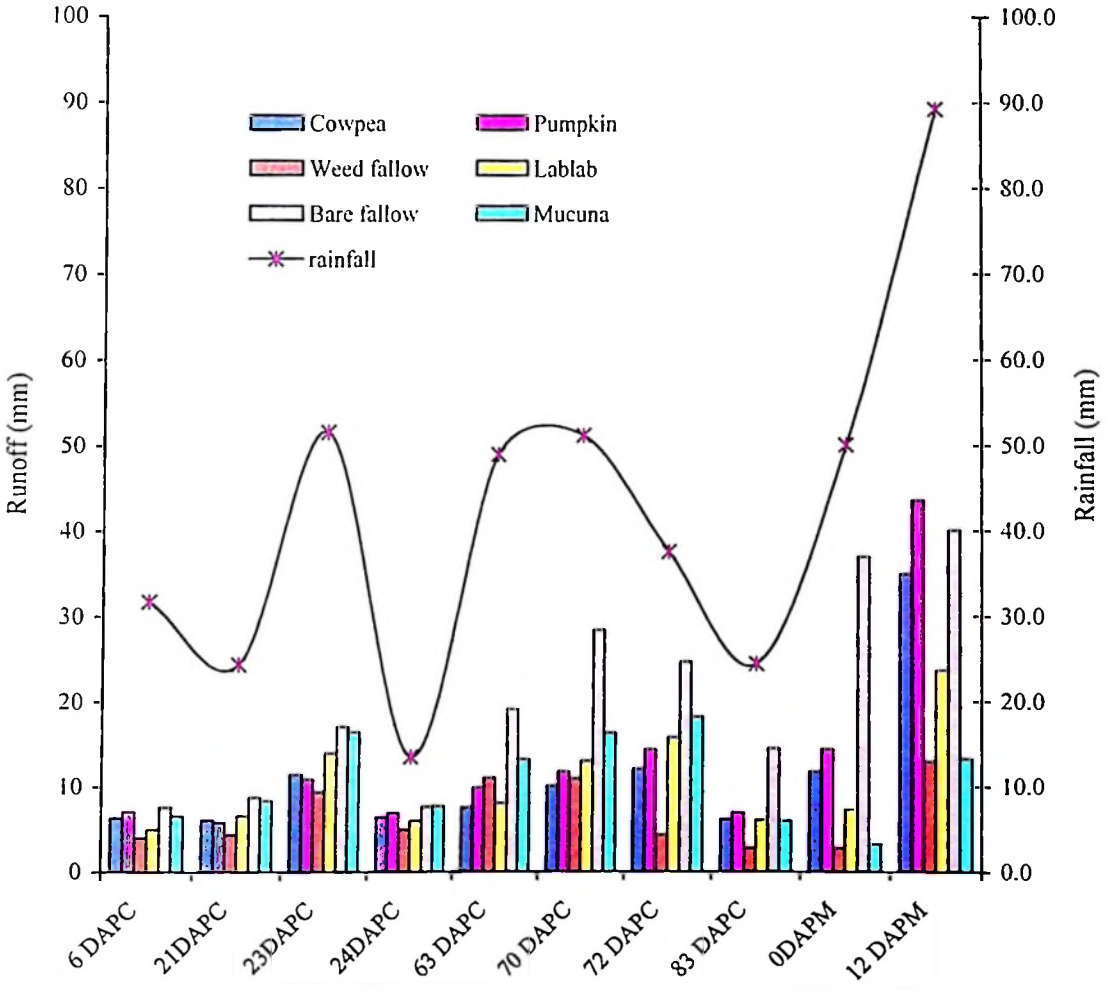


Figure 8: Effect of cover crops planted during the short rains on runoff in 2002/03

Table 13: Amount of rainfall lost as runoff in the 2001/02 and 2002/03 seasons

| | 2001/02 | | | 2002/03 | | |
|---|---|---|---|---|---|---|
| | SR | LR | Annual | SR | LR | Annual |
| Cover crop | .....(%)..... | | | | | |
| Bare fallow | 60b | 45a | 55a | 43a | 30a | 38a |
| Cowpea | 39c | 14c | 27b | 26c | 18b | 19bc |
| Lablab | 36c | 13c | 25b | 24c | 6c | 21b |
| Mucuna | 80a | 15c | 48a | 32b | 6c | 25b |
| Pumpkin | 76a | 22b | 50a | 26c | 23b | 28b |
| Weed fallow | 51b | 10c | 31b | 16d | 6c | 14c |

Values followed by the same letter in the column are not statistically different at P = 0.05 using DNMRT.

LR = long rains

SR = Short rains

The results of the current study are supported Bazugba (2001) who also reported that 85% of seasonal runoff in the same area took place at the beginning of the long rains (March – April). More runoff was obtained at the end of the short rains and at the beginning of the long rains because more rains are received during these periods than the other part of the year. In addition to high amount, rainfall received in these periods is of high intensity (Gebremedhin, 1996). The study by Gebremedhin (1996) showed that about 56% of rainstorms in the long rainy season had the 30 minutes maximum intensity ($I_{30}$) > 2.5 cm $h^{-1}$, 17% had ($I_{30}$) > 5.0 cm $h^{-1}$ and occasionally rainstorm with ($I_{30}$) as high as 9.7 cm $h^{-1}$ was obtained in this area. Highest runoff was obtained from bare fallow treatment in both short and long rains. This amounted to 43 and 30% of total rains received in the short and long rains of 2002/03, respectively (Table 13).

These results are similar to those reported by Gebremedhin (1996) where runoff in the bare plots during the long rains accounted for 32% of the seasonal rainfall. Lack of crop residue on the soil surface to protect the soil from the impact of rain drops and to reduce the speed of surface flow of water (Lal, 1990; Trojan and Linden, 1998) explains the observed high runoff in bare fallow treatment.

The results for 2001/02 and 2002/03 seasons (Table 13) showed that cover crops were more effective in reducing runoff in the long rainy seasons than in the short rainy seasons indicating that cover crop residues were more effective in reducing runoff than live stand of cover crops. The reasons for this observation could be the difference in ground cover and the contact between soil and residues. This observation is explained by the fact that at the beginning of the short rains when there were large amounts of rain to cause runoff, cover crops were still at establishment stage, with ground cover of < 30% (Fig. 4 and 5) hence less effective in reducing runoff. This is as opposed to the situation at the beginning of the long rains as cover crop residues covered the soil surface and runoff was reduced substantially. However, the live cover crop stands were still less effective in reducing runoff even towards the end of the short rains. At 77 DAPC in 2001/02 for example, the cover crops had ground cover ranging from 53 to 71% (Fig. 5) but still their effect on runoff relative to that of the residues in the long rainy season was still lower (Table 13). This shows that the tested cover crops are less effective in reducing runoff in the short rains. The relationships between runoff and infiltration rate, macro aggregates, biomass generated by cover crops during the short rains and ground cover by cover crop residues as obtained from regression analysis are shown in Table 14.

Table 14: Correlation coefficients (r) relating runoff at various rainfall events and infiltration rate, soil macro - aggregates (>250 μm), biomass of cover crop residues at the end of short rains of 2002/03

| Rainfall | infiltration | Aggregate >250 μm | biomass |
|---|---|---|---|
| (mm) | ..... r ..... | | |
| 24.5 | -0.267ns | 0.054ns | -0.674** |
| 50.1 | -0.220ns | 0.116ns | -0.715** |
| 89.3 | 0.071ns | -0.279ns | -0.837** |

ns = not significant at P = 0.05

* = Significant at P = 0.05

** = Significant at P = 0.01

There was no relationship between runoff and infiltration rate or percentage of macro - aggregates ( >250 μm). This is probably due to the lack of difference in infiltration rate and aggregate stability between plots under different cover crops indicating that runoff in this study was more influenced by surface behaviour of the soil than internal properties such as soil aggregation. However, when the rainfall intensities reported for this area of 2.5 - 5.0 cm $h^{-1}$ (Gebremedhin, 1996) were compared with the infiltration rates obtained in this study of 3.6 - 6.2 cm $h^{-1}$ (Table 6) the differences were not high enough to explain the high amount of runoff obtained.

This could be due to the fact that the infiltration rates obtained in this study was not able to portray the effect of surface sealing on water infiltration. In the determination of infiltration rate using the tension infiltrometer the water was confined to ensure that lateral movement was minimal and the water was moving by gravity, with no energy to cause soil

dispersion and surface sealing. Runoff was negatively correlated with the biomass generated by the cover crops in the short rains.

There was negative relationship between biomass and runoff when rainfall amount was increased. The coefficient of correlation (r), were -0.674, -0.715 and -0.837 when 24.5, 50.1 and 89.3 mm of rainfall were received, respectively, indicating that increasing the biomass of cover crops residues reduced runoff significantly ($P < 0.01$). Cover crop residues reduced runoff by absorbing rainfall energy that would otherwise disperse soil particles and caused surface sealing (Lal, 1990). They also slow down the velocity of surface runoff giving more time for the infiltration process (Wall et al., 1991; Dabney, 1998). The relationship between runoff and biomass of cover crop residues was stronger when the amount of rainfall increased because runoff was higher with high amount of rainfall. The effect of varying the amount of cover crop residue was expressed more under high runoff than under low runoff. These results demonstrate the usefulness of cover crops in reducing surface runoff.

## 4.9 Effect of the cover crops on soil moisture content

### 4.9.1 Effect of live cover crops on soil moisture content in the short rains

The effect of cover crops on soil moisture content in the topsoil during the short rains of 2000/01 and 2002/03 seasons is shown in Figures 9 and 10 respectively. Soil moisture content in 2000/01 at cover crops planting ranged from 17.5 to 18.6% and was statistically similar in all plots and thereafter, it decreased to as low as 12%. Soil moisture content in weed fallow was highest throughout the short rains but it was only significantly different early in the short rains at 14 DAPC.

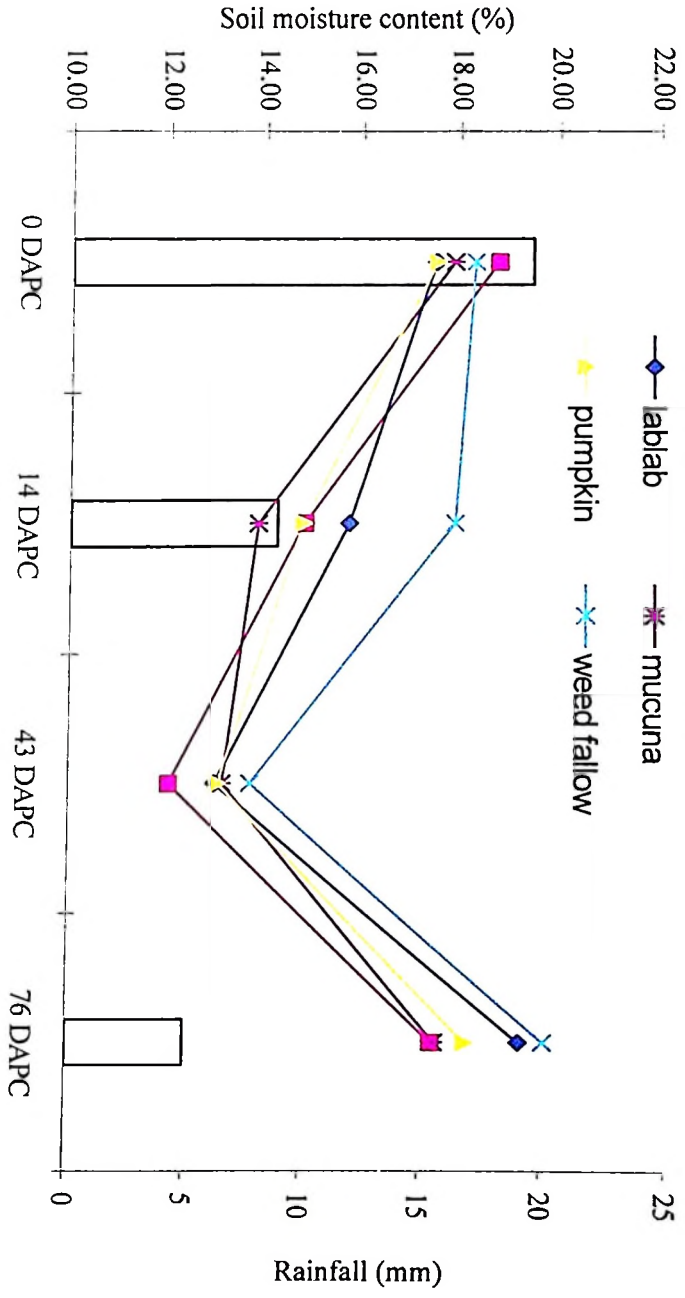


Figure 9: Soil moisture content during the growing period of the cover crops in the short rains of 2000/01

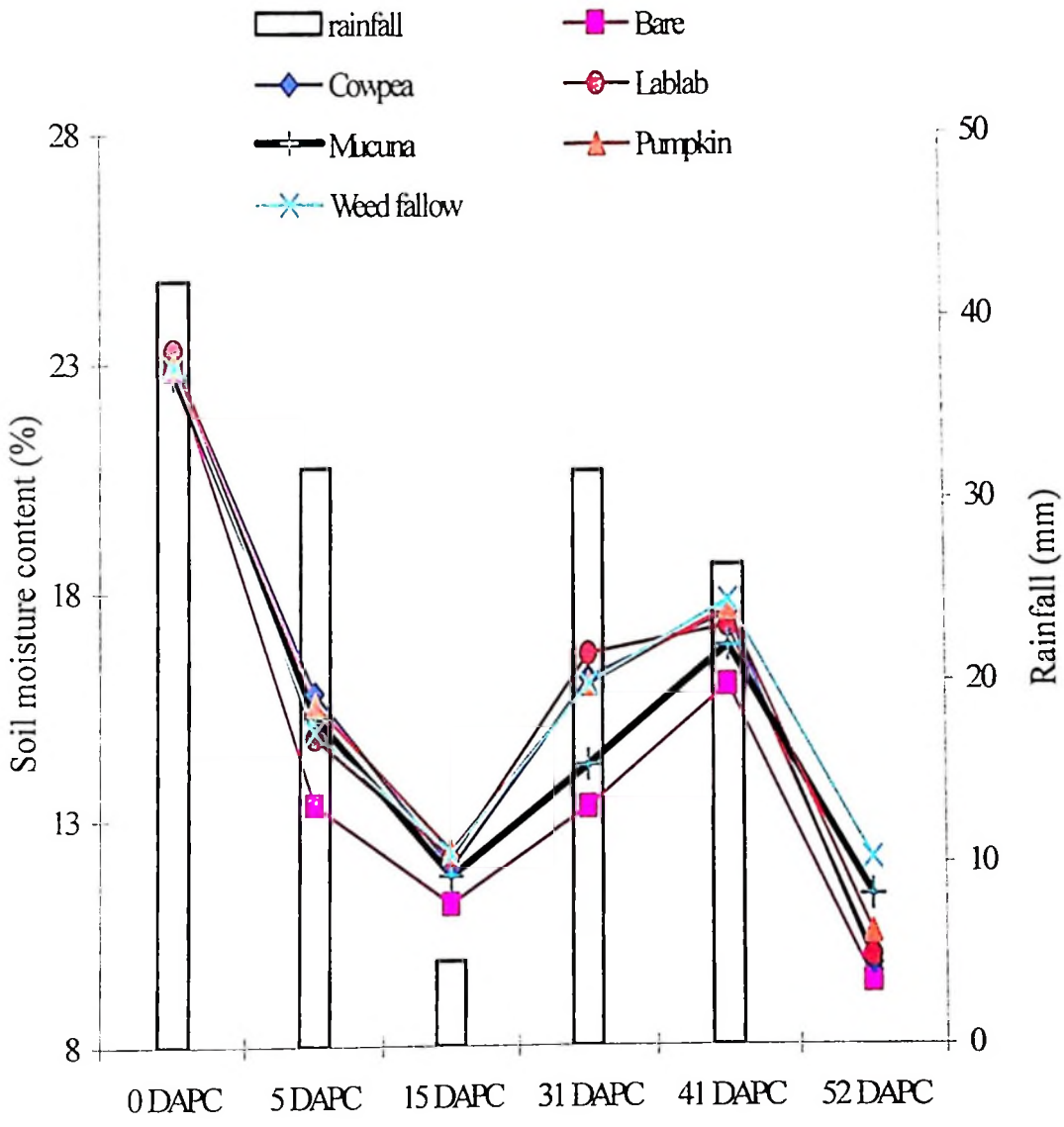


Figure 10: Soil moisture content during the growing period of the cover crops in the short rains of 2002/03

The soil moisture content under cover crops was statistically similar throughout the short rains of 2000/01 indicating that the effect of cover crops on moisture content in the short rainy season was similar. Unlike in 2000/01, soil moisture in weed fallow during the short rains in 2002/03 season was similar to that in lablab, cowpea and pumpkin (Fig. 10). The soil moisture content under weed fallow at 31 DAPC was significantly higher than that in mucuna and bare plots.

Generally Figures 9 and 10 show that no extra benefit on soil moisture content in the topsoil (0 –20 cm) over weed fallow was obtained during the short rains from growing cover crops. However, the data indicated that soil moisture at 0 – 20 cm depth at early cover crop growth stages, was relatively lower under mucuna than under other cover crops. The lower soil moisture content under mucuna than under other cover crops is supported by the report by Salako and Tian (2003) that mucuna extracts more water at its early growth stages. Salako and Tian (2003) observed that *M. pruriens* extracted more soil water in first 10 weeks but towards the end of growth season mucuna treatment had higher soil moisture content than *C. ochroleuca*, *C. pascuorum* and *A. histrix* in the topsoil (0 - 15 cm).

The moisture content in the soil profile at the beginning and towards the end of the short rains when the cover crops had grown for 45 days is shown in Figures 11 and 12, respectively. The soil moisture profile indicated that moisture was lower in the top 0 - 10 cm soil layer, than in the subsoil (10 - 20 cm). Low soil moisture in the top 0 – 10 cm soil layer was attributed to high root activity in the top soil and water evaporation from this soil layer. The 10 – 20 cm soil layer had more soil moisture as it had relatively lower root activity and water evaporation.

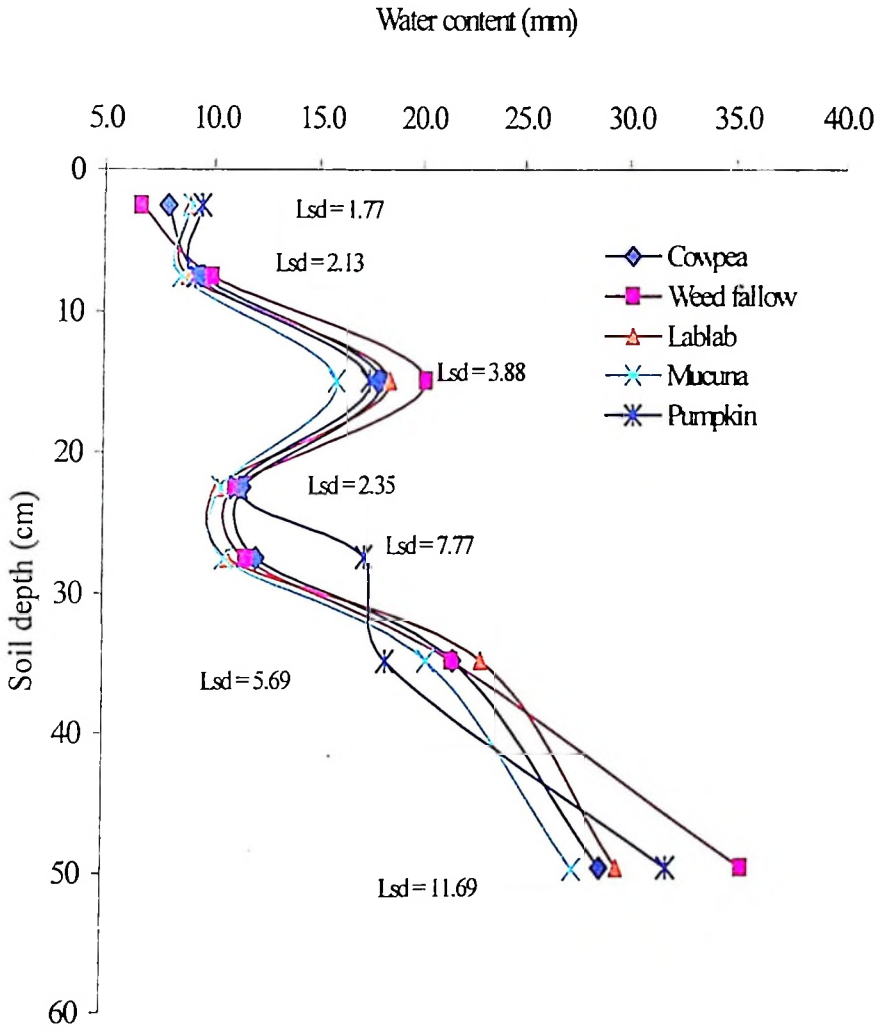


Figure 11: Soil moisture profile at the beginning of the short rains

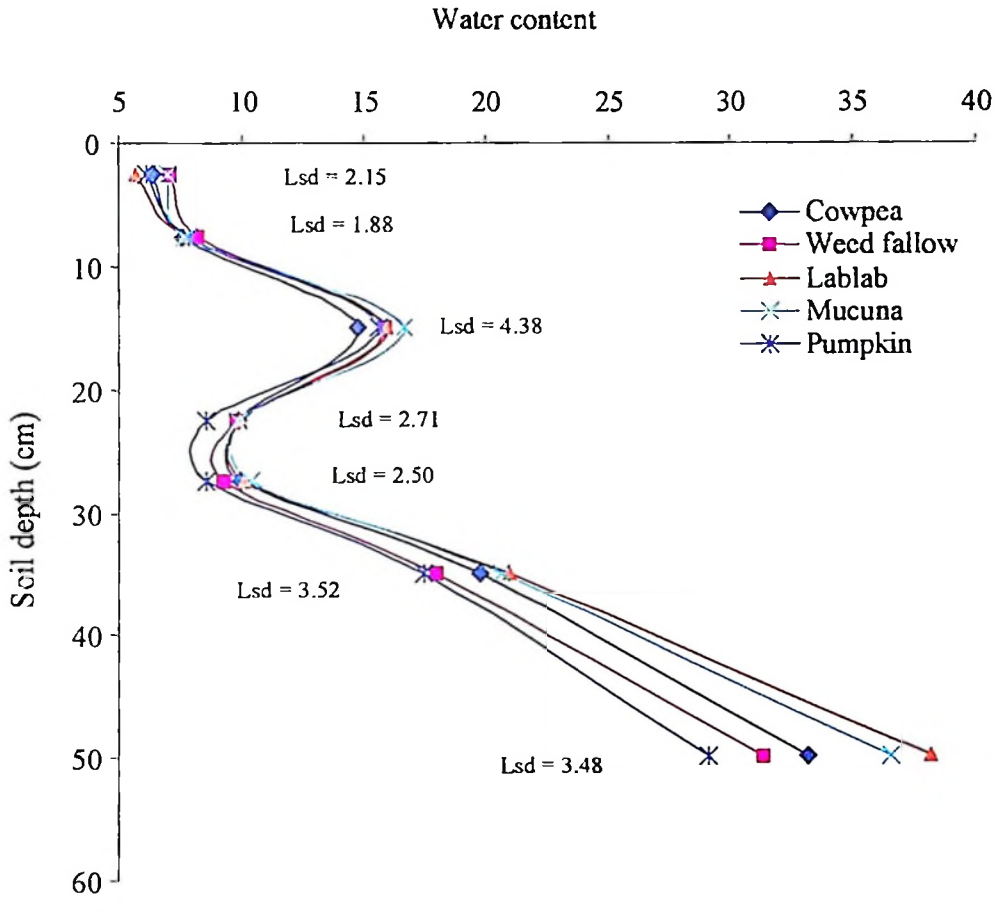


Figure 12: Soil moisture profile at 45 days after planting of cover crops

Also, water infiltrating the soil accumulated in this soil layer because of less permeability of the underlying plough layer at the 20 - 25 cm depth as expressed by its high bulk density (Table 1). Due to its high bulk density, the 20 - 30 cm had lower moisture content than the overlaying and underlying layers (Fig. 11 and 12) Soil moisture content at the beginning of the short rains ranged from 6.6 to 9.4 mm in the top 0 - 5 cm, 8.5 to 9.9 mm in the 5 - 10 cm, 54.1 to 64.5 mm in the 0 - 30 cm and 47.6 to 56.6 mm in the 30 - 60 cm layer (Fig. 11). All treatments were statistically similar in terms of soil moisture content.

At 45 days after cover crop planting, the moisture content ranged from 5.7 to 7.1 mm in the 0 - 5 cm and 7.6 to 8.2 mm in the 5 - 10 cm. The top 0 - 30 cm soil layer had 46.5 to 51.4 mm. The subsoil, 30 - 60 cm had soil moisture content ranging from 46.5 to 59.0 cm. The soil moisture content in the top 0 - 40 cm soil layer was statistically similar in all treatments (Fig 12). In the 40 - 60 cm soil layer, soil moisture content was in the order pumpkin < weed fallow < cowpea < mucuna < lablab. Soil moisture content in the 40 - 60 cm soil layer was significantly higher ($P < 0.05$) under mucuna and lablab than under pumpkin and weed fallow. The magnitude of changes in moisture content in the soil profile at day 45 after cover crop planting is shown in Table 15.

At 45 DAPC there was a negative soil water balance in the 0 – 40 cm layer indicating that this soil layer was drier at 45 DAPC than at the beginning of the short rains possibly due to uptake by cover crops and weeds. In the 40 – 60 cm layer, the positive balance was obtained in cowpea, lablab and mucuna and negative balance in pumpkin and weed fallow treatments showing that cowpea, lablab and mucuna increased soil moisture in this soil layer whereas weed fallow and pumpkin depleted soil moisture from this soil layer.

Table 15: Soil moisture changes (mm) under cover crops at the end of the short rains (2000/01)

| Soil depth (cm) | cowpea | Weed fallow | Lablab | Mucuna | Pumpkin |
|---|---|---|---|---|---|
| | | | mm | | |
| 0-5 | -1.5a | 0.5a | -3.2a | -2.0a | -3.3a |
| 5-10 | -1.8a | -1.7a | -1.1a | -0.8a | -1.3a |
| 10-20 | -3.3a | -4.4a | -2.6a | 0.8a | -1.9a |
| 0-20 | -6.6 | -5.7 | -6.8 | -1.9 | -6.5 |
| 20-25 | -1.6a | -1.3a | -0.3a | -0.6a | -2.7a |
| 25-30 | -2.2a | -2.3ab | -0.6a | -0.2a | -8.7b |
| 20-30 | -3.7 | -3.7 | -0.9 | -0.8 | -11.5 |
| 30-40 | -1.9a | -3.6a | -2.0a | 0.3a | -0.9a |
| 20-40 | -5.6 | -7.3 | -2.9 | -0.5 | -12.4 |
| 40-60 | 4.5b | -3.8c | 8.7a | 9.2a | -2.6c |
| 0-60 | -7.7 | -16.8 | -1.0 | 6.8 | -21.5 |

Values in the row followed by the same letter are not significantly different at P = 0.05 using DNMRT.

Improved infiltration of rain water into the soil was reported to be among factors that increase amount of water stored in the soil (Lal *et al.*, 1991). The current study showed that infiltration rate was significantly increased under pumpkin, mucuna and weed fallow (Table 11). The observation that the soil profile was drier under weed fallow and pumpkin than under the other cover crops in the 40 – 60 cm soil layer indicated that improvement in infiltration rate could not solely explain the obseved soil moisture profile. High runoff during the short rains (Table 13) may explain the low moisture content obtained under pumpkin but not the high moisture content under mucuna.

Other workers associated the differences in soil moisture content in the profile to variation in root depth of the cover crops. Deep-rooted plants extract more water from deeper soil layers than shallow rooted ones (Hartemink *et al.*, 1996). In their study, Hartemink *et al.* (1996) found that water content was higher in the topsoil and lower in the subsoil (> 50

cm) with deep - rooted *Sesbania* plants and it was *vice versa* with relatively shallow rooted weed fallow and maize. In the current study weed fallow was among the treatments that had the lowest profile moisture content in the subsoil. Therefore, the differences in water content in the subsoil might not be entirely explained by water extraction by roots of the cover crops. The vegetative parts of cover crops influence rain water entering the soil by slowing down runoff and increasing time of infiltration, thus increasing cummulative infiltration and soil moisture in the profile. This effect also varies between crops depending on leaf size, crops having large leaves concentrate rainwater into large drops, which may increase runoff.

### 4.9.2 Effect of cover crops on soil moisture content in the long rains

The effect of cover crops previously planted in the short rains on soil moisture content in the surface (0 - 20 cm) horizon during the long rainy season of 2000/01 is shown in Table 16. The soil moisture contents at 0, 21, 35 and 53 days after planting maize was not significantly different between cover crop treatments.

Table 16: Effect of cover crops on soil moisture content in the top 0 - 20 cm in the subsequent long rains of the 2000/01 season

| | Days after maize planting | | | |
|---|---|---|---|---|
| | 0 | 21 | 35 | 53 |
| Cover crop | ..... | ..... | % ..... | ..... |
| Weed fallow | 27a | 19a | 26a | 14a |
| Cowpea | 28a | 20a | 23a | 15a |
| Lablab | 24a | 20a | 24a | 14a |
| Mucuna | 23a | 21a | 23a | 14a |
| Pumpkin | 25a | 19a | 22a | 13a |

Values in the column followed by the same letter are not significantly different at P = 0.05 by DNMRT.

The lack of difference in soil moisture content between the treatments particularly at the beginning of the long rains was due to high amount and good distribution of long rains in 2000/01 (Fig. 1). The effect of cover crop residue mulch was therefore, masked by adequate and frequent long rains at the beginning of the long rains in 2000/01 season. However, lack of differences in soil moisture content between cover crop treatments at 53 DAPM, when the soil moisture was low indicates that the cover crops tested were less effective in moisture conservation. Soil moisture contents in different cover crop treatments in the long rainy season in 2001/02 are shown in Table 17. At 7 DAPM, in the 2001/02 season, the soil moisture content was 17, 19, 18, 19, 18 and 18 following the order bare fallow < pumpkin < cowpea = mucuna = lablab = weed fallow. Bare fallow plots had significantly lower ($P < 0.05$) soil moisture content than plots which were under weed fallow and cover crops in the short rains.

Table 17: Soil moisture content in the top 0 – 20 cm soil layer in the long rains of 2001/02 as influenced by cover crops grown in preceding short rainy season

| Cover crop planted prior maize | Days after planting maize | | | | |
|---|---|---|---|---|---|
| | 7 | 14 | 21 | 28 | 35 |
| | .....% | | | | |
| Bare | 17b | 15b | 17a | 13a | 9a |
| Cowpea | 19a | 19a | 20a | 16a | 10a |
| Lablab | 19a | 18a | 19a | 16a | 10a |
| Mucuna | 19a | 18a | 19a | 15a | 10a |
| Pumpkin | 18ab | 18a | 20a | 15a | 10a |
| Weed fallow | 19a | 17ab | 19a | 16a | 12a |

Values in the column followed by the same letter are not significantly different at P = 0.05 by DNMRT.

The soil moisture content in plots that were previously under weed fallow and cover crops was statistically similar. The same trend of soil moisture content was obtained at 14, 21 and 28 days after planting of maize. These results indicated that the residue mulch was effective in conserving soil moisture of the topsoil regardless of the source of the residue.

At 35 days after planting maize, in mid May, the rainfall had stopped and the soil moisture content was very low and did not differ significantly between treatments showing that cover crops were not effective in soil moisture conservation under prolonged dry spell. Soil moisture content in different cover crop treatment during the long rainy season in 2002/03 are shown in Table 18.

Table 18: Soil moisture content during the 2002/03 long rainy season

| Cover crop | Days after planting maize (DAPM) | | | | | |
|---|---|---|---|---|---|---|
| | 0 | 7 | 21 | 26 | 35 | 47 |
| | .....% | | | | | |
| Bare fallow | 10c | 6c | 12c | 13b | 14b | 6b |
| Cowpea | 15ab | 9b | 13bc | 15ab | 17a | 6b |
| Lablab | 16ab | 9b | 15b | 14b | 18a | 8ab |
| Mucuna | 19a | 13a | 17a | 18a | 18a | 8ab |
| Pumpkin | 13b | 9b | 14b | 15ab | 17a | 7b |
| Weed fallow | 18a | 14a | 18a | 19a | 17a | 10a |

Values in a column followed by the same letter are not significantly different at P 0.05 using DNMRT.

In the long rains of 2002/03 season, soil moisture content ranged from 6 to 19%. Bare fallow was the driest of all plots throughout the long rains whereas mucuna and weed fallow plots had highest soil moisture content. Soil moisture contents in cowpea, lablab

and pumpkin plots were intermediate and were not significantly different between each other. Plots that were bare in the short rains had poor maize germination at the beginning of the long rainy season and maize plants were smaller than those in cover crop treatments. Maize plants in the bare fallow treatments therefore, did not cover the soil surface adequately to reduce evaporation. Apart from the possibility of high evaporation losses, bare plots lost 43 and 30% respectively of the short rains and the long rains as runoff (Table 13). All these contributed to reduced soil moisture content in bare plots. On the other hand, plots which were under mucuna during the short rainy season had relatively vigorous maize plants as was reflected in plant height and biomass in sections 4.9.2 and 4.9.3.

Other work has shown that high biomass production is accompanied by high water uptake (Hanks, 1983). Therefore, maize plants in mucuna plots might have extracted more water from the soil than that in bare and weed fallow plots. However, due to low runoff in this treatment during the long rains (Table 13), more water entered the soil and raised soil moisture content despite high water uptake by maize crop. Weed fallow treatment on the other hand, had weak maize plants and low runoff (Table 13) leading to the observed high soil moisture content in this treatment.

Soil moisture content at 47 DAPM in weed fallow plots was significantly higher than in the other treatments and statistically similar in cover crop treatments. The levels of soil moisture content in all plots at 47 DAPM were too low to support a good maize crop as it was lower than 10.2% which is a permanent wilting point of the study soil (Table 1). The low moisture content was attributed to drought, which started at 35 days after maize planting (Fig. 1). The lack of cover crop effect on soil moisture content at this period may

indicate that cover crops are not effective in moisture conservation under prolonged dry periods.

The relationship between soil moisture, and runoff, macro - aggregates and cover crop biomass is shown in Table 19. Significant negative correlation was observed between runoff at 77 DAPC and moisture content at planting ($r = -0.763$, $P < 0.05$) and between runoff at the beginning of the long rains and moisture content at planting ($r = -0.849$, $P < 0.01$). The negative correlation obtained between runoff and the soil moisture content indicated that runoff had a big influence on soil moisture content in the sub humid area of Morogoro.

Table 19: Correlation coefficients relating soil moisture content and runoff, macroaggregates and cover crop biomass for the 2002/03 growing season

| | Runoff | | | Infiltration Rate | Aggregates >250µm | CC biomass |
|---|---|---|---|---|---|---|
| Date of mc determination | 77 DAPC | 0 DAPM | 12 DAPM | | | |
| | ..... r ..... | | | | | |
| 0 DAPM | -0.763** | -0.849 | na | -0.094 ns | 0.121 ns | 0.805** |
| 7 DAPM | -0.170 ns | -0.398ns | na | -0.150ns | -0.276ns | 0.401ns |
| 21 DAPM | -0.257ns | -0.430ns | -0.509ns | 0.126ns | 0.096ns | 0.585* |
| 47 DAPM | -0.188ns | -0.298ns | -0.539ns | -0.154ns | 0.323ns | 0.585* |

DAPM = days after maize planting

DAPC = days after cover crop planting

CC = Cover crop

na = not applicable

mc = soil moisture content

As runoff increased, more rain water was lost leaving little amount to infiltrate into the soil resulting to low soil moisture content and vice versa (Eq.3).

The negative correlation between runoff at 77 DAPC and soil moisture content at 0 DAPM may be explained by the residual soil moisture content and the influence of antecedent soil moisture content on cumulative infiltration (Ghildyal and Tripathi, 1987; Rao *et al.*, 1998). Antecedent moisture content influences soil slaking and the velocity of wetting front thus determining the amount of rain water entering the soil. Slaking and crust formation is lower in moist soil than in dry soils (Rao *et al.*, 1998), indicating that less water is lost as runoff in moist soil. The movement of wetting front is faster in moist soil than in dry soil (Ghildyal and Tripathi, 1987), suggesting that more water enter the profile in moist than in dry soil.

In the current study, treatments like bare fallow and pumpkin that had high runoff at 77 DAPC had lower soil moisture content at 0 DAPM than weed fallow and cowpeas (Table 18). Unlike, bare fallow and pumpkin, mucuna had high soil moisture content at 0 DAPM despite having high runoff at 77 DAPC (Fig. 8). The negative effect of runoff observed in the short rains on soil moisture content of mucuna treatment at 0 DAPM may have been counteracted by runoff reduction by mucuna residue mulch at the beginning of the long rains.

High amount of mucuna residue mulch could explain the high moisture content in mucuna treatment. Mucuna generated high amount of residue than pumpkin and cowpeas (Table 5) thus, provided better protection to the soil surface against the impact of raindrops at the beginning of the long rainy season than pumpkin and cowpea. The residue mulch of

mucuna increased soil moisture content by slowing down runoff velocity hence giving more time for water to infiltrate into the soil and reducing runoff (Fig. 8).

The improvement of soil moisture by reduction of runoff through increased residue biomass on the soil surface obtained in this study is similar to that reported by Lal (1977). Lal (1977) reported that runoff was reduced by 61% when residue mulch was applied at the rate of 2 Mg DM $ha^{-1}$ and was further reduced by 84% when the residue mulch was increased to 4 Mg DM $ha^{-1}$. The relationship between runoff at the beginning of the long rains and soil moisture content became weak with time ($r = -0.849$, $P < 0.01$ at 0 DAPM, to $r = -0.298$, ns, at 47 DAPM) because other factors influencing soil moisture content like evaporation and plant uptake also came to play.

The soil moisture content was positively correlated with biomass generated by cover crops in the short rains. Highest correlation coefficient was obtained at the beginning of the long rains ($r = 0.805$, $P < 0.01$) afterwards it decreased to $r = 0.585$ ($P < 0.05$) at 45 DAPM. These results demonstrate the effect of residue mulch on soil moisture conservation. Soil moisture content was higher in treatment that had higher residue mulch than in treatments with lower amount of residues. The positive correlation between soil moisture and cover crop biomass explains why soil moisture content obtained in weed fallow, mucuna and lablab treatment was higher than that in bare fallow, pumpkin and cowpea treatments from 0 DAPM to 47 DAPM in the long rains of 2002/03 season. The effect of cover crop biomass on soil moisture content in the long rains is attributed to the reduced runoff (Table 14).

Soil moisture content was poorly correlated with infiltration rate and soil aggregate size fraction of > 250μm (Table 14). These results suggested that increasing soil aggregate size fraction of > 250μm and increasing infiltration rate could have had little effect on the moisture content in the topsoil. The weak correlation between infiltration rate and the moisture content in the topsoil could be due to the fact that the soil had moderate to moderately rapid infiltration rate hence infiltration rate is not a major limitation to moisture content in this soil.

### 4.10 Effect of cover crops on soil mineral N forms in the top soil

#### 4.10.1 Effect of cover crops on soil mineral N ($NH_4^+ + NO_3^-$)

The effect of cover crops planted in the short rains on soil mineral N in 2000/01 is shown in Figure 13. Soil mineral N ($NH_4^+ + NO_3^-$) in all plots decreased with the age of the cover crop between 0 and 75 DAPC except in mucuna treatment. The lowest mineral N values were obtained at 75 DAPC. Mineral N decreased by 36, 39, 42, and 45% in pumpkin, cowpea, lablab and weed fallow, respectively (Appendix 12). On the other hand, mineral N in mucuna plots increased steadily up to 75 days after planting. At 75 DAPC, mineral N under mucuna plots increased by 2% and was significantly higher than that under other cover crops ($P < 0.05$).

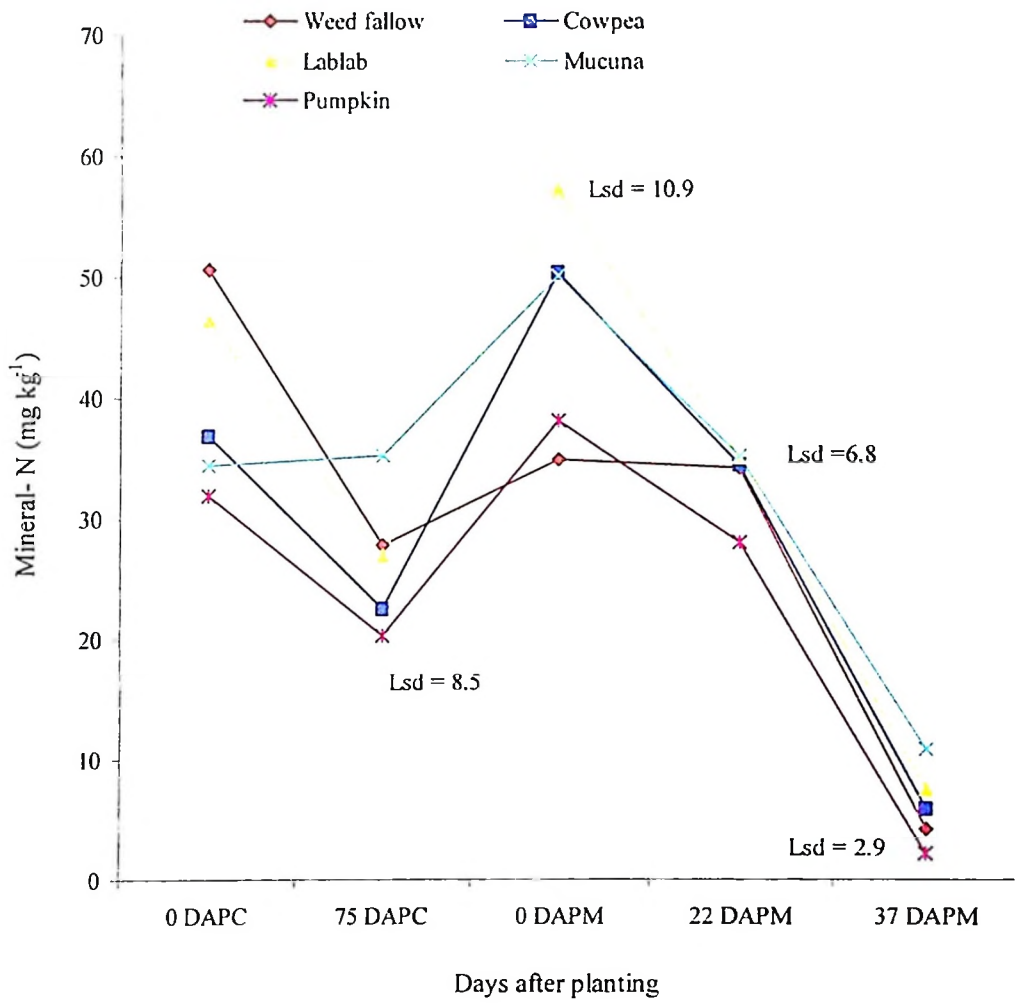


Figure 13: Soil mineral N ($NO_3^-$ + $NH_4^+$) in the top 0 –20 cm in the 2000/01 growing season

The effect of cover crops on mineral N in 2001/02 and 2002/03 is shown in Tables 20 and 21, respectively.

Table 20: Effect of cover crops grown in the short rains of the 2001/02 season on mineral N levels in the topsoil (0 - 20 cm) during the long rainy season

| | Days after planting maize | | | |
|---|---|---|---|---|
| | 7 | 14 | 21 | 35 |
| Surface cover | .....mg $kg^{-1}$..... | | | |
| Bare fallow | 3.56 | 2.96 | 3.35 | 3.71 |
| Weed fallow | 8.76 | 4.43 | 4.15 | 6.35 |
| Cowpea | 10.98 | 5.68 | 7.95 | 8.86 |
| Lablab | 7.12 | 5.19 | 5.49 | 11.01 |
| Mucuna | 6.91 | 5.96 | 4.80 | 6.34 |
| Pumpkin | 7.60 | 8.38 | 4.05 | 10.58 |
| Orthogonal contrasts | | | | |
| Bare fallow vs rest | P= 0.002 | 0.000 | 0.014 | 0.000 |
| Weed fallow vs cover crops | P= ns | 0.002 | 0.057 | 0.005 |
| Pumpkin &Cowpea vs other covers | P= 0.049 | 0.005 | 0.177 | 0.175 |
| Pumpkin vs Cowpea | P= 0.041 | 0.001 | 0.001 | 0.122 |
| Mucuna vs lablab | P= ns | 0.218 | ns | 0.001 |

Table 21: Effect of cover crops on soil mineral- N ($NH_4$ + $NO_3$) in the 2002/03 season

| | .....DAPC..... | | .....DAPM..... | | | |
|---|---|---|---|---|---|---|
| | 7 | 75 | 7 | 21 | 35 | 42 |
| Cover crop | .....mg $kg^{-1}$..... | | | | | |
| Cowpea | 26.5a | 19.1c | 24.2bc | 18.3bc | 29.5a | 14.8cd |
| Lablab | 26.6a | 19.3c | 18.3cd | 20.4bc | 12.4d | 16.8bc |
| Mucuna | 31.4a | 41.4a | 27.7b | 14.1c | 14.7cd | 12.4d |
| Pumpkin | 26.5a | 27.3b | 21.0cd | 24.5b | 22.6ab | 17.4bc |
| Weed fallow | 24.7a | 16.3c | 14.7d | 19.2bc | 19.9bc | 19.6b |
| Bare | 27.9a | 28.6b | 40.9a | 20.4bc | 23.1ab | 26.4a |

Values in a column followed by the same letter are not significantly different at P =0.05 using DNMRT

DAPC = Days after planting cover crop

DAPM = Days after planting maize

In 2002/03 season, mineral N at 7 DAPC ranged from 24.7 to 31.4 mg $kg^{-1}$ and was statistically similar in all treatments. At 75 DAPC, mineral N ranged from 16.3 to 41.4 mg $kg^{-1}$. When compared to the levels at 7 DAPC, mineral - N at 75 DAPC had increased by 32% under mucuna, decreased by 28, 27 and 34% under cowpea, lablab and weed fallow, respectively. Under pumpkin and bare fallow mineral N at 75 DAPC was almost similar to that at 7 DAPC.

The observed increase in mineral N under mucuna during the short rains in 2000/01 and 2002/03 could be from decomposition of senescent roots, nodules and leaves that dropped during the growing period or released as root exudates. Another reason for the increase could be mucuna had N sparing effect, which means that it used little soil N and left more N in the soil than was for the other cover crops, and weed fallow. Nitrogen sparing effect was reported to account for the residual N observed in soil under N fixing legumes (Wani *et al.*, 1995). The potential for biological $N_2$ fixation of the cover crop determines the amount of soil N that can be spared in the soil. Wortmann *et al.* (2000) and Chikowo *et al.* (2004) reported that mucuna derives substantial amount of its N from biological $N_2$ fixation. Mucuna was reported to derive 43 - 57% of the accumulated N in its above ground biomass from biological $N_2$ fixation in Uganda (Wortmann *et al.*, 2000). Chikowo *et al.* (2004) reported that the amount as high as 93% of accumulated N in mucuna biomass was obtained from biological N fixation in Zimbabwe.

The reduced mineral N under cowpea and lablab between 7 DAPC and 75 DAPC, on the other hand (Table 21), could indicate that most of N taken was derived from the soil, suggesting that these cover crops had lower $N_2$ fixation ability than mucuna. The reduced mineral N under weed fallow between 7 DAPC and 75 DAPC was expected because the

entire N requirement of weeds was derived from the soil. The absence of plants in the bare fallow treatment during the short rainy season and hence the lack of N uptake explains the observed constant mineral N levels in this treatment.

Mineral N in all plots had increased to the maximum level at 0 DAPM (Twenty days after 75 DAPC) during the long rains in all of the three seasons (Fig. 13, Tables 20 and 21). In 2000/01 season, mineral N in cover crop treatments at 0 DAPM was 19 - 45% higher than at planting of cover crops in the order pumpkin < lablab < cowpea < mucuna whereas that of weed fallow was 31% lower (Appendix 12). The increase in mineral N under lablab, mucuna and cowpea indicated that these cover crops added N to the soil possibly through $N_2$ fixation. Nodulating legumes are known for their contribution to soil N through $N_2$ fixation (Giller and Wilson, 1991). Although the current study did not quantify the amount of $N_2$ fixed, cowpea, lablab and mucuna formed effective nodules, which is an indication of $N_2$ fixation capability. This could explain the higher N contribution obtained from legume treatments relative to that of the pumpkin and weed fallow. Low mineral N increase in pumpkin plots could be due to accumulation of N absorbed from the other soil layers to the topsoil upon residue decomposition. Being of high quality (Table 4), the pumpkin residues might have had a rapid mineralization at the beginning of the long rains, leading to the observed increased mineral N. The high mineralization rate of pumpkin residues was confirmed by the results of an incubation study (section 4.3.3). Mineral N under the weed fallow decreased due to the fact that the fallow was composed of non-legume species (section 3.4.1) whose entire N requirement was obtained from the soil. In addition, the residues of the weed fallow, unlike that of the pumpkin, had C:N ratio that was higher than the critical value of 25 for a net N mineralization of decomposing residues to occur (Myers *et al.*, 1994). This high C:N ratio might have led to a net N

immobilization of the soil mineral N at the beginning of the long rainy season (0 DAPM). The net N immobilization implied that soil N was taken up by soil microorganisms responsible for the decomposition processes of residues at the initial stages before the organically bond N was released (Brady and Weil, 2000) causing the observed decline in soil mineral N.

Mineral N decreased sharply during the long rains. At 21 DAPM, the mineral N had decreased by 2, 27, 27, 32 and 39% of the amount which was present at maize planting in the weed fallow, pumpkin, mucuna, cowpea and lablab treatments, respectively. At 35 DAPM, the mineral N had decreased by 78% in mucuna and 94% in pumpkin plots. This shows that the benefits of the cover crops on soil mineral N lasted for not more than 5 weeks after the beginning of the long rains. A large and short lived increase in mineral N at the beginning of the long rains on tropical soils was also reported by Sanchez (1976), Warren *et al.* (1997) and Ikerra *et al.* (2001). Nitrogen levels were high at the beginning of the rainy season when adequate soil water was available for mineralization of soil organic matter. Roy and Singh (1995) reported that leaching losses, uptake by vegetation during active growth stages and volatilization losses caused decline in mineral N levels during the rainy season. In the 2001/02 season, mineral N determined at 7 DAPM was as low as 3.56 mg $kg^{-1}$ in previously bare plots and this was significantly lower ($P < 0.01$) than in plots that were previously under weed fallow and cover crops (Table 20). The effects of previous cowpea and pumpkin on mineral N levels were slightly greater than that of lablab and mucuna. At 14 days after planting maize the levels of mineral N were slightly lower than those at day 7. Still, plots that were under bare fallow in the short rains had significantly lower levels ($P < 0.01$) than the other treatments. Plots that were previously under cowpea and pumpkin had significantly higher levels of mineral N than under weed

fallow, lablab and mucuna ($P < 0.01$). Fast N release pattern of pumpkin and cowpea after application could explain high mineral N levels obtained at 7 and 14 DAPM. Mineral N obtained in cover crop treatments at 21 DAPM was statistically similar with that in weed fallow treatment but significantly higher than in bare fallow treatment. At 35 DAPM, mineral N in plots that were previously under cover crops was significantly higher ($P < 0.01$) than those previously under weed and bare fallows. Generally, cover crop and weed fallow treatments had higher mineral N than the bare treatment during 35 days after maize planting. Cover crops and weed fallow unlike the bare treatment generated various amount of biomass during the short rains. Mineralization of cover crop residues and weed explain the observed high levels of mineral N in cover crop and weed fallow treatment compared to bare treatment.

In 2002/03, the trend of mineral N was different. Mineral N at 7 DAPM was lower than that at 75 DAPC except in bare and cowpea treatments. During the long rain season in 2002/03, pumpkin, cowpea and bare treatments had higher mineral N levels at 21, 35 and 45 DAPM than mucuna, lablab and weed fallow. Pumpkin, cowpea and bare treatments had relatively low soil moisture content (Table 18). This low soil moisture might have hindered the uptake of N by maize plants leaving high levels of mineral N in the soil in pumpkin, cowpea and bare treatments.

### 4.10.2 Effect of the cover crops on $NH_4^+$ - N and $NO_3^-$ - N

#### 4.10.2.1 Effect of the cover crops on $NH_4^+$ - N and $NO_3^-$ - N in 2000/01 season

The effect of cover crops on $NH_4^+$ - N and $NO_3^-$ - N in the topsoil in season 2000/01 is shown in Figures 14 and 15 respectively. More details are shown in Appendix 11.

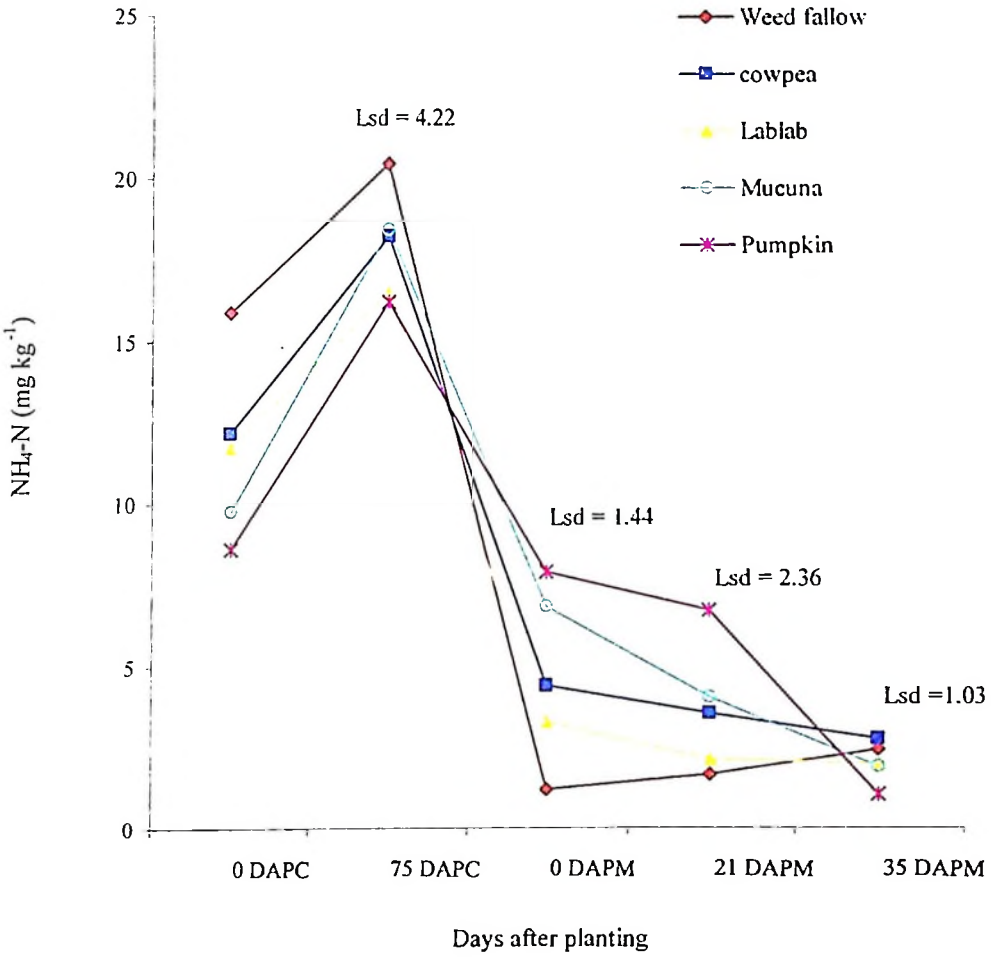


Figure 14: $NH_4^+$ in the top 0 – 20 cm in the 2000/01 season.

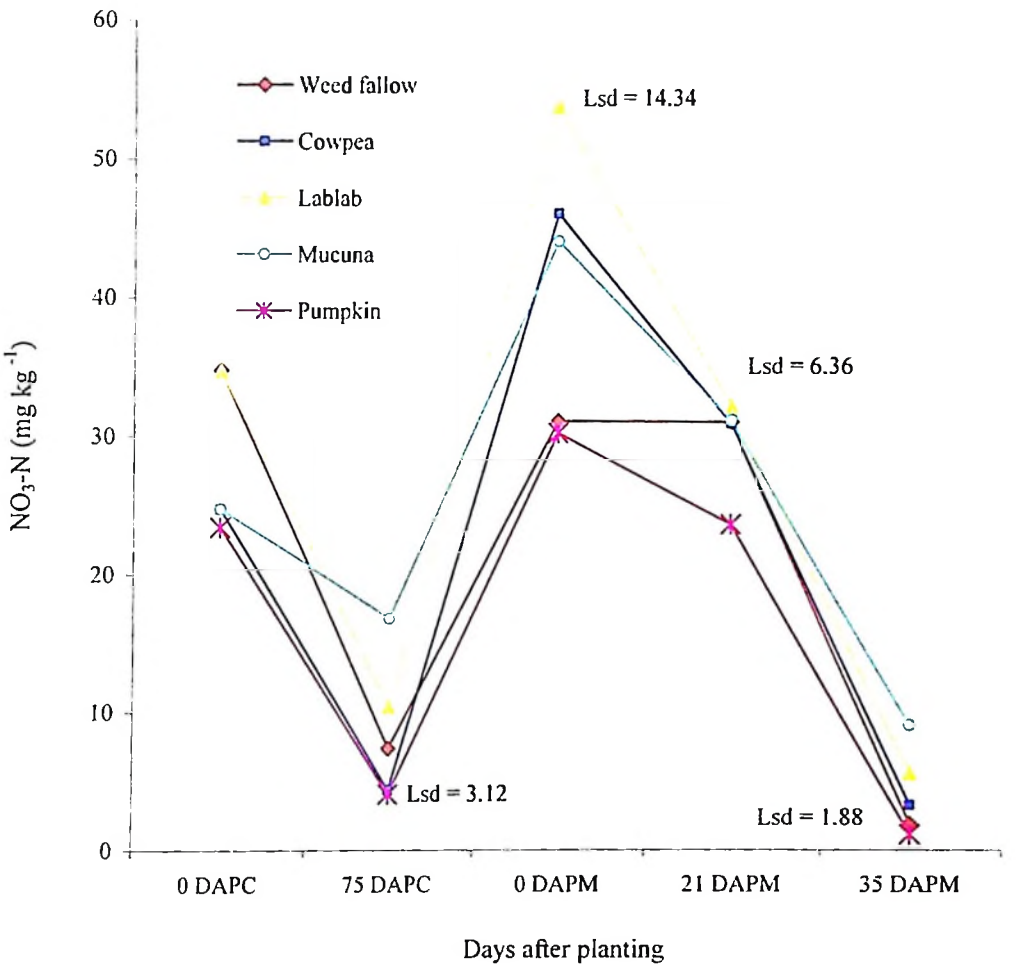


Figure 15: Soil $NO_3^-$ in the top 0 –20 cm in the 2000/01 season

In 2000/01 season, all the cover crops increased $NH_4^+$ - N during their growth period up to 75 DAPC. Mucuna and pumpkin resulted to significantly higher $NH_4^+$ - N increment, which amounted to 89% of the levels at planting cover crops. Lablab and cowpea increased $NH_4^+$ - N levels by 40 and 50%, respectively (Appendix 13). The lowest increment (29%) was obtained in weed fallow plots. At 75 DAPC, $NO_3^-$ - N levels were significantly lower in pumpkin and cowpea plots and significantly higher in mucuna plots. By this time $NO_3^-$ – N had decreased by 32 - 83% relative to that at 0 DAPC (Appendix 14). The decline was in the order mucuna < lablab < weed fallow < cowpea < pumpkin. The drop was steady under mucuna and sharp under the other cover crops.

The increase in $NH_4^+$ - N which was accompanied by the decrease in $NO_3^-$ – N indicates that the cover crops preferred to take $NO_3^-$ - N to $NH_4^+$ - N. High increment in $NH_4^+$ - N and less decrease in $NO_3^-$ – N under mucuna show that less amount of these mineral N fractions was taken from the soil or there was more addition of $NO_3^-$ - N from the decomposition of fallen leaves and senescent roots under mucuna compared to other cover crops. The current study showed that mucuna and lablab accumulated significantly higher N in the above - ground biomass than other cover crops (Table 6). The study however, does not establish which portion of the accumulated N by the legume cover crops was derived from the soil and from biological $N_2$ fixation.

Studies by Sanginga *et al.* (1996a), Becker and Johnson (1998), Ibewiro *et al.* (2000) and Wortmann *et al.* (2000) showed that mucuna fixes between 55 and 86% of N accumulated in its biomass. This may suggest that the drop in soil $NO_3^-$ - N at 75 DAPC under mucuna could partly be due to the possibility that mucuna derived little N from the soil to

compliment the biologically fixed $N_2$. Unlike mucuna, pumpkin treatment had high reduction in $NO_3^-$ – N, indicating that pumpkin took larger amount of $NO_3^-$ – N from the soil than mucuna. Pumpkin is a non - $N_2$ fixer thus its entire N requirements were obtained from the soil. In view of the high N content in pumpkin residues (Table 6), and biomass production of 1.8 Mg DM $ha^{-1}$ (Table 5), pumpkin extracted about 52 kg N $ha^{-1}$ from the soil. High reduction in $NO_3^-$ - N under cowpea may indicate that this crop had a high uptake of this nutrient from the soil.

At the beginning of the long rains in 2000/01, $NH_4^+$ - N dropped sharply in the weed fallow and legume cover crops plots, but steadily in the pumpkin plots (Fig.14). When compared to the $NH_4^+$ - N levels at 75 DAPC, the levels at maize planting, 20 days later, had decreased by 51 - 94%. The decrease was in the order pumpkin < mucuna < cowpea < lablab < weed fallow. The drop in $NH_4^+$ - N was significantly higher under the weed fallow than under the cover crops (Fig. 14). The drop in $NH_4^+$ - N was accompanied by an increase in $NO_3^-$ - N in all treatments (Fig. 15), indicating that most of $NH_4^+$ - N was nitrified to $NO_3^-$ - N in this period. The nitrification process was enhanced by the availability of soil moisture at the onset of the long rains. The $NO_3^-$ - N increments were significantly higher ($P < 0.05$) in lablab, cowpea and mucuna than in fallow and pumpkin treatments. Nitrate - N increased by 24 to 43 mg $kg^{-1}$ soil between 75 DAPC and 0 DAPM which was a duration of 20 days. As the long rainy season progressed, $NO_3^-$ - N levels dropped in all treatments and within 35 days, at 35 DAPM, $NO_3^-$ - N had dropped to lower levels than that obtained at 75 DAPC. The short-lived $NO_3^-$ - N flush observed in this study was similar to that reported by other workers (Hartemink *et al.*, 1996; Warren *et al.*, 1997; Hagedorn *et al.*, 1997; Ikerra *et al.*, 1999; Whitbread *et al.*, 2000; Ikerra *et al.*, 2001) on agroforestry fallows using species with high quality residues.

The levels of $NH_4^+$ - N at 21 DAPM in plots previously under cover crops were 15 to 41% lower than that at maize planting, but in weed fallow plots $NH_4^+$ - N was 42% higher. This shows that net mineralization in weed fallow plots took place later in the long rains than was the case in cover crop treatments. The late occurrence of net mineralization during maize growing season in the weed fallow plots is explained by the high C:N ratio of the weed residues (Table 4). In the period between 21 and 35 DAPM, $NH_4^+$ - N levels were slightly raised in the weed fallow and lablab plots. In this period the levels of $NO_3^-$ - N dropped as well, indicating that the nitrification process was reduced. The reduction in the nitrification is explained by inadequate soil moisture content due to insufficient rains experienced in this period (Fig. 1). At 35 DAPM, $NO_3^-$ - N in the top 0 – 20 cm soil layer was 86 – 140 kg $ha^{-1}$ lower than the amount present at the beginning of the long rains (Appendix 15). This accounted for 79, 90 and 96% of the $NO_3^-$ - N at the beginning of the long rains in mucuna, lablab and pumpkin treatments respectively. The reduction in $NO_3^-$ - N is partly attributed to maize uptake, leaching, volatilisation, denitrification and erosion. However, this study did not quantify the amount taken up by maize at this stage and that of leaching and volatilisation losses.

### 4.10.2.2 Effect of the cover crops on $NH_4^+$ - N and $NO_3^-$ - N in 2001/02 season

The effect of cover crops on $NH_4^+$ - N and $NO_3^-$ - N in the topsoil in season 2001/02 is shown in Tables 22 and 23, respectively. In 2001/02, ammonium - N ranged from 3 to 11 mg $kg^{-1}$ at the beginning of the long rains and was significantly lower in previously bare plots than in the other plots ($P < 0.01$). Weed fallow and pumpkin plots had statistically equal $NH_4^+$ - N with legume cover crop plots. At 7 DAPM, most of mineral N was in the ammoniacal form (Tables 21 and 22) suggesting that the rate of ammonification was higher than that of nitrification at this time.

Table 22: Soil $NH_4^+$ - N during maize growing period in 2001/02

| Cover crop | Days after planting maize | | | |
|---|---|---|---|---|
| | 7 | 14 | 21 | 35 |
| | ..... (mg $kg^{-1}$)..... | | | |
| Cowpea | 11.0 | 2.0 | 5.5 | 3.9 |
| Pumpkin | 7.3 | 5.4 | 3.7 | 4.7 |
| Weed fallow | 8.8 | 3.6 | 3.9 | 3.2 |
| Labalab | 6.8 | 3.1 | 4.1 | 4.2 |
| Bare fallow | 3.6 | 2.5 | 2.2 | 1.9 |
| Mucuna | 6.9 | 3.9 | 3.4 | 2.5 |

Table 23: Soil $NO_3^-$ - N in the top soil (0 – 20 cm) during maize growing period in 2001/02

| Cover crop | Days after planting maize | | | |
|---|---|---|---|---|
| | 7 | 14 | 21 | 35 |
| | .....mg $kg^{-1}$..... | | | |
| Cowpea | 0.03a | 3.64a | 2.41a | 4.95bc |
| Pumpkin | 0.30a | 3.00b | 0.35bc | 5.84ab |
| Weed fallow | 0.00a | 0.81d | 0.23c | 3.14de |
| Lablab | 0.31a | 2.12c | 1.40ab | 6.77a |
| Bare fallow | 0.00a | 0.48d | 1.12bc | 1.85e |
| Mucuna | 0.01a | 2.05c | 1.37abc | 3.87cd |

Values in a column followed by the same letter are not significantly different at P = 0.05 using DNMRT.

Soil $NO_3^-$ - N at 7 DAPM in 2001/02 in all plots was very low. At maize planting, N flush from re-wetting of dry soil had already occurred and most of this N might have been taken up by the cover crops or by weeds, lost through erosion or leached out, leading to the low $NO_3^-$ - N observed at 7 DAPM. After 7 DAPM, $NO_3^-$ - N increased to values ranging from 0.48 to 3.64 at 14 DAPM and 1.85 to 6.77 at 35 DAPM. This increase could be due to mineralization of cover crop residues. Relatively higher $NO_3^-$ - N was obtained in plots that were previously under cover crops than under bare or weed fallows.

At 14 DAPM, $NH_4^+$ - N declined in all plots with the highest decline observed in cowpea. There were corresponding increases in $NO_3^-$ - N at this time (Table 23), but were not large enough to explain the observed decline in $NH_4^+$ - N in most of the treatments. The decline in $NH_4^+$ - N further indicates that $NH_4^+$ - N was taken out of the soil through other path ways. After 14 DAPM, the $NH_4^+$ - N levels were almost constant except for the cowpea, in which the $NH_4^+$ - N at 21 DAPM was more than twice that at the 14 DAPM.

At 21 DAPM, there was a decline in $NO_3^-$ - N except in previously bare fallow plots. This decline could be attributed mainly to plant uptake because at this period there was no rain to cause leaching or erosion. This decline was accompanied by slight increase in $NH_4^+$ - N in cowpea and lablab plot, which may indicate that some nitrate was immobilized due to low soil moisture.

### 4.10.2.3 Effect of the cover crops on $NH_4^+$ - N and $NO_3^-$ - N in 2002/03 season

The effect of cover crops on $NH_4^+$ - N and $NO_3^-$ - N in the topsoil in season 2002/03 is shown in Tables 24 and 25, respectively.

Table 24: Effect of cover crops on soil ammonium - N (mg $kg^{-1}$) in the 2002/03 season

| | DAPC | | DAPM | | | |
|---|---|---|---|---|---|---|
| | 7 | 75 | 7 | 21 | 35 | 42 |
| Cover crop | ..... mg $kg^{-1}$ ..... | | | | | |
| Cowpea | 9.7a | 7.8b | 8.7ab | 4.3c | 16.6a | 5.4ab |
| Lablab | 12.4a | 6.4b | 6.1b | 4.3c | 6.3b | 8.5a |
| Mucuna | 10.7a | 23.2a | 11.2a | 8.9abc | 7.7b | 8.9a |
| Pumpkin | 10.2a | 19.6a | 7.3ab | 6.7bc | 6.2b | 7.4a |
| Weed fallow | 10.1a | 14.0ab | 7.1ab | 14.1a | 10.1b | 5.1ab |
| Bare | 11.5a | 12.5ab | 4.4b | 10.4ab | 5.5b | 7.3ab |

Means in a column with similar letter are not significantly different at P=0.05 using DMRT.

DAPM = Days after maize planting.

DAPC = Days after cover crop planting.

Table 25: Effect of cover crops on soil $NO_3^-$ - N (mg $kg^{-1}$) in the 2002/03 season

| | DAPC | | DAPM | | | |
|---|---|---|---|---|---|---|
| | 7 | 75 | 7 | 21 | 35 | 42 |
| Cover crop | ..... mg $kg^{-1}$ ..... | | | | | |
| Cowpea | 16.9a | 11.2bc | 15.6b | 14.0b | 12.8bc | 9.4c |
| Lablab | 14.2a | 12.9bc | 12.1bc | 16.2b | 6.1d | 7.5cd |
| Mucuna | 20.6a | 18.2a | 16.5b | 5.2c | 7.0d | 3.5d |
| Pumpkin | 16.3a | 7.7c | 13.7bc | 17.8b | 16.4ab | 9.9bc |
| Weed fallow | 14.6a | 10.6bc | 7.6c | 5.1c | 9.8cd | 14.5ab |
| Bare | 16.4a | 14.2ab | 36.5a | 23.0a | 17.6a | 19.1a |

Numbers followed by the same letter in the column are not significantly different at P= 0.05.

In 2002/03, $NH_4^+$ - N at 7 DAPC ranged from 9.7 to 12.4 mg kg-1 and was statistically similar in all treatments. At 75 DAPC, just before the cover crops were slashed, $NH_4^+$ - N had the highest values except in cowpea and lablab plots. The highest increment was obtained under mucuna which increased from 10.7 mg $kg^{-1}$ at 7 DAPC to 23.2 mg $kg^{-1}$ at 75 DAPC. This was followed by pumpkin which increased from 10.2 mg $kg^{-1}$ at 7 DAPC to 19.6 mg $kg^{-1}$ at 75 DAPC. These increments in ammonium - N amounted to 9.4 and 12.5 mg $kg^{-1}$ under pumpkin and mucuna, respectively.

Under lablab, $NH_4^+$ - N decreased from 12.4 mg $kg^{-1}$ at 7 DAPC to 6.4 mg $kg^{-1}$ at 75 DAPC (6.0 mg $kg^{-1}$) whereas under cowpea, weed and bare fallow was almost unchanged (Table 24). Soil $NO_3^-$ - N during the 2002/03 season, ranged from 14.2 to 20.6 mg $kg^{-1}$ at the beginning of the short rains (7 DAPC) and was not significantly different between treatments. Soil $NO_3^-$ - N at 75 DAPC in all treatments was lower than at 7 DAPC and that in mucuna treatment was significantly higher than in pumpkin, weed fallow, cowpea and lablab treatments ($P < 0.05$).

At 7 DAPM in 2002/03, $NH_4^+$ – N decreased from 19.6 mg $kg^{-1}$ at 75 DAPC to 7.3 mg $kg^{-1}$ (12.3 mg $kg^{-1}$) in pumpkin and from 14.0 mg $kg^{-1}$ to 7.1 mg $kg^{-1}$ (6.9 mg $kg^{-1}$) in weed fallow treatment. The decrease ranged from 6.9 to 12.3 mg $kg^{-1}$ in the order weed fallow < bare fallow < mucuna < pumpkin. The decline may be explained by mineralization of $NH_4^+$ to $NO_3^-$ following the onset of the long rains (Tables 24 and 25). This indicated that mucuna and pumpkin residues had higher mineralization rates, which is explained by their high N content (Table 4). The decline in $NH_4^+$ – N in bare treatment was caused by high nitrification as shown by the increase in $NO_3^-$ - N in Table 25. The decline in $NH_4^+$ – N in

weed fallow treatment is explained by immobilization of mineral N due to high C:N ratio of weeds (Table 4).

Ammonium N peak was obtained at 21 DAPM in weed and bare fallow treatments whereas under cowpea it was obtained at 35 DAPM. This indicated that N mineralization in these treatments occurred later in the long rain season than the other cover crops due to their relatively lower N contents (Table 4). At tasselling stage of maize (42 DAPM), $NH_4^+$ – N ranged from 5.1 to 8.9 and were lower than those obtained at 7 DAPC in the short rains of the 2002/03 season. Soil $NO_3^-$ - N during the 2002/03 season at the beginning of the long rains (7 DAPM) was highest in bare fallow and was significantly higher ($P < 0.05$) than those in the other treatments. This observation is explained by the length of dry period preceding the onset of rains. The level of $NO_3^-$ - N flush increased with the length of dry period preceding rainfall onset (Wong and Nortcliff, 1995). The dry period between the long and short rains (May - November) in this study, was longer than between short and long rains (Jan - March), accounting for the observed highest flush at the beginning of the short rains. On the other hand, higher N flush at the beginning of the long rains in previously bare fallow is explained by the lack of plant N uptake throughout the short rains under this treatment which gave more time for N build up.

In the rest of the long rainy season, mucuna plots had the lowest amount of $NO_3^-$ – N, whereas plots that were bare during the short rains had highest levels of $NO_3^-$ – N. The levels of $NO_3^-$ - N at 35 DAPM were higher than that of 2000/01 and 2001/02 in all treatments except under lablab. The higher $NO_3^-$ N in the 2002/03 could be attributed to low rainfall in the long rain season and poor maize performance, which could have led to lower leaching losses and low N uptake, respectively.

## 4.11 Effect of cover crops on the distribution of soil mineral N forms in the top 60 cm soil layer

### 4.11.1 Effect of cover crops on the distribution of soil $NH_4^+$ – N in the top 60 cm soil layer

The amount of $NH_4^+$ - N in the top 60 cm soil layer at the end of the long rains of 2001/02 and 2002/03 seasons as influenced by cover crops are shown in Figures 16 and 17 and Appendix 18 and 19, respectively. At the end of the long rains of 2001/02 season bare fallow plots had the lowest $NH_4^+$ - N in the top 40 cm and had similar amount with cowpea and pumpkin in the 40 – 60 cm soil layer. Weed fallow had the highest $NH_4^+$ - N in the top 20 cm and in the 40 – 60 cm layer. Lablab plots had similar $NH_4^+$ - N to pumpkin, mucuna and cowpea in the top 20 cm but significantly higher in the 40 – 60 cm layer. The levels of $NH_4^+$ - N in mucuna and cowpea plots in the top 40 cm was almost similar but it decreased in the 40 - 60 cm layer.

The great changes in $NH_4^+$ - N between the soil layers was obtained in weed fallow, lablab and bare fallow plots. In these plots there was a sharp decrease in $NH_4^+$ - N between the 0 - 20 cm and 20 - 40 cm and a sharp increase between 20 - 40 and 40 - 60 cm layers. Pumpkin plots showed a sharp $NH_4^+$ - N decrease between the 0 - 20 cm but $NH_4^+$ - N in 20 - 40 cm and 40 - 60 cm was almost similar. Except for mucuna and cowpea, the 20 - 40 layer had the lowest $NH_4^+$ - N. At the end of the long rains of 2002/03, $NH_4^+$ - N in the top 20 cm was not significantly different between treatments but in the 20 - 40 cm layer it was significantly higher in cowpea than in the other treatments (Fig. 17).

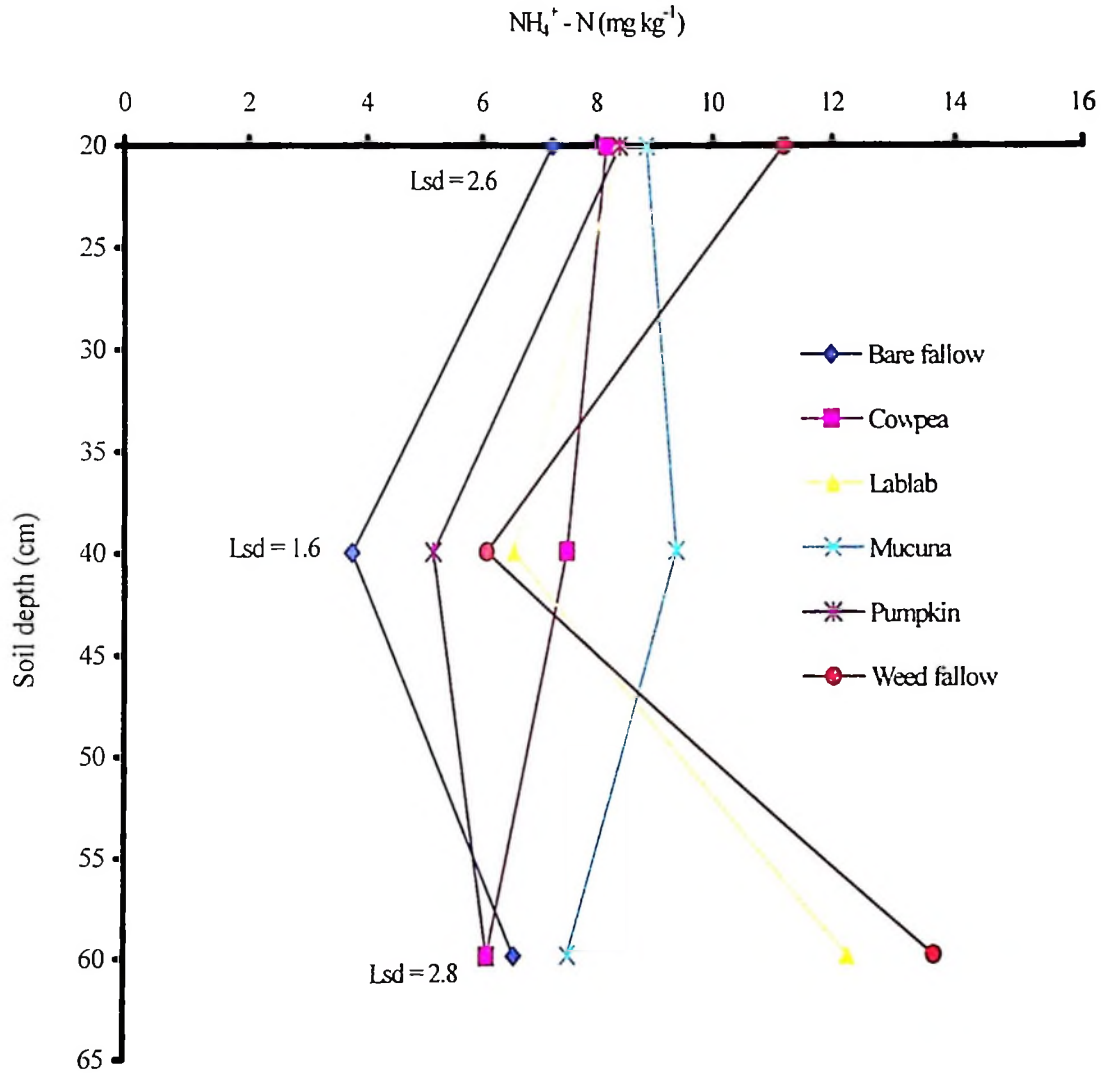


Figure 16: Ammonium – N pattern in the soil as affected by the cover crops in the 2001/02 season

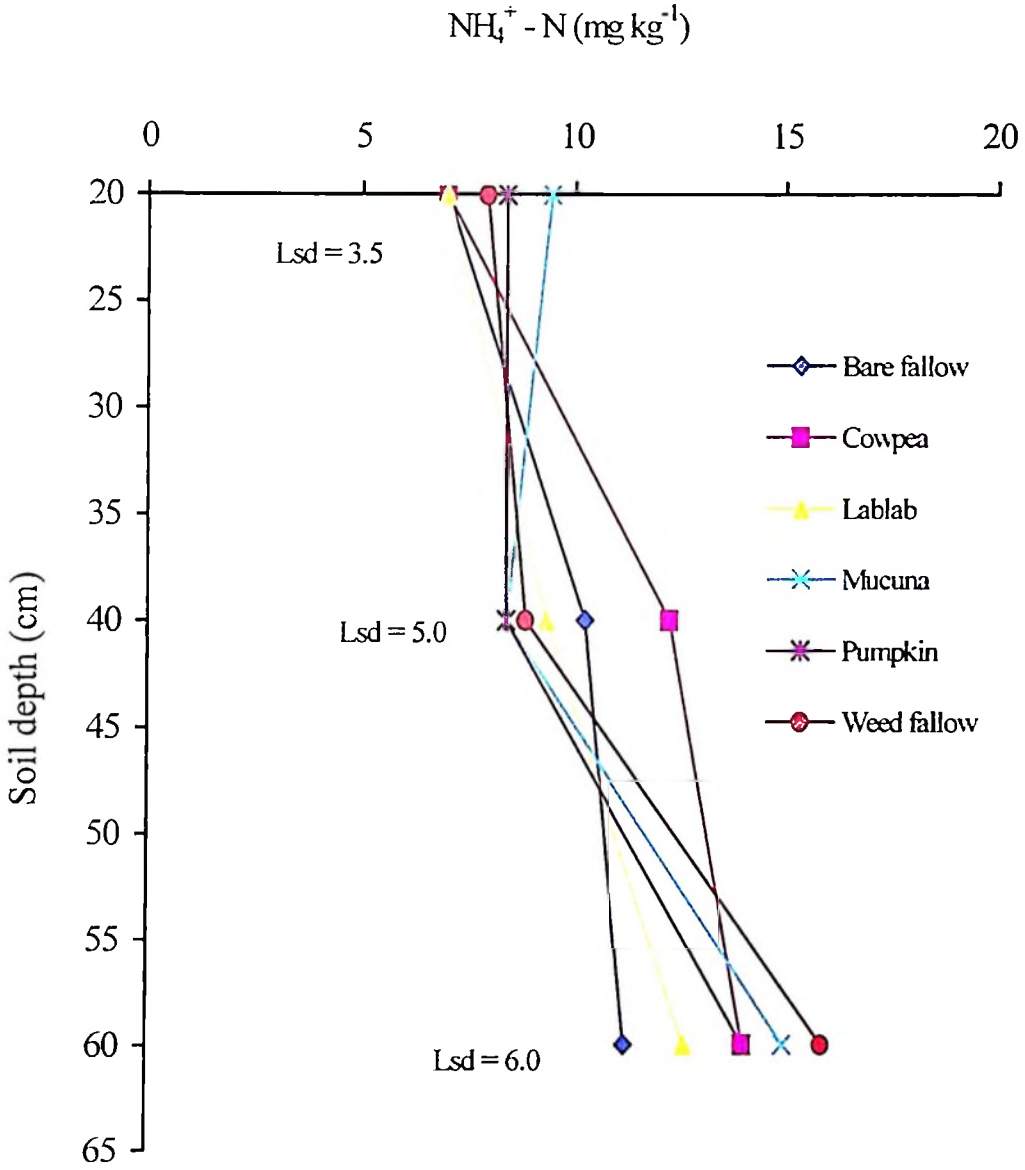


Figure 17: Ammonium – N pattern in the soil as affected by the cover crops in the 2002/03 season

In the 40 - 60 cm layer, $NH_4^+$ - N was statistically similar in plots that was under cover crops and was significantly higher in plots that were previously under weed fallow than under bare treatment. The differences in $NH_4^+$ - N between 0 - 20 and 20 - 40 cm soil layers was not significant except for cowpea which increased by 5 mg $NH_4^+$ $kg^{-1}$. In the 40 - 60 cm soil layer, $NH_4^+$ - N increase ranging from 0.9 to 7.0 mg $NH_4^+$ $kg^{-1}$ was obtained. Except in mucuna, and weed fallow the increase was little. The little differences in levels $NH_4^+$ - N between soil layers and between cover crop treatments in 2002/03 could be due to inadequate soil moisture experienced in the long rains. This may have hindered biological activities, which are responsible for mineralization of organic matter.

### 4.11.2 Effect of cover crops on the distribution of soil $NO_3^-$ – N in the top 60 cm soil layer

The amount of $NO_3^-$ - N in the top 60 cm soil layer at the end of the long rains in 2001/02 and 2002/03 seasons as influenced by cover crops are shown in Figures 18 and 19 and Appendix 18 and 19, respectively. After the cover crop - maize cycle for the 2001/02 season, $NO_3^-$ - N in the top 20 cm was significantly higher in plots that were under bare fallow and cowpea than under mucuna, pumpkin, lablab and weed fallow (Fig. 18). In the 20 - 40 cm layer it was significantly higher in bare fallow than the other treatments. In the 40 - 60 cm layer was significantly higher in plots that were under cowpea and mucuna than the other treatments.

Nitrate - N in bare and weed fallows, increased between 0 - 20 and 20 - 40 cm and decreased between 20 - 40 and 40 - 60 cm. In cowpea and mucuna it decreased slightly between 0 - 20 and 20 - 40 cm and increased between 20 - 40 and 40 - 60 cm. Pumpkin

plots showed slight change in $NO_3^-$ - N between 0 - 20 and 20 - 40 cm and a decline between 20 - 40 and 40 – 60 cm.

Unlike in other treatments, $NO_3^-$ - N in lablab was constant throughout the 0 - 60 cm soil depth. Nitrate profiles (Fig. 18) also indicated that there was not much difference in $NO_3^-$ - N between the soil layers and between the cover crop treatments except in bare fallow, where $NO_3^-$ - N accumulated in the 20 - 40 cm soil layer.

Accumulation of $NO_3^-$ - N in the 20 - 40 cm under bare fallow during the short rains could be attributed to low soil moisture content in both short and long rains (Fig.10 and Table 19). Previous studies showed that wetting front moves slower in dry than in wet soil (FAO, 1978) leading to less leaching. Low soil moisture content in bare fallow plots reduced leaching resulting into nitrate bulge in the 20 - 40 cm soil layer. Also the nitrogen bulge observed in bare fallow plot could be explained by low plant N uptake due to lack of crop in the short rains and weak maize plants in the long rains.

Generally, the results for 2001/02 and 2002/03 showed that the top soil (0 - 20 cm) had higher concentration of $NH_4^+$ - N than $NO_3^-$ - N except under cowpea. The 20 - 40 cm layer had higher $NO_3^-$ - N than $NH_4^+$ - N in 2001/02 but in 2002/03, $NH_4^+$ - N was higher than $NO_3^-$ - N except under bare fallow. The concentration of $NH_4^+$ - N in the 40 - 60 cm layer was higher than $NO_3^-$ - N except under cowpea and mucuna in 2001/02 season. The low concentration of $NO_3^-$ - N relative to $NH_4^+$ - N in the top soil was also reported in Kenya by Njunie and Wagger (2000) and in Malawi by Ikerra (2001).

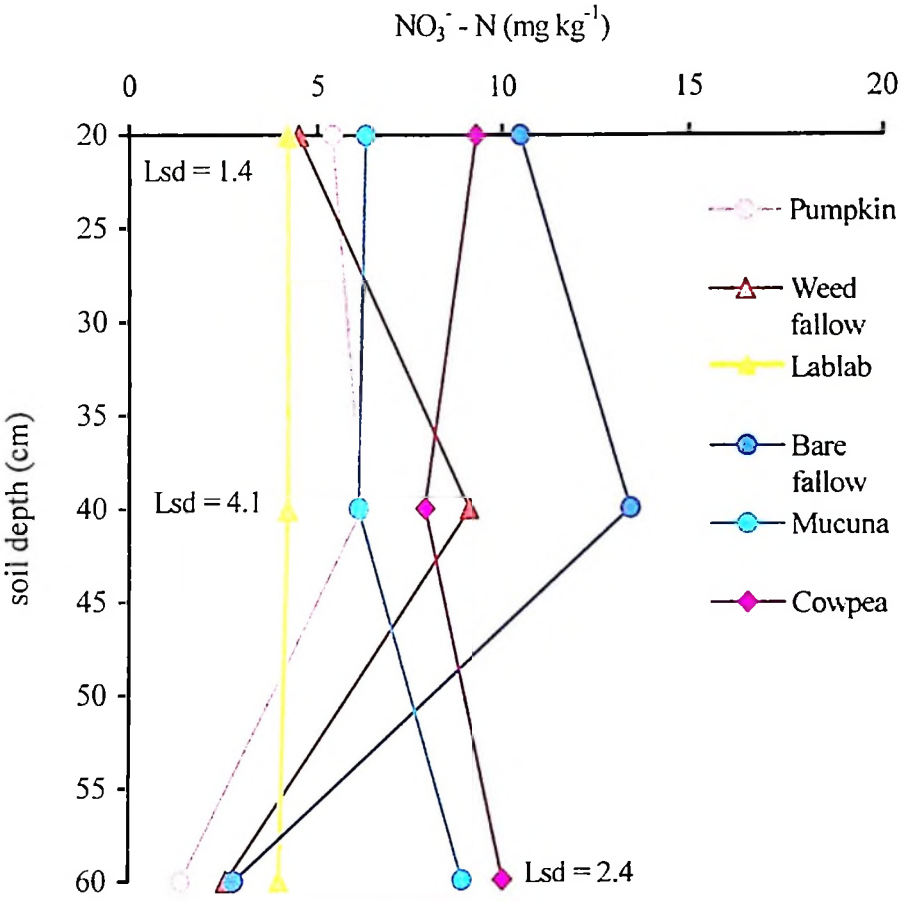


Figure 18: Nitrate – N profile as affected by the cover crops in the 2001/02 season

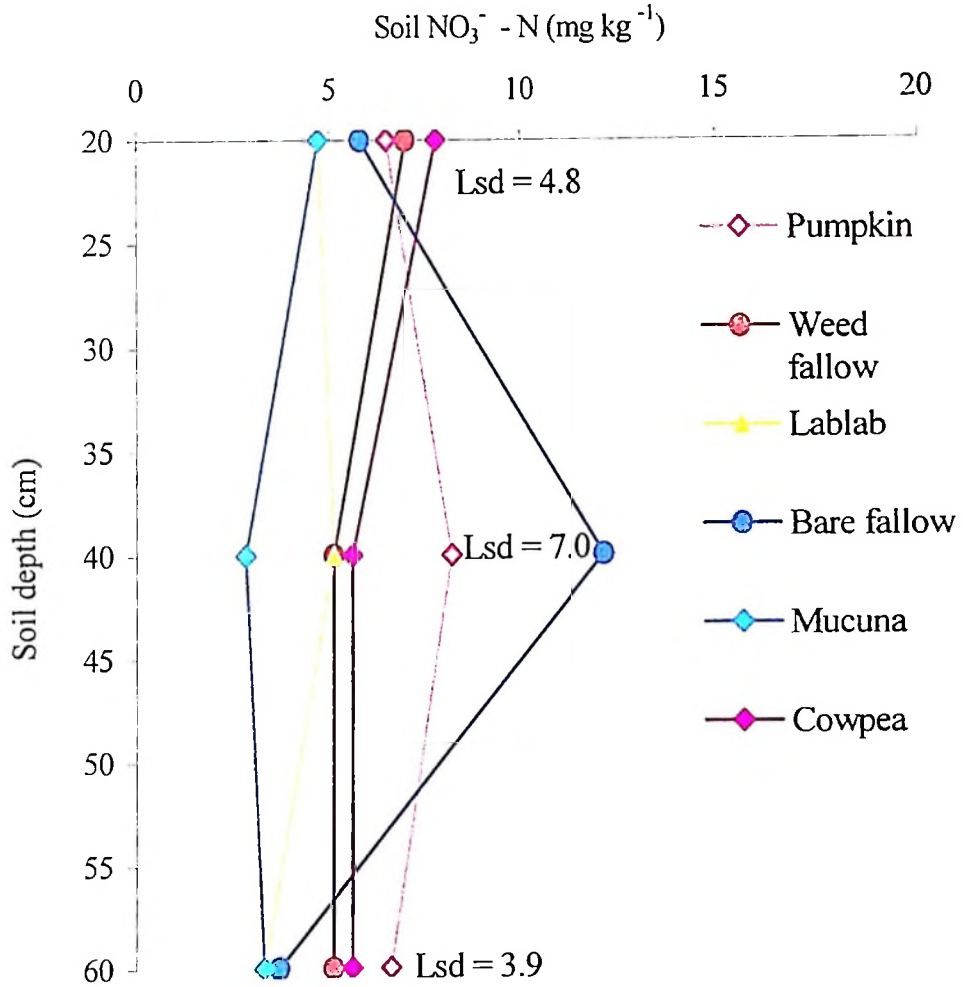


Figure 19: Nitrate – N profile as affected by the cover crops in the 2002/03 season

This high $NH_4^+$: $NO_3^-$ - N indicated the preferential outflow of $NO_3^-$ - N from the topsoil either by plant N uptake or by leaching, and low soil moisture condition. The higher $NO_3^-$ - N in the subsoil than $NH_4^+$ - N could suggest that $NO_3^-$ - N was leached from the topsoil and accumulated in the subsoil (20 - 40 cm).

Under bare, weed fallow and pumpkin, $NO_3^-$ - N accumulation in 20 - 40 cm was followed by a sharp decline of the same in the 40 - 60 cm depth. This pattern could be explained by accumulation of $NO_3^-$ - N due to less crop uptake and reduced leaching due to inadequate water running down the profile (Fig. 12). The dry condition in the 40 - 60 cm layer could have reduced the nitrification process leading to the observed high $NH_4^+$ - N in bare, weed fallow and pumpkin plots (Fig. 17).

Under cowpea and mucuna the trend was different. Nitrate - N was depleted in the 20 - 40 cm and increased in the 40 - 60 cm layer. This pattern could indicate that there was leaching of $NO_3^-$ - N from the top 40 cm to lower soil depth. Such $NO_3^-$ - N depletion in 20 – 40 cm soil layer could be caused by an imbalance between N input from organic residues and plant N uptake and adequate water to facilitate leaching. Mucuna, cowpea and lablab plots had $NO_3^-$ - N ranging from 133 to 156 kg $ha^{-1}$ in the 0 – 20 cm soil layer at the beginning of the long rains but 35 days after maize planting, 79 to 93% of this amount was already taken out of the 0 - 20 cm (Appendix 15). Most of this amount could have been leached because the amount was beyond N requirement of young maize plant. The soil moisture profile further indicated that there was enough water under mucuna, cowpea and lablab to move the $NO_3^-$ - N down the profile (Fig. 12). This explained the observed $NO_3^-$ - N increase below 40 cm depth. In case of lablab, $NO_3^-$ - N could have been leached beyond 60 cm depth resulting to the observed constant level. The results of

this study showed a weak correlation between $NO_3^-$ - N in the 20 - 40 soil layer after harvest of maize and N uptake by maize (r = -0.13394) indicating that N uptake could not explain the observed $NO_3^-$ - N pattern in the subsoil.

### 4.12 Effect of cover crops on maize performance

Maize was planted in early April, one month after the beginning of the long rainy season. At this time, reasonable amounts of cover crop biomass had been generated. Maize germinated well except in the 2002/03 season where germination was negatively affected by irregular rainfall distribution at the beginning of the season.

#### 4.12.1 Effect of cover crops on germination of the subsequent maize crop

Inadequate amount rainfall and erratic distribution of long rains at the beginning of the season negatively affected germination of maize during the long rains. A one-week dry period experienced after maize planting in the 2002/03 season resulted to moisture inadequacy for seed germination. Maize germination under different cover crops treatments at 10 DAPM, soil moisture at planting and at 7 DAPM in the 2002/03 season are shown in Table 26. The plants that had germinated 10 days after planting ranged from 3 to 57 percent of the expected population. Highest germination was observed in mucuna and weed fallow treatments and the lowest was observed in bare fallow treatment.

This difference in maize germination was explained by the variation in soil moisture content between treatments (Table 26). High germination percentage was obtained in mucuna and weed fallow treatments because they had high soil moisture content at planting and in the first 7 days after planting unlike the bare plots. Most of the maize seeds

germinated two weeks after planting following the second rainstorm and resulting to variation in plant age and overall maize grain yield.

Table 26: Maize germination at 10 DAPM in the 2002/03 season and soil moisture content at 0 and 7 DAPM

| Cover Crop | Plant $ha^{-1}$ | % of expected population | MC 0 DAPM | MC 7 DAPM |
|---|---|---|---|---|
| Bare fallow | 1 300 | 3b | 10.1c | 6.2c |
| Cowpea | 14 567 | 38a | 15.3ab | 8.9b |
| Pumpkin | 16 767 | 44a | 13.2b | 8.9b |
| Lablab | 17 533 | 46a | 16.3ab | 9.2b |
| Mucuna | 19 133 | 50a | 18.7a | 12.9a |
| Weed fallow | 22 067 | 57a | 17.8a | 14.0a |

Values in a column followed by the same letter are not significantly different at P = 0.05 using DNMRT.

MC = Soil moisture content.

### 4.12.2 Effect of cover crops on maize dry matter production and major nutrients concentration and uptake

In 2000/01 there was no notable difference in maize performance during the growing season. Nitrogen concentration was 2.7% in pumpkin, 2.8% in cowpea, 2.8% in mucuna and 2.9% in lablab. Nitrogen concentrations were above the critical level of 2.5%, indicating that N was not a major limiting factor of maize production in the 2000/01 growing season. The N concentrations in cover crop treatments were not significantly different. In the 2001/02 and 2002/03 seasons, maize plants showed differences in their

performance. At early stages of maize growth, seedlings in plots that were previously under pumpkin had better performance in terms of plant vigour than those in the other treatments. Seedlings in plots that were previously under bare and weed fallow were yellowish in colour manifesting N deficiency. Those in plots previously under mucuna were greenish in colour but thin and weak. The effect of cover crops planted prior to planting maize on dry matter production, N concentration and N, P and K uptake at the early stages of maize growth is shown on Table 27.

Table 27. Effect of cover crops on dry matter yield, N concentrations and N, P and K uptake of the subsequent maize crop at 17 DAPM

| Cover crop of the previous season | DMY | N | P | K | N | P | K |
|---|---|---|---|---|---|---|---|
| | (kg ha$^{-1}$) | ....Conc (%)..... | | | ...Uptake (g ha$^{-1}$)..... | | |
| Bare | 13.9d | 2.72a | 0.33a | 5.38a | 378.1d | 48.5b | 775c |
| Cowpea | 22.5b | 2.99a | 0.32a | 6.18a | 672.8ab | 72.5a | 1 397a |
| Lablab | 22.4b | 2.79a | 0.33a | 6.06a | 625.0bc | 74.4a | 1 361a |
| Mucuna | 19.8bc | 3.29a | 0.31a | 5.81a | 651.4ab | 63.0a | 1 169b |
| Pumpkin | 25.0a | 3.11a | 0.29a | 5.80a | 777.5a | 72.7a | 1 435a |
| Weed fallow | 17.6c | 2.85a | 0.23b | 5.41a | 501.6cd | 46.0b | 1 071b |

Values in a column followed by the same letter are not significantly different at P = 0.05 using DNMRT and numbers in the same column with no letter are statistically similar at P = 0.05 using ANOVA.

Maize dry matter yield at 17 DAPM ranged from 13.9 to 25.0 kg ha$^{-1}$. Maize dry matter yield followed the order: pumpkin > cowpea > mucuna > weed follow > bare fallow. Plots

that were previously under pumpkin had significantly higher yields than the other treatments while the bare fallow treatment had significantly lower dry matter yield than the other treatments. There was no significant difference in maize dry matter yield between cowpea, lablab and mucuna treatments. Nitrogen concentration in the above ground maize biomass at 17 DAPM in 2001/02 ranged from 2.72 in bare fallow to 3.29% in mucuna treatment, and was in the order mucuna > pumpkin > cowpea > weed fallow > lablab > bare fallow.

Nitrogen concentrations in all treatments except mucuna and pumpkin were lower than the sufficiency range of 3.0 - 4.0% (Campbell and Plank, 2000). The results showed that except for mucuna and pumpkin treatments, maize plants at the early growth stages were suffering N deficiency. This indicates that apart from mucuna and pumpkin, cover crops tested supplied inadequate N right from early growth stage of maize. Low N supply in cowpea, lablab, weed fallow and bare treatments is explained by low mineral N levels obtained in these treatments at the beginning of the long rainy season (Table 20).

All treatments except pumpkin and weed fallow had P concentration in maize plants that were within the sufficiency range of 0.3 - 0.5% reported by Campbell and Plank (2000). The results indicate that the basal P applied at maize planting at the rate of 80 kg P $ha^{-1}$ was sufficient to meet P demand for maize at the early maize growth stage except in pumpkin and weed fallow treatments. The low P concentration observed in maize under pumpkin treatment could be due to the dilution effect as a result of high dry matter production (Table 27). The immobilization of major plant nutrients due to low quality of weed fallow could explain the low P concentration in weed fallow treatment at 17 DAPM. Potassium concentrations in maize plants in all treatments were above the sufficiency

range of 2.0 - 3.0% established by Campbell and Plank (2000) suggesting that the plants were not deficient in K.

Nitrogen uptake by maize ranged from 378 g N $ha^{-1}$ in bare fallow to 777 g N $ha^{-1}$ in pumpkin treatment. Nitrogen uptake by maize in pumpkin, mucuna and cowpea treatments was significantly higher than in bare and weed fallow treatments. Nitrogen uptake by maize in lablab treatment was significantly higher than that in the bare fallow but lower than in the pumpkin treatment. Phosphorous uptake by maize ranged from 46 to 74 g $ha^{-1}$ and was significantly higher ($P < 0.05$) in cover crops than in weed and bare fallow treatments. Likewise, the K uptake by maize in cover crops was significantly higher ($P < 0.05$) than bare and weed fallow treatments except for mucuna in which K uptake was similar to that of the weed fallow treatment.

The high maize dry matter yield at 17 DAPM and the corresponding high N uptake observed in cowpea and pumpkin could be explained by high initial mineralization rate of the cover crop residues observed under incubation study (Fig. 4). The incubation study showed that cowpea and pumpkin released significantly higher mineral N in the first 7 - 14 days than the other cover crops. The released N was taken up by the young maize plants, resulting into higher N uptake and dry matter yield at early maize growth stages. The low maize DM obtained at 17 DAPM in bare treatment was mainly due to low soil moisture content in this treatment (Table 18). Low soil moisture content was more limiting than mineral N in bare treatment because it limited N uptake (Table 30).

The effect of cover crops on dry matter production, N concentration and N uptake at silking stages (53 DAPM) of the subsequent maize crop is shown in Table 28. The maize

dry matter yield at 53 DAPM ranged from 0.62 Mg $ha^{-1}$ in previously bare fallow to 3.52 Mg $ha^{-1}$ in mucuna plots. Plots that were under lablab and mucuna during the short rainy season produced significantly higher ($P < 0.01$) maize dry matter than those under cowpea, pumpkin, weed and bare fallow. Maize dry matter yields from weed fallow, cowpea and pumpkin treatments were statistically equal but significantly higher ($P < 0.01$) than that obtained from bare fallow treatment.

Table 28: Effect of cover crops on dry matter yield, N, P and K concentrations and N, P and K uptake of the subsequent maize crop at 53 DAPM in 2002/03 season

| | DMY | Concentration | | | Uptake | | |
|---|---|---|---|---|---|---|---|
| | | N | P | K | N | P | K |
| Cover crop | (Mg $ha^{-1}$) | .....% | | | .....kg $ha^{-1}$ | | |
| Cowpea | 2.39b | 1.18b | 0.09b | 2.35ab | 28bc | 2.23c | 56b |
| Lablab | 3.40a | 1.07b | 0.11ab | 2.26ab | 36ab | 3.74ab | 77a |
| Mucuna | 3.52a | 1.22ab | 0.14ab | 2.17b | 43a | 4.93a | 76a |
| Pumpkin | 2.22b | 1.28ab | 0.10b | 2.39ab | 28bc | 2.28c | 52b |
| Weed fallow | 1.93b | 1.17b | 0.17a | 2.49ab | 23c | 3.28bc | 48b |
| Bare fallow | 0.62c | 1.53a | 0.11ab | 2.71a | 9d | 0.70d | 17c |

Means in a column followed by same letter are not significantly different at P = 0.05 using DNMRT.

DMY = dry matter yield

Higher maize dry matter yield in mucuna and lablab than in the other treatments may be explained by high amount of N that was accumulated by mucuna and lablab residues (Table 6). At the end of short rains, mucuna and lablab had accumulated 118 and 86 kg N $ha^{-1}$, respectively whereas other treatments accumulated lower N. Plots that were

previously under weed fallow produced significantly similar maize dry matter to the plots that were previously under cowpea and pumpkin despite the higher accumulation of N (61 kg N $ha^{-1}$). The weed fallow had C:N ratio greater than the critical value of 25 for net mineralization (Myers *et al.*, 1994) or 30 (Follet *et al.*, 1981; Harris, 1988; Fox *et al.*, 1990) (Table 4).

The high C:N ratio of weed fallow might have led to immobilization of soil N at the early maize growth stages and hence negatively affecting maize dry matter production as was observed at 17 and 53 DAPM. The result of dry matter production in weed fallow treatment indicated that the dry matter production by maize planted in the subsequent season was not only explained by N accumulated in cover crop biomass but also by the availability of the accumulated N to maize plants.

In 2002/03, nitrogen concentration of maize plants at 53 DAPM ranged from 1.07 to 1.53% following the order bare fallow > pumpkin > mucuna > cowpea > weed fallow > lablab treatment (Table 29). Nitrogen concentrations of maize plants in all treatments were lower than the sufficiency range of 3.5 - 5.0% proposed by Robert (1998), indicating that the plants were suffering from N deficiency. This deficiency was manifested by yellowish maize plants in weed fallow, pumpkin, cowpea and mucuna treatments. However, maize plants in bare fallow treatment were shorter but green indicating that there was another factor limiting maize growth in this treatment, than N.

The detected N deficiency in cover crops treatments could be explained by the N release pattern of the cover crop residues (section 4.3.3) and soil mineral N ($NO_3^-$ - N + $NH_4^+$ - N) levels (section 4.10). The incubation study showed that cover crop residues had rapid N

release at the initial stages of mineralization. The rapid N release was also observed in the field where high levels of mineral N were obtained at the beginning of the rainy season followed by a rapid decline thereafter (Fig. 13 and Table 22). The rapid N release and a short lived high N flush that occurred ahead of the peak N demand by maize crop exposed most of the N to leaching losses, causing N deficiency to maize crop at the later maize growth stages.

Nitrogen uptake at 53 DAPM ranged from 9 to 43 kg $ha^{-1}$ in the order mucuna > lablab >pumpkin = cowpea > weed fallow > bare fallow. Maize N uptake in mucuna treatment was statistically similar to that in lablab but significantly higher than that in the other treatments. Maize N uptake in cowpea, pumpkin and weed fallow treatment did not differ significantly whereas that in bare fallow treatment was significantly lower than all treatments. High maize N uptake in mucuna and lablab treatments could be explained by high N content and dry matter yield whereas low uptake in other treatments by low dry matter production (Table 28). Nitrogen supply by cover crops to subsequent maize crop was adequate at early maize growth stage and only in pumpkin and mucuna treatments. With time, N supplied by cover crops became inadequate as shown by N concentration in maize plants at 53 DAPM. This indicates that there is a need to topdress maize plants with mineral N at 28 – 35 DAPM.

### 4.12.3 Effect of cover crops on plant height of the subsequent maize crop

The effect of cover crops on the height of the succeeding maize at 42 DAPM is shown in Figure 20. Maize plants in plots that were previously under pumpkin and cowpea had better performance in terms of height and biomass production than those in plots that were previously under bare or under weed fallow.

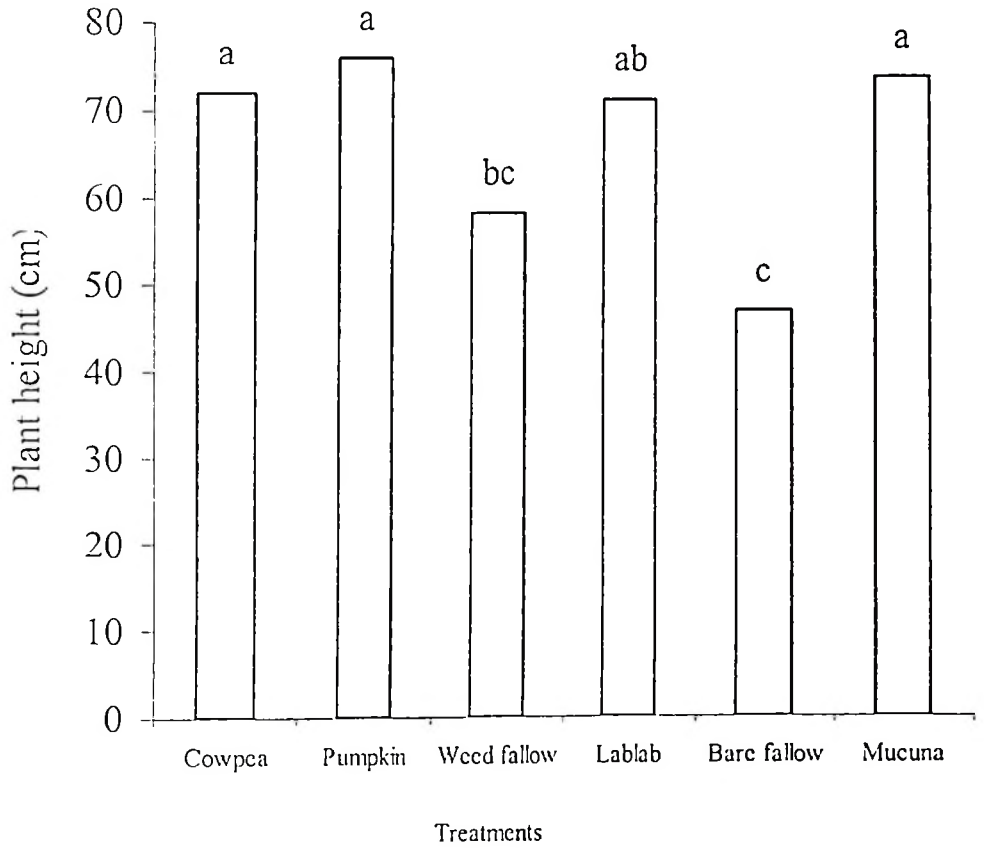


Figure 20: Maize plant height as influenced by cover crop grown in the previous short rainy season

For instance, six weeks after planting, maize plant heights ranged from 47 to 76 cm. Plant heights were 76, 74, 72, 71, 58 and 47 cm in plots that were previously under pumpkin, mucuna, cowpea, lablab, weed fallow and bare fallow, respectively.

Maize plants in plots that were previously under pumpkin, cowpea and mucuna were significantly taller ($P < 0.01$) than those in previously bare and weed fallow plots. The rains ceased when maize was 4 weeks old. This premature cessation of rainfall negatively affected cob formation and grain filling leading to low grain yield.

### 4.12.4 The effect of cover crops on maize silking

Maize silking was delayed or completely hampered in other treatments by dry spells that were experienced in the 2001/02 and 2002/03 seasons. The percentages of silking plants at 53 DAPM in the 2001/02 and 2002/03 seasons are shown in Table 29.

Table 29: Percentages of maize silking at 53 DAPM as influenced by cover crops in the 2001/02 and 2002/03 growing seasons

| Cover crop planted in the previous short rains | 2001/02 | 2002/03 |
|---|---|---|
| | .....% | |
| Bare fallow | 3b | 0 c |
| Cowpea | 12a | 7bc |
| Lablab | 18a | 13ab |
| Mucuna | 20a | 17a |
| Pumpkin | 11ab | 4c |
| Weed follow | 3b | 2c |

Means in the column followed by the same letter are not significantly different at $P < 0.05$ using DNMRT.

Maize plants silking in 2001/02 ranged from 3 to 20% of the total plant population following the order bare fallow = weed fallow < pumpkin < cowpea < lablab < mucuna. In 2002/03, maize plants silking ranged from 0 to 17.3% of total plant population following the order mucuna > lablab > cowpea > pumpkin > weed fallow > bare fallow. The cover crops grown prior to maize planting had positive effects on silking and cob formation of the maize crop. For example, the number of plants that silk or formed cobs at 53 DAPM, was significantly higher in cover crop treatments than in the other treatments ($P < 0.05$). In both seasons, mucuna and lablab treatments had significantly more plants silking than weed and bare fallow treatments.

The observation that weed fallow treatment had only few plants silking although it had highest soil moisture content during the long rainy season (Table 16, 17 and 18) would suggest that the number of plants silking was not solely dependent on soil moisture content. The number of maize plants silking could be explained by the interaction of soil moisture and $NO_3^-$ during the vegetative stage of maize growth. The high preseason $NO_3^-$-N (Fig. 15, Table 25) and soil moisture contents during the long rainy season (Table 16, 17 and 18) in mucuna and lablab plots could explain the higher number of maize plants silking in these treatments than in the rest of the treatments. In addition to drought, termites and wind negatively affected maize performance. For instance, during the dry period starting from May 2002 some plants fell prematurely due to termite attack and wind. A significantly higher ($P = 0.016$) number of plants fell in plots that were previously under pumpkin and cowpea than in other plots. For instance, at 45 DAPM, 37 and 30 maize plants had fallen in pumpkin and cowpea plots which amounted to 51 and 42% of plant population in the plot. In bare, weed fallow, lablab and mucuna plots maize plants

that had fallen ranged from 11 to 14 plants, accounting for only 15 to 19% of total plant population.

### 4.12.5 Effect of cover crops on subsequent maize grain yield

The effect of cover crops on subsequent maize grain yield is shown in Figure 21. Maize grain yields in the first year of the experiment (2000/01) ranged from 1800 to 2200 in the order cowpea = weed fallow > lablab = mucuna > pumpkin > bare fallow. Maize grain yields were not significantly different between the treatments.

In the 2001/02 season maize grain yields were very low ranging from 74 to 442 kg $ha^{-1}$ in the order mucuna > cowpea > lablab > bare fallow > pumpkin > weed fallow. The lower yields obtained in 2001/02 was caused by early cessation of long rains. In this year, the long rains ceased at the end of April (Fig. 1), 3 weeks earlier than normal. This occurred when maize plants were at tassling stage and silking and grain filling were negatively affected, leading to low maize grain yield. Cowpea and mucuna treatments had statistically similar maize grain yields with lablab treatment but significantly higher ($P < 0.05$) than those in pumpkin, weed and bare fallow. When compared with weed fallow treatment, maize yields in mucuna and cowpea treatments were 497 and 403% higher.

Maize grain yields in 2002/03 ranged from 603 to 1933 kg $ha^{-1}$ in the order mucuna > lablab > pumpkin > bare fallow > cowpea > weed fallow. Maize yield in mucuna treatment was significantly higher ($P < 0.01$) than in the other treatments and that in lablab treatment was significantly higher ($P < 0.01$) than in cowpea, pumpkin, weed and bare fallow treatments.

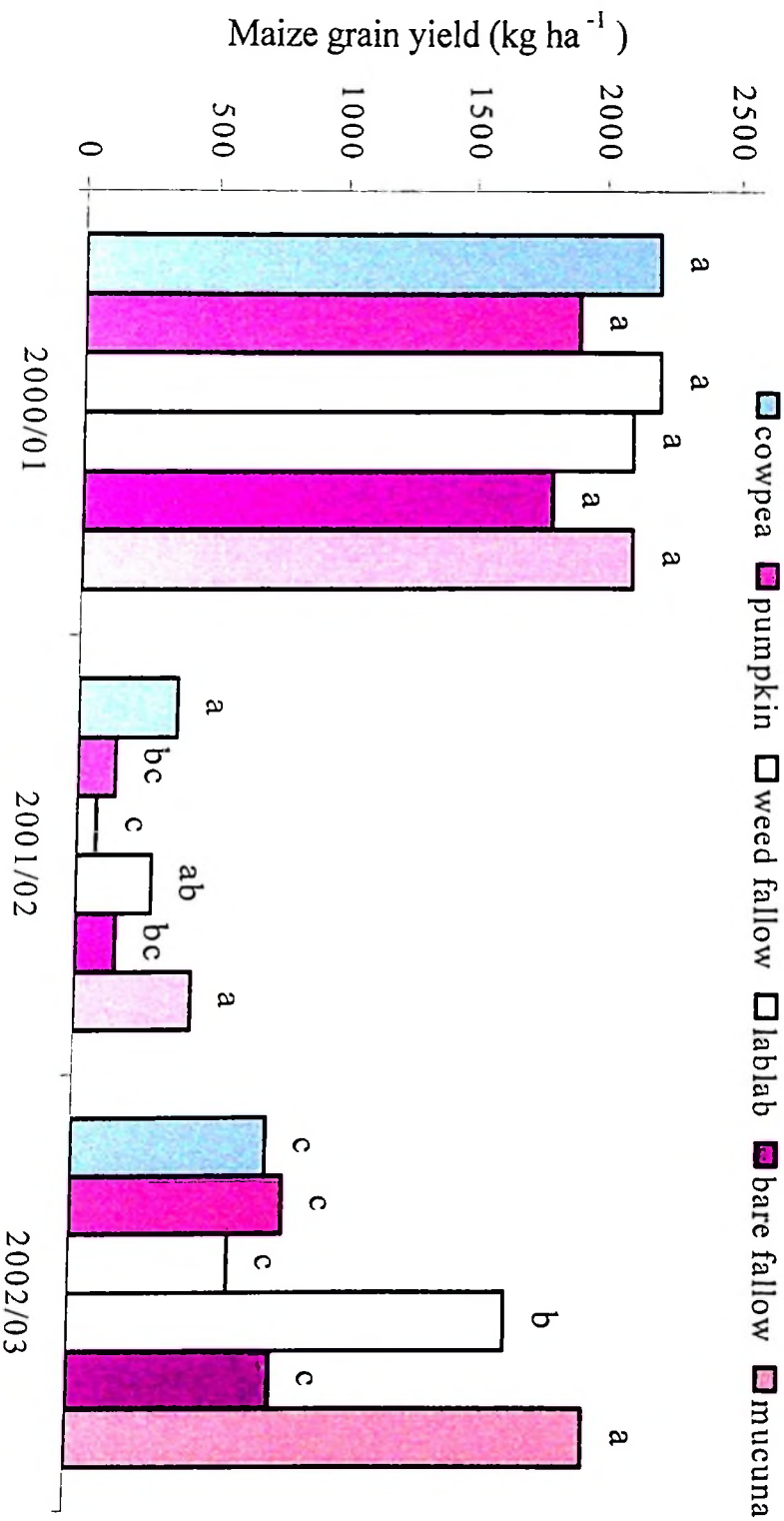


Figure 21: Influence of the cover crops planted on maize grain yields

Maize increase in mucuna treatment relative to weed fallow of 603 to 1933 kg $ha^{-1}$ was similar to that reported in West Africa by Galiba *et al.* (1998) on maize preceded by mucuna of 480 to 1140 kg $ha^{-1}$. The increase in maize yield obtained in this study due to lablab (173%) and mucuna (221%) in 2002/03 season were higher than those reported in Nigeria by Agboola (1980) and in Uganda by Fischler and Wortman (1999) but was comparable to those reported in West Africa by Galiba *et al.* (1998) and Carsky *et al.* (1999). Agboola (1980) reported that maize yield subsequent to pigeon pea, mucuna and cowpea was increased by 10 – 30% in a sub humid province of Nigeria. In Uganda, maize succeeding lablab and mucuna was increased by 50 and 60%, respectively (Fischler and Wortman, 1999). Carsky *et al.* (1999) and Galiba *et al.* (1998) reported maize yield increase subsequent to mucuna amounting to 111 and 138%, respectively in West Africa.

In the current study, maize grain yields in lablab, mucuna and cowpea treatments were significantly higher than in weed fallow. The observation that lablab, mucuna and cowpea treatments had statistically similar soil moisture content with weed fallow (Table 16), indicated that the difference in maize grain yield between the cover crop treatments could therefore be due to variation in their nitrogen content.

### 4.12.6 Correlation analysis relating soil moisture and mineral N to N and P uptake and maize grain yield

The soil moisture content at maize planting and at the beginning of maize growing period had a significant positive influence on N and P uptake and maize grain yield (Table 30).

Table 30: Correlation analysis between soil moisture content at different DAPM and N, P uptake and grain yield of maize for the 2002/03 season

| DAPM | Uptake | | Maize grain yield |
|---|---|---|---|
| | N | P | |
| | .....r..... | | |
| 0 | 0.52* | 0.80** | 0.51* |
| 7 | 0.48* | 0.55** | 0.56** |
| 21 | 0.40ns | 0.76** | 0.61** |
| 35 | 0.26ns | 0.44* | 0.53* |
| 45 | -0.26ns | 0.05ns | 0.05ns |

r = correlation coefficient

* = Significant at P = 0.05

** = Significant at P = 0.01

ns = Not significant

The moisture content at this stage was better correlated with N uptake than at later maize growth stages. This suggested that a unit increase in soil moisture content at maize planting and at early growth stages resulted into higher N uptake by maize than was in the later growth stages. The soil moisture content influenced N availability to the subsequent maize crop by regulating mineralization process and acting as a solvent and medium from which N was taken by maize plants (Myers *et al.*, 1994).

The results showed that adequate soil moisture content at planting and at early part of the maize growing season had more impact on N uptake. The amount of biomass generated by the cover crops in the short rains also had a significant positive correlation ($r = 0.424$, $P < 0.05$) with maize grain yield obtained in the succeeding long rains. The effect of cover crop biomass on maize grain yield might be through its effect on soil moisture content because in section 4.7 it was observed that cover crop biomass and soil moisture content

were positively correlated. The relationships between N uptake at 53 DAPM and mineral N forms in the soil at selected sampling periods are shown in Table 31.

Table 31. Correlation coefficients (r) relating the soil $NH_4^+$ and $NO_3^-$ - N at different DAPM to maize N uptake at 53 DAPM and maize grain yield in the 2002/03

| DAPM | $NH_4^+$ - N | | $NO_3^-$ - N | |
|---|---|---|---|---|
| | Uptake | Yield | Uptake | Yield |
| | .....(r )..... | | | |
| $69^{\Phi}$ | 0.22 ns | 0.40 ns | 0.34 ns | 0.67** |
| 7 | 0.32 ns | 0.30 ns | -0.35 ns | -0.10 ns |
| 24 | -0.07 ns | -0.02 ns | -0.46* | -0.46* |
| 39 | 0.05 ns | -0.25 ns | -0.53* | -0.54* |
| 49 | 0.31 ns | 0.28 ns | -0.69** | -0.60** |

ns = Not significant at P = 0.05

* = Significant at P = 0.05

** = Significant at P = 0.01

$^{\Phi}$ = Days before maize planting

Soil $NH_4^+$ - N before maize planting and during maize growth was weakly correlated with both N uptake and maize grain yield. The good correlation was obtained with soil $NO_3^-$ - N. Nitrate N determined in January 2003 before the onset of the long rains significantly correlated ($P<0.01$) with maize grain yield. The observation that the preseason $NO_3^-$ is highly correlated with maize grain yield in this study is in conformity with that of Barrios *et al.* (1998), Ikerra *et al.* (1999) and Hatermink *et al.* (1996). After maize planting, soil $NO_3^-$ - N was negatively correlated with maize grain yield and this effect increased with maize growth period. This trend was similar to that of N uptake indicating that N taken by maize was mainly in form of $NO_3^-$ - N and consequently reduced its levels in the soil. The negative correlation between soil $NO_3^-$ - N and grain yield may thus indicate that higher $NO_3^-$ - N uptake was associated with higher maize grain yield.

# CHAPTER FIVE

# CONCLUSIONS AND RECOMMENDATIONS

From the results obtained in this study the following conclusions and recommendations are made:

## 5.1 Conclusions

(1) The biomass of the cover crops had higher N and lower lignin contents than weed fallow indicating that they were of higher quality hence higher potential of supplying N than those of the weed fallow.

(2) Most of biomass - N was released at 7 and 14 days of application for cowpea and pumpkin, respectively, whereas it was at 28 – 35 days for mucuna and lablab. This showed that mucuna and lablab might have relatively better N supply pattern to maize than cowpea and pumpkin as their N release peaks occurred slightly later in the maize growing period. Also due to relatively slower mineralization, residues of mucuna and lablab may provide ground cover for longer duration in the long rains than that of cowpea and pumpkin thereby protecting the soil from rain splash, checking runoff and reducing evaporation.

(3) The use of mucuna and pumpkin slightly improved soil bulk density and basic infiltration rate but that of cowpea and lablab had no effect. However, all the tested cover crops had no effect on soil aggregate stability and porosity.

(4) Cover crops lowered moisture content in the topsoil and did not significantly reduce runoff during the short rainy season, but in the long rainy season, cover crop residues

significantly lowered runoff thereby increasing soil moisture content in cover crop treatments.

(5) The amount of biomass added on the soil surface had more influence on runoff than on basic infiltration rate or water stable aggregates. This suggested that the possible mechanism by which cover crop biomass would have reduced runoff through modification of soil surface behaviour, consequently increasing time for infiltration and water sorption.

(6) The ability of cover crops to produce high amount of biomass was found to be the overriding factor in soil moisture conservation in the study area. The extraction of soil moisture by cover crops during the short rainy season had no negative effect on maize grain yield of the subsequent long rains.

(7) The amount of N accumulated in cover crop biomass was in the order of mucuna>lablab>cowpea >pumpkin. However, amount of N made available even from mucuna biomass was lower than the N rate recommended for maize production. Furthermore, most of N from cover crops was released early in the subsequent long rains. This resulted into lack of synchrony between N supply and N demand by maize. It is, therefore, recommended that supplemental N from mineral fertilizers be topdressed at 28 to 35 DAPM for optimum maize yield. Farmers who are unable to use mineral N fertilizers, should plant mucuna or lablab in the short rainy season instead of leaving their field under weed fallow.

(8) Mucuna and lablab were the best cover crops with respect to biomass production, reduction of runoff, moisture conservation, N supply and maize grain yield. The biomass production and effect on soil moisture conservation of mucuna and lablab was similar to that of weed fallow, but the two cover crops had higher quality biomass hence higher N supply potential. It is recommended that lablab or mucuna be sown in the short rains for both soil moisture conservation and N provision to maize crop in the subsequent long rains instead of leaving the land under weed fallow.

## 5.2 Recommendations

(1) Mucuna was observed to be superior to weed fallow and other cover crops in terms of soil moisture conservation, N supply and maize grain yield. It is recommended that mucuna should be planted in the short rains instead of leaving the land under weed fallow and supplemental mineral N fertilizer should be topdressed at 28 to 35 days after maize planting in order to increase maize grain yield.

(2) This study was conducted for a short duration and did not go into the social economic analysis of using mucuna against weed fallow. It is therefore, recommended that further studies be conducted for a longer period to evaluate social economic aspects of growing mucuna during the short rains.

(3) The short rains in the sub humid area of Morogoro are inadequate for maize production and most of farmers leave their land under weed during the short rainy season. Hence planting mucuna during the short rainy season may not create a problem of competition for land with the main crops but may be less acceptable by

farmers due to its limited uses. It is therefore recommended that more work be done to investigate alternative uses of mucuna in the sub humid areas of Morogoro.

(4) This study showed that pumpkin, although not a leguminous plant had the ability to accumulate substantial amounts of N, P and bases. It is therefore recommended that further studies be conducted to evaluate the potential of pumpkin on crop nutrient management.

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# APPENDICES.

Appendix 1: Maximum and minimum daily temperatures during the experimental period

Temp mean-daily

| Short rains | | | | | | |
|---|---|---|---|---|---|---|
| Max | Sep | Oct | Nov | Dec | Jan | Feb |
| 2000/01 | 29.8 | 32.4 | 33.0 | 30.9 | 30.4 | 31.0 |
| 2001/02 | 30.2 | 31.7 | 33.7 | 33.3 | 32.0 | 31.8 |
| 2002/03 | 30.1 | 31.3 | 31.8 | 32.5 | 32.1 | 34.0 |
| Min | | | | | | |
| 2000/01 | 17.1 | 18.6 | 21.4 | 21.6 | 21.7 | 21.2 |
| 2001/02 | 17.0 | 18.5 | 20.2 | 22.6 | 22.6 | 22.0 |
| 2002/03 | 18.1 | 19.3 | 20.6 | 21.8 | 21.4 | 21.9 |
| Long rains | | | | | | |
| Max | Mar | Apr | May | Jun | Jul | Aug |
| 2000/01 | 31.3 | 29.5 | 28.7 | 27.7 | 26.5 | 28.5 |
| 2001/02 | 30.5 | 28.5 | 29.1 | 27.7 | 28.2 | 28.4 |
| 2002/03 | 33.8 | 30.8 | | | | |
| Min | | | | | | |
| 2000/01 | 21.4 | 21.0 | 20.0 | 17.2 | 15.8 | 15.9 |
| 2001/02 | 21.8 | 21.1 | 18.6 | 15.6 | 16.9 | 17.0 |
| 2002/03 | 22.0 | 21.1 | | | | |

Appendix 2. Some selected characteristics of soil at the experimental site.

| Soil depth | sand | silt | clay | textural class | pH($H_2O$) | pH(KCl) | Ca | Mg | K | BS | CEC | CECclay |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ...cm... | | .....%..... | | | | | .....cmol $kg^{-1}$..... | | | ...%... | ...cmol $kg^{-1}$.... | |
| 0-10 | 58 | 2 | 40 | sandy clay | 6.32 | 5.11 | 4.5 | 2.8 | 1.13 | 64 | 13 | 32 |
| 10-25 | 34 | 8 | 58 | clay | 6.14 | 4.77 | 4.2 | 2.7 | 0.82 | 37 | 21 | 36 |
| 25- 65 | 26 | 4 | 70 | clay | 5.33 | 4.21 | 3.0 | 2.9 | 0.26 | 34 | 18 | 26 |
| 65-105 | 28 | 4 | 68 | clay | 5.35 | 4.71 | 1.9 | 2.5 | 0.10 | 27 | 17 | 24 |
| 105-145 | 32 | 8 | 60 | clay | 4.61 | 4.41 | 3.9 | 5.9 | 0.08 | 68 | 15 | 24 |



Appendix 3. Bulk density and water characteristics of the soil at the study site.

| Soil depth (cm) | 0 - 5 | 5 - 20 | 20 - 25 | 25 - 45 | 45 - 60 | 60 - 70 | 70 - 90 | 90 - 95 | 95+ |
|---|---|---|---|---|---|---|---|---|---|
| bulk density (Mg $m^{-3}$) | 1.19 | 1.19 | 1.39 | 1.33 | 1.13 | 1.18 | 1.16 | 1.32 | 1.27 |
| mc at FC (%vol) | 19 | 26 | 24 | 26 | 25 | 22 | 26 | 23 | 31 |
| mc at PWP (%vol) | 9.7 | 10.2 | 12.3 | 13.3 | 13.2 | 16 | 16 | 16 | 16 |
| AWC (%vol) | 9.3 | 15.8 | 11.7 | 12.7 | 11.8 | 6 | 10 | 7 | 15 |

Appendix 4: Mineral N release pattern of cover crop residues.

| Cover Crop | Days of incubation | | | |
|---|---|---|---|---|
| | 0 | 7 | 14 | 35 |
| | ..... $mg\ kg^{-1}$ ..... | | | |
| Lablab | 17.5a | 24.8bc | 36.7a | 36.8c |
| Pumpkin | 13.9b | 33.5ab | 41.7a | 48.3a |
| Mucuna | 14.1b | 25.3bc | 34.6a | 42.0b |
| Control | 8.9c | 22.3c | 23.6b | 25.7de |
| Cowpea | 10.1c | 37.9a | 37.2a | 33.7cd |
| Lsd | 2.2 | 8.2 | 9.6 | 5.2 |
| CV (%) | 9 | 15 | 15 | 7 |

Means in a column with same letter are not significantly different at P = 0.05 using DNMRT

Appendix 5: Changes in soil mineral N as affected by cover crop residues in the incubation study

| | Duration of incubation (days) | Cover crop residue | | | | | |
|---|---|---|---|---|---|---|---|
| | | Lablab | Pumpkin | weed fallow | Mucuna | Cowpea | Control |
| Change over Previous sampling (%) | 7 | 41.8 | 141.0 | 132.9 | 79.6 | 276.0 | 149.9 |
| | 14 | 48.4 | 24.7 | 1.3 | 37.0 | -1.8 | 5.8 |
| | 35 | 0.2 | 15.7 | -6.8 | 21.1 | -9.6 | 8.8 |
| Change over control ($mg\ kg^{-1}$) | 7 | 2.4 | 11.1 | 9.5 | 3.0 | 15.6 | n.a |
| | 14 | 13.1 | 18.1 | 8.6 | 11.0 | 13.6 | n.a |
| | 35 | 11.1 | 22.6 | 4.4 | 16.3 | 8.0 | n.a |
| Change over control (%) | 7 | 11.2 | 50.2 | 42.6 | 13.5 | 70.0 | n.a |
| | 14 | 55.5 | 76.7 | 36.6 | 46.6 | 36.4 | n.a |
| | 35 | 43.2 | 87.9 | 17.0 | 63.4 | 31.1 | n.a |

na = Not applicable

Appendix 6: Ground cover generated by cover crops during the short rains of 2001/02

| Cover crop | Days after planting of cover crops | | | | | | |
|---|---|---|---|---|---|---|---|
| | 14 | 28 | 42 | 56 | 70 | 84 | 96 |
| | ..... % ..... | | | | | | |
| cowpea | 4.0a | 9.5b | 15.3c | 20.3bc | 51.2b | 62.0c | 67.0c |
| pumpkin | 2.7b | 13.7b | 20.0b | 22.3b | 46.7c | 75.0b | 85.7b |
| lablab | 2.3bc | 10.3b | 15.3c | 19.0c | 41.5d | 60.0d | 68.0c |
| mucuna | 1.5c | 21.0a | 26.3a | 41.0a | 77.3a | 94.8a | 100.0a |
| Lsd | 1.1 | 4.0 | 3.0 | 3.8 | 2.8 | 1.9 | 1.5 |
| CV (%) | 21 | 15 | 8 | 8 | 2 | 1 | 1 |

Appendix 7: Ground cover generated by cover crops during the short rains of 2002/03

| Cover crop | Days after planting of cover crops | | |
|---|---|---|---|
| | 30 | 60 | 90 |
| | ..... % ..... | | |
| Cowpea | 43.9b | 71.3b | 89.4ab |
| Lablab | 27.9c | 51.7c | 73.6b |
| Mucuna | 40.6b | 68.0b | 100.0a |
| Pumpkin | 34.6bc | 53.0c | 78.9b |
| Weed fallow | 93.7a | 92.7a | 100.0a |
| Lsd | 10.7 | 11.2 | 12.4 |
| CV (%) | 15 | 11 | 9 |

Appendix 8: Soil moisture content as influenced by the use of cover crops during the short rains of 2000/01

| | Duration After Planting CC (Days) | | | |
|---|---|---|---|---|
| | 0 | 14 | 43 | 76 |
| CC | | ..... % ..... | | |
| Cowpea | 18.76 | 14.8bc | 12.0 | 17.5 |
| Lablab | 17.51 | 15.7b | 13.0 | 19.2 |
| Mucuna | 17.88 | 13.9c | 13.2 | 17.5 |
| Pumpkin | 17.52 | 14.8bc | 13.1 | 18.1 |
| weed fallow | 18.29 | 17.9a | 13.7 | 19.7 |
| Lsd | | 1.7 | 2.3 | 4.8 |
| CV (%) | | 6 | 10 | 10 |

Appendix 9: Soil moisture content as influenced by the use of cover crops during the short rains of 2002/03

| Cover crop | Duration After Planting CC (Days) | | | | | |
|---|---|---|---|---|---|---|
| | 0 | 5 | 15 | 31 | 41 | 52 |
| | ..... | | | %..... | | |
| Bare fallow | 23 | 13 | 11 | 13 | 16 | 9 |
| Cowpea | 23 | 16 | 12 | 16 | 18 | 10 |
| Lablab | 23 | 15 | 12 | 17 | 17 | 10 |
| Mucuna | 23 | 15 | 12 | 14 | 17 | 11 |
| Pumpkin | 23 | 16 | 12 | 16 | 18 | 10 |
| Weed fallow | 23 | 15 | 12 | 16 | 18 | 12 |
| Lsd | | | | | | |
| CV | | | | | | |

Appendix 10: Soil moisture profile at the beginning and end of short rains as influenced by the use of cover crops during the short rains of 2000/01

| Depth (cm) | Cowpea | Weed fallow | Lablab | Mucuna | Pumpkin | Lsd | CV |
|---|---|---|---|---|---|---|---|
| | Soil moisture content at the beginning of the season | | | | | | |
| | ..... | | | mm layer$^{-1}$ | | ..... | ...%... |
| 2.5 | 7.9 | 6.6 | 8.9 | 9.0 | 9.4 | 1.77 | 9 |
| 7.5 | 9.4 | 9.9 | 8.8 | 8.5 | 9.1 | 2.13 | 11 |
| 15 | 18.0 | 20.2 | 18.5 | 15.8 | 17.5 | 3.88 | 11 |
| 22.5 | 11.4 | 11.0 | 10.2 | 10.4 | 11.2 | 2.35 | 10 |
| 27.5 | 12.1 | 11.5 | 10.7 | 10.5 | 17.2 | 7.77 | 30 |
| 35 | 21.6 | 21.5 | 22.9 | 20.3 | 18.3 | 5.69 | 13 |
| 50 | 28.6 | 35.1 | 29.4 | 27.3 | 31.7 | 11.69 | 18 |
| 0-60 | 108.9 | 116.0 | 109.3 | 101.7 | 114.5 | | |
| | Soil moisture content at the end of the season | | | | | | |
| 2.5 | 6.4 | 7.1 | 5.7 | 7 | 6.1 | 2.14 | 16 |
| 7.5 | 7.6 | 8.2 | 7.7 | 7.7 | 7.8 | 1.82 | 11 |
| 15 | 14.7 | 15.8 | 15.9 | 16.6 | 15.6 | 4.38 | 13 |
| 22.5 | 9.8 | 9.7 | 9.9 | 9.8 | 8.5 | 2.72 | 14 |
| 27.5 | 9.9 | 9.2 | 10.1 | 10.3 | 8.5 | 2.51 | 12 |
| 35 | 19.7 | 17.9 | 20.9 | 20.6 | 17.4 | 3.55 | 9 |
| 50 | 33.1 | 31.3 | 38.1 | 36.5 | 29.1 | 3.50 | 5 |
| 0-60 | 101.2 | 99.2 | 108.3 | 108.5 | 93 | | |

The Lsd separates means that are in a same row.

Appendix 11. Soil $NH_4^+$, $NO_3^-$ and mineral N ($NH_4^+ + NO_3^-$) at the end of the short rains, at maize planting and during maize growing period in 2000/01.

| | Days after planting of maize | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | PS | 0 | 21 | 35 | PS | 0 | 21 | 35 | PS | 0 | 21 | 35 |
| Cover crop | $NH_4$ - N | | | | $NO_3$ - N | | | | $(NH_4 + NO_3)$ - N | | | |
| | ..... mg $kg^{-1}$ ..... | | | | | | | | | | | |
| Weed fallow | 20.5 | 1.2 | 1.7 | 2.4 | 7.4 | 31.1 | 31.0 | 1.9 | 27.9 | 34.9 | 34.2 | 4.3 |
| cowpea | 18.3 | 4.4 | 3.5 | 2.7 | 4.3 | 46.0 | 31.3 | 3.3 | 22.6 | 50.4 | 34.4 | 6.0 |
| Lablab | 16. 6 | 3.3 | 2.1 | 2.0 | 10.4 | 53.8 | 32.1 | 5.6 | 27.0 | 57.2 | 35.0 | 7.6 |
| Mucuna | 18.5 | 6.8 | 4.0 | 1.9 | 16.8 | 44.0 | 31.4 | 9.0 | 35.3 | 50.1 | 35.2 | 10.9 |
| Pumpkin | 16.3 | 7.9 | 6.7 | 1.0 | 4.1 | 30.2 | 24.0 | 1.1 | 20.3 | 38.1 | 28.0 | 2.1 |
| Lsd | 5.9 | 1.7 | 3.6 | 3.3 | 3.1 | 14.3 | 6.4 | 1.9 | 8.5 | 10.9 | 6.8 | 2.9 |
| CV | 20 | 14 | 38 | 35 | 20 | 15 | 12 | 24 | 18 | 10 | 7 | 16 |

Cover crop = Cover crop planted in short rains
PS = At the end of the short rains

Appendix 12: Changes in soil mineral N during the short and the long rains 2000/01

| Cover crop | 0 – 75 DAPC | 75 DAPC – 0 DAPM | 0 – 21DAPM | 0 – 35DAPM |
|---|---|---|---|---|
| Weed fallow | -45 | -31 | -2 | -88 |
| Cowpea | -39 | 36 | -32 | -88 |
| Lablab | -42 | 23 | -39 | -87 |
| Mucuna | 2 | 45 | -30 | -78 |
| Pumpkin | -36 | 19 | -27 | -94 |

DAPC = Days after cover crop planting
DAPM = Days after maize planting

Appendix 13: Changes in $NH_4^+$ - N in the top 0 – 20 cm at the end of the short and in the long rains of 2000/01 season.

| Cover crop | 0 -75DAPC | 75DAPC - 0DAPM | 0 - 21DAPM | 21 - 35DAPM |
|---|---|---|---|---|
| | .....Change (%)..... | | | |
| Weed fallow | 29 | -94 | 42 | 45 |
| cowpea | 50 | -76 | -19 | -23 |
| Lablab | 40 | -80 | -36 | -5 |
| Mucuna | 89 | -63 | -41 | -53 |
| Pumpkin | 89 | -51 | -15 | -85 |

DAPC = Days after cover crop planting
DAPM = Days after maize planting

Appendix 14: Changes in $NO_3^-$ - N in the top 0 – 20 cm at the end of the short and in the long rains of 2000/01 season.

| Cover crop | 0 -75DAPC | 75DAPC - 0DAPM | 0 - 21DAPM | 21 - 35DAPM |
|---|---|---|---|---|
| | .....Change (%)..... | | | |
| Weed fallow | -79 | 321 | 0 | -94 |
| cowpea | -82 | 960 | -33 | -93 |
| Lablab | -70 | 418 | -40 | -90 |
| Mucuna | -32 | 162 | -29 | -79 |
| Pumpkin | -83 | 645 | -22 | -96 |

DAPC = Days after cover crop planting
DAPM = Days after maize planting

Appendix 15: Effect of cover crops on $NO_3^-$ - N levels in first 35 days of the long rains 2000/01.

| | Bulk density | Days after planting 0 | 35 | 0 | 35 | Change 0 - 35 | |
|---|---|---|---|---|---|---|---|
| Cover crop | Mg $m^{-3}$ | .....mg $kg^{-1}$..... | | .....kg $ha^{-1}$... | | kg $ha^{-1}$ | % |
| Fallow | 1.47 | 31 | 2 | 91 | 5 | 86 | 94 |
| Cowpea | 1.45 | 46 | 3 | 133 | 9 | 124 | 93 |
| Lablab | 1.45 | 54 | 6 | 156 | 16 | 140 | 90 |
| Mucuna | 1.52 | 44 | 9 | 134 | 28 | 106 | 79 |
| Pumpkin | 1.51 | 30 | 1 | 91 | 3 | 88 | 96 |

kg $NO_3^-$ - N $ha^{-1}$ = mg $NO_3^-$ - N $kg^{-1}$ * bulk density *10 000$m^2$/(5*10)$m^2$*10/100

Appendix 16: Soil $NH_4^+$ at planting and at harvesting of the cover crops and during maize growing period in 2000/01.

| | Days after planting CC | | Days after maize planting | | |
|---|---|---|---|---|---|
| Cover | 0 | 75 | 0 | 21 | 35 |
| crops | Soil $NH_4^+$ (mg $kg^{-1}$) | | | | |
| Weed fallow | 15.9 | 20.5 | 1.2 | 1.7 | 2.4 |
| cowpea | 12.2 | 18.3 | 4.4 | 3.5 | 2.7 |
| Lablab | 11.8 | 16.6 | 3.3 | 2.1 | 2.0 |
| Mucuna | 9.8 | 18.5 | 6.8 | 4.0 | 1.9 |
| Pumpkin | 8.6 | 16.3 | 7.9 | 6.7 | 1.0 |
| Lsd | | 11.7 | 8.7 | 6.2 | 3.3 |
| CV | | 41 | 66 | 83 | 38 |

Appendix 17: Nitrate levels in the top 0 –20 cm soil layer at 7 and 75 DAPC and changes between the two dates crop planting in 2002/03 season.

| | Days after cover crop planting 0 | 75 | Change 0-75 |
|---|---|---|---|
| Cover crops | .....mg $kg^{-1}$..... | | .....%..... |
| Cowpea | 16.9 | 11.2 | -5.7 | -34 |
| Lablab | 14.2 | 12.9 | -1.3 | -9 |
| Mucuna | 20.6 | 18.2 | -2.4 | -12 |
| Pumpkin | 16.3 | 7.7 | -8.6 | -53 |
| Weed fallow | 14.6 | 10.6 | -4.0 | -27 |
| Bare | 16.4 | 14.2 | -2.2 | -13 |

Appendix 18: Soil $NH_4^+$ and $NO_3^-$ profiles at the end of 2001/02 cover crop/maize growing period.

| | $NH_4^+$ - N | | | | | $NO_3^-$ - N | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Soil depth (cm) | | | | | | | | | |
| Cover | 20 | 40 | | 60 | | 20 | 40 | | 60 | |
| Crops | ..... mg $kg^{-1}$ ..... | | | | | | | | | |
| Bare fallow | 7.23 | (-3.50) | 3.73 | (2.80) | 6.53 | 10.5 | (2.9) | 13.4 | (-10.6) | 2.8 |
| Cowpea | 8.17 | (-0.70) | 7.47 | (-1.40) | 6.07 | 9.3 | (-1.4) | 7.9 | (2.1) | 10.0 |
| Lablab | 8.40 | (-1.87) | 6.53 | (5.60) | 12.13 | 4.2 | (0) | 4.2 | (-0.2) | 4.0 |
| Mucuna | 8.87 | (0.47) | 9.33 | (-1.87) | 7.47 | 6.3 | (-0.2) | 6.1 | (2.8) | 8.9 |
| Pumpkin | 8.40 | (-3.27) | 5.13 | (0.93) | 6.07 | 5.4 | (0.8) | 6.2 | (-4.8) | 1.4 |
| Weed fallow | 11.20 | (-5.13) | 6.07 | (7.47) | 13.53 | 4.5 | (4.6) | 9.1 | (-6.5) | 2.6 |
| Lsd | 2.60 | | 1.67 | | 2.78 | 1.37 | | 4.13 | | 2.43 |
| CV | 18 | | 15 | | 18 | 11 | | 31 | | 27 |

Numbers in the bracket show $NH_4^+$ - N change between adjacent depths.

Appendix 19: Soil $NH_4^+$ and $NO_3^-$ profiles at the end of 2002/03 cover crop/maize growing period.

| | $NH_4^+$ - N | | | | | $NO_3^-$ - N | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Soil depth (cm) | | | | | | | | | |
| Cover | 20 | 40 | | 60 | | 20 | 40 | | 60 | |
| Crop | ..... mg $kg^{-1}$ ..... | | | | | | | | | |
| Bare fallow | 7.00 | (3.27) | 10.27 | (0.93) | 11.20 | 5.8 | (6.3) | 12.1 | (-8.4) | 3.7 |
| Cowpea | 7.00 | (5.25) | 12.25 | (1.75) | 14.00 | 7.8 | (-2.2) | 5.6 | (0) | 5.6 |
| Lablab | 7.00 | (2.33) | 9.33 | (3.27) | 12.60 | 4.7 | (0.4) | 5.1 | (-1.8) | 3.3 |
| Mucuna | 9.45 | (-1.05) | 8.40 | (6.53) | 14.93 | 4.7 | (-1.9) | 2.8 | (0.5) | 3.3 |
| Pumpkin | 8.40 | (0.00) | 8.40 | (5.60) | 14.00 | 6.5 | (1.7) | 8.2 | (-1.6) | 6.6 |
| Weed fallow | 7.93 | (0.93) | 8.87 | (7.00) | 15.87 | 7 | (-1.9) | 5.1 | (0) | 5.1 |
| Lsd | 3.52 | | 5.04 | | 6.04 | 4.82 | | 7.04 | | 3.9 |
| CV | 24 | | 28 | | 23 | 48 | | 59 | | 46 |

Numbers in the bracket show $NO_3^-$ - N change between adjacent depths.

Appendix 20: Maize grain yield as affected by cover crops grown in the short rains.

| Cover crop | 2000/01 | 2001/02 | 2002/03 | overall mean | 01&03 mean | overall mean | 01&03 mean |
|---|---|---|---|---|---|---|---|
| | Maize grain yield ($kgha^{-1}$) | | | | | Increase (%) | |
| Cowpea | 2200 | 372ab | 742cd | 1105 | 1471 | 22 | 14 |
| Pumpkin | 1900 | 142bc | 809c | 950 | 1355 | 5 | 5 |
| Weed fallow | 2200 | 74c | 603d | 959 | 1402 | 6 | 9 |
| Lablab | 2100 | 285abc | 1649b | 1345 | 1875 | 48 | 46 |
| Bare | 1800 | 154bc | 771cd | 908 | 1286 | | |
| Mucuna | 2100 | 442a | 1933a | 1492 | 2017 | 64 | 57 |
| Lsd | 425 | 212 | 276 | | | | |
| CV (%) | 18 | 47 | 14 | | | | |

Appendix 21: Correlation coefficients (r) relating infiltration rate and sorptivity to soil soil aggregates, bulk density, and cover crops biomass

| | Soil aggregate size fraction | | Bulk | Above ground |
|---|---|---|---|---|
| | 53-250 µm | >250 µm | density | biomass |
| Basic infiltration rate | 0.337 ns | -0.308 ns | 0.225 ns | 0.274 ns |
| Sorptivity | -0.170 ns | 0.193 ns | 0.019 ns | 0.637 * |

ns = not significant at P = 0.05
* = Significant at P = 0.05

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