

**NITROGEN FERTILIZER EQUIVALENCY VALUES FOR
ORGANIC MATERIALS OF CONTRASTING QUALITIES
BASED ON MAIZE PERFORMANCE AT KABETE, KENYA**

By

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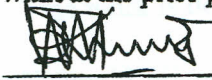
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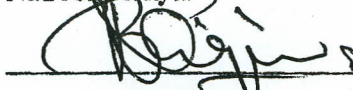
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DEDICATION

This work is dedicated to my beloved parents Mr. Edward K. Nguku and Mrs. Esther N. Kimetu for their commitment and sacrifice towards my education.

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ABSTRACT

Decline in food production has been a major problem facing smallholder farming in Kenya and the entire Sub-Saharan region. This is attributed mainly to the mining of major nutrients due to continuous cropping without external addition of adequate nutrients. Inorganic fertilizers are expensive hence unaffordable by most smallholder farmers. Although organic nutrient sources are available, information about the right proportions of application is scanty.

A completely randomized block experiment was set up in 1999 at the National Agricultural Research Laboratories (NARL) at Kabete with the overall objective of determining nitrogen fertilizer equivalencies based on high quality organic inputs. The specific objectives of the study included determination of the nitrogen fertilizer equivalency values of *Tithonia diversifolia*, *Senna spectabilis* and *Calliandra calothyrsus* and the investigation of nitrogen use efficiency from combined organic and inorganic inputs. The effect of the organic material on the soil chemical properties was also investigated.

The experiment consisted of maize plots to which freshly collected leaves of *Tithonia diversifolia* (tithonia), *Senna spectabilis* (senna) and *Calliandra calothyrsus* (calliandra) (all with % N >3) obtained from hedgerows grown *ex situ* (biomass transfer from outside) and urea (inorganic nitrogen source) were applied. Results obtained indicated that a combination of both organic and inorganic nutrient source gave higher maize grain yield than when each is applied separately, except for tithonia whose sole application gave better grain yield than

a combination of the same with mineral fertilizer. Maize grain yield production after organic and inorganic application was in the order of tithonia > tithonia+urea = calliandra+urea > urea > senna+urea > calliandra > senna > control. The percentage N recovery was highest in sole application of urea followed by a combination of both urea and tithonia while sole application of tithonia biomass had relatively lower percentage N recoveries. In both seasons, the mineral N content was high in sole application of tithonia than in senna and calliandra treatments. The three organic materials (senna, calliandra and tithonia) gave fertilizer equivalency values of 68%, 72% and 130% respectively.

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ABBREVIATIONS

N	Nitrogen
SS	<i>Senna spectabilis</i>
CC	<i>Calliandra calothyrsus</i>
TD	<i>Tithonia diversifolia</i>
FE	Fertilizer equivalency
WAP	Week(s) after planting
N ₂ O	Nitrous oxide
CO ₂	Carbon dioxide
CH ₄	Methane
NH ₄ ⁺	Ammonium
NH ₃	Ammonia
NO ₃ ⁻	Nitrate
P	Phosphorus
Ca	Calcium
Mg	Magnesium
K	Potassium
ha	Hectare
ICRAF	International Center for Research in Agroforestry
<u>N</u> KCl	Normal Potassium chloride
Cd	Cadmium
Dy	Slope; 'E' 'S' Degrees East and degrees South respectively

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background information

Decline in soil fertility is an acute problem facing smallholder farming in Kenya. Due to the high cost and the uncertainty in the availability of inorganic fertilizers, it is important to provide alternative sources of nutrients such as organic materials that are readily available. In the recent past there has been increased interest in the use of leafy biomass from woody perennials as a source of nutrients to annual crops (Kang, et al., 1990; Palm et al., 1997; Mugendi, et al., 1999). The big challenge to this approach is ensuring that crops efficiently utilize nutrients from the applied organic materials. Synchronizing release of nutrients from decomposing biomass with crop demand could lead to increased nutrient-use efficiency (Becker et al., 1994; Mwale et al., 2000b), and this in turn could minimize nutrient loss (Swift, 1987; Myers et al., 1994; Mugendi et al., 1999).

The use of organic materials of differing quality in combination with inorganic fertilizers to optimize nutrient availability to annual crops is the challenge to scientists currently. This is mainly due to the varied roles and complexity of organic materials. It is therefore important to understand how nutrient content and carbon quality of organic materials may influence nutrient availability from inorganic or organic fertilizers (Palm et al., 1997). Murwira et al. (2002) predicted that the performance of organic resources as compared to inorganic fertilizers (fertilizer equivalency of organics) is positively

correlated to the N content in the organic material. However, to improve the predictability this needed more research.

Much research has been done to determine the use of organic plant materials as a source of nutrients in place of inorganic fertilizers and most of this research has revealed both advantages and disadvantages of combining nutrient sources (Palm et al., 1997). However, information on nutrient content and quality of organic inputs used is often lacking (Mutuo et al., 1999) and thus, little predictive understanding for the management of organic inputs especially in tropical agroecosystems is available (Palm et al., 2001). It has been therefore difficult to give valid advice to farmers on the best organic N source for direct application and the right combinations with inorganic N source.

1.2 Problem statement and Justification

Although organic N sources have the potential to supply large quantities of N required by growing crops, to obtain maximum production, they should be supplemented with inorganic fertilizers (Mugendi, 1997; Jama et al., 2000; Vanlauwe et al., 2001). The combination of inorganic N fertilizer with organic N sources is said to increase the rate of decomposition and mineralization (Mugendi et al., 1999) of low quality materials. This coupled with the right time of application can improve synchrony of the N released from the decomposing biomass and annual crop demand thereby reducing N losses. This postulation is however, yet to be ascertained. This research was therefore aimed at shedding light on the combined use of organic (*Tithonia*

diversifolia (Hemsl.) A.Gray; *Senna spectabilis* (D.C) H.S Irwin and R.C Barneby; and *Calliandra calothyrsus*, Meissner) and inorganic N sources as well as providing guidelines for the use of the same for farmers in the central region of Kenya. In addition, the study has provided information to link the fertilizer equivalency of organic materials (specific amount of an organic material that can have same effect on crop yield as a certain amount of inorganic fertilizer) with the resource quality as well as identifying the pathways in which nitrogen is lost from the rooting zone minimizing the amount available for plant uptake.

1.3 Research questions

The study aimed at answering the following questions: -

1. Can inorganic nitrogen sources be replaced supplemented with organic nitrogen sources?
2. What amount of organic nitrogen input is required to have equal effect as a given amount of inorganic nitrogen fertilizer and is this related to the organic input quality?
3. Can a combination of both organic and inorganic nutrient sources give better crop yields than sole application of equal nutrient levels?
4. What effect do organic materials have on soil chemical properties?
5. What is the influence of the N sources on N losses through volatilization, denitrification and leaching?

1.4 Hypotheses

From the above questions, the following hypotheses were formulated for testing:

1. Inorganic fertilizers cannot be replaced with cheaper and more readily available organic nutrient sources and give better crop yield even in small scale farming.
2. Fertilizer equivalencies of organic materials are not related to input quality.
3. Combined use of organic and inorganic nitrogen sources does not increase N use efficiency.
4. Use of organic N sources will not reduce N losses as well as help improve soil chemical properties.

1.5 Objectives of the study

The main aim of this study was to determine the nitrogen fertilizer equivalency values of high quality organic materials and establish their optimum combination with inorganic N source and the effect on maize yield.

The specific objectives of this study were: -

- (1) To determine the nitrogen fertilizer equivalency values of *Tithonia diversifolia*, *Senna spectabilis* and *Calliandra calothyrsus*.
- (2) To investigate the effect of organic, inorganic, or combined N sources on maize grain and biomass yields and nitrogen use efficiency.
- (3) To determine the effects of N sources on soil chemical properties and N losses via denitrification and leaching.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Potential of organic materials for soil fertility management

The major factor contributing to crop yield decline in smallholder farming in the tropics is soil fertility decline. This is due to continuous cropping with inadequate addition of external nutrient inputs especially nitrogen (N) which is one of the most limiting nutrients to crop production (FAO, 1990; Mugendi et al, 1999). One of the approaches that has been used in soil fertility management is use of biological processes to optimize nutrient cycling, minimizing the need for mineral nutrient inputs and maximizing the efficiency of their use. One approach to this strategy is to incorporate organic materials into the soil. However, due to their limited supply, organic materials alone might not be enough to offer sufficient nutrients to sustain crop yields and build soil fertility (Palm et al., 2001). Larger crop yield improvements could be attained with mineral fertilizers though from a nutrient conservation point of view, organic materials are preferred to inorganic fertilizers (Lehmann et al., 1999). Therefore, a more practical and sustainable approach to soil fertility management in Sub Saharan Africa might be combining organic and inorganic nutrient sources. There is need for more research to be done to ascertain this hypothesis. Several trials have shown better results from combined inorganic and organic nutrient sources compared to either input alone (Palm et al., 1997), however, this has not been tried for different organic nutrient sources readily available to smallholder farmers.

In addition to soil nutrient balance restoration, organic matter has potentially other functions in the soil (Chen and Avnimelech, 1986; Wallace, 1996; Mutuo et al., 1999). The added organic matter induces changes in the physical properties of soils especially soil structure, and this effect is of prime importance in intensive agriculture. Not only do organic materials add nutrients to the soil, but also influence mineralization-immobilization patterns in the soil as well as providing energy for microbial activities and helping in reducing phosphorus (P) sorption of the soil (Palm, et al., 1997; Jama et al., 2000).

2.2 Organic Resource Quality

Decomposition and nutrient release patterns from organic materials is dependent on chemical composition of the plant tissues (Swift et al., 1979) among other factors. Initial N content of the biomass, C: N ratio, lignin content, and polyphenol and its ratios with N are the main chemical qualities that determine decomposition rates of an organic material hence nutrient release (Mafongoya et al., 1998). Reasonable predictions about decomposition rates of plant materials that are commonly used in agroforestry systems can therefore be made by understanding the chemical composition of the different plant materials (Nair et al., 1999). Mafongoya et al. (1998) states that less lignified leaves (e.g. those of *Gliricidia sepium* and *Sesbania* species) included in this study will decompose quickly and release a large portion of their N while highly lignified leaves (e.g. those of *Dactyladenia barteri* and *Flemingia macrophylla*) will decompose slowly and may cause immobilization

of soil N. The decomposition pattern of biomass of species with high N and polyphenol contents may also be governed by the protein-binding capacity of the polyphenols; decomposition being rapid when protein-binding capacity is low as in some provenances of *Leucaena leucocephala* and slow when protein-binding capacity is high as in *Calliandra calothyrsus* (also included in this study).

Palm et al. (2001) reported that organic materials of different quality can be utilized in different ways for proper soil nutrient replenishment, whereby leafy biomass with N content greater than 2.5%, lignin content less than 15% and polyphenol content less than 4% can be incorporated directly into the soil. For organic materials with N content above 2.5%, lignin content more than 15% and polyphenol content greater than 4%, the recommendation is to mix the organic materials with N fertilizer or with another high quality organic material. The recommendation for organic materials with N content less than 2.5% and lignin content less than 15% is to mix it with N fertilizer or add to compost. Those organic materials with N content less than 2.5% and lignin content greater than 15%, they are recommended for surface application for weed, erosion, and water control (Palm et al., 1997; Mutuo et al., 1999; Delve et al., 2000; Palm et al., 2001). Research is therefore required to validate the Organic Resource Database (ORD) decision support tool using above mentioned organic materials (*Tithonia diversifolia*, *Calliandra calothyrsus* and *Senna spectabilis*) and to ascertain the appropriate proportions to combine the same with inorganic fertilizers for the best maize yields.

2.3 Decomposition of organic materials and nutrient-use efficiency and recovery

Decomposition of organic materials can be manipulated to improve the efficiency of uptake and utilization of nutrients by growing crops (Nair et al., 1999). One of the main strategies suggested by Mafongoya et al. (1998) is to regulate the rate of nutrient release to improve the synchrony of nutrient supply with crop demand. This is called the "synchrony concept" and as stated by Swift (1987), it is an issue of great concern in current research. Improved synchrony will enhance nutrient-use efficiency by minimizing the loss of nutrients (Becker et al., 1994; Myers et al., 1994; Nair et al., 1999) from the plant-soil system and this will help in achieving higher crop yield (Pang and Letey, 2000). Combination of organic and inorganic nutrient sources at the right proportions could be a solution to this (Palm et al., 1997).

Nair et al. (1999) suggest that there are some field operations that can be used to alter decomposition rate of organic materials hence improving synchrony. These include: (1) state of the material before application (fresh prunings decompose faster than sun-dried prunings); (2) the physical size of the material (small-sized or ground materials decompose faster than larger and coarser materials) (Thonnissen et al., 2000); (3) mixing of biomass of differing compositions, and, (4) the method of applying the materials (incorporating materials into the soil results in faster decomposition than surface placement).

Nutrient recovery from organic materials or mineral fertilizers is the extent to which nutrients are taken up by the current and subsequent season's crops (Nair et al., 1999). Many leguminous tree species used in agroforestry

systems, especially alley cropping and biomass transfer systems are capable of producing substantial quantities of biomass through which nutrients are recycled in quantities sufficient to support crop growth (Young, 1989; Szott et al., 1991; Palm, 1995; Nair et al., 1999).

Palm (1995) reported that organic materials from most multipurpose trees (MPTs) (for example *Leucaena leucocephala*, *Senna siamea*, *Inga edulis* and *Erythrina poeppigiana*) are good sources of nutrients especially nitrogen. After decomposition, the amount of nitrogen released from these organic inputs can be sufficient to meet crop requirements. However, with some tree species like *Calliandra calothyrsus* and *Leucaena leucocephala*, the highest amounts of mineralized N were obtained only at four weeks after planting maize (Mugendi et al., 1999). This implies that, though the decomposing biomass is capable of releasing enough mineral N for the growing crop, synchronizing the same with the crop demand is an essential aspect (Mwale et al., 2000b) which needs more research.

2.4 Nitrogen Losses

One of the aims of synchrony is to minimize the loss of nutrients, therefore it is necessary to understand how N source and management affect N losses. Significant amount of nitrogen (N) is lost directly and indirectly from both organic materials and mineral fertilizers when applied to the soil (Loomis and Connor, 1992). Some of the major processes through which N is lost from the plant-soil system include denitrification, leaching, and volatilization. Soils are the major contributor to the global budget of N_2O , especially the humid

tropical soils (Veldkamp et al., 1999). This gas can be produced by nitrification, denitrification or dissimilatory nitrate reduction to ammonium (Stevens et al., 1998). It is a powerful greenhouse gas with 300 times the effect of each molecule of carbon dioxide (CO₂) and it contributes to depletion of the ozone in the stratosphere (Weiss, 1981; Cicerone, 1987). There is little information of the magnitude of the various losses from tropical soils under different management regimes and soil types.

2.4.1 Denitrification

Denitrification refers to nitrate reduction to gaseous nitric oxide (NO), nitrous oxide (N₂O) or dinitrogen gas (N₂) and this mainly takes place under anaerobic conditions by several bacteria (Loomis and Connor, 1992; Singh and Vaje, 1998; Brady and Weil, 1999) resulting in a net N loss from the system. These N gas losses can be reduced significantly through better soil and fertilizer management. Lehmann et al. (1999) reported that the rate of N loss was lower with mulches compared to inorganic N source and attributed their findings to microclimate amelioration by the organic material. They also observed higher rates of N loss with application of ammonium sulphate [(NH₄)₂SO₄] fertilizer compared to *Acacia saligna* mulches in a study in the dry tropical savanna of northern Kenya. Matson et al. (1998) working on wheat in Mexico found that a reduction of gaseous loss of N from about 14 kg N/ha to almost zero could be attained by improved system management. This depicts that organic inputs can be used to minimize gaseous N losses. However, other studies have shown higher denitrification losses with organic

as compared to mineral fertilizers (Janzen and Schaalje, 1992) but more research to ascertain this is needed especially for different agroecological zones, soil types and different organic materials.

2.4.2 Leaching

Nitrogen in nitrate form (soluble in water) is loosely held by soil particles and can easily be washed down the soil profile (Loomis and Connor, 1992; Singh and Vaje, 1998; Pang and Letey, 2000). This leaching is highly dependent on the soil type, rainfall intensity (Brady and Weil, 1999), amount of fertilizer applied and timing (Freney and Simpson, 1983; Singh and Vaje, 1998). Loomis and Connor (1992) observed that under high rainfall amounts, much N is lost through leaching especially at the beginning of the wet season within the first two weeks (Hagedorn et al., 1997), before the annual crop establishes a rooting system and has little nutrient demand. However, substrate quality is said to influence decomposition and subsequent nutrient release hence affecting nutrient leaching from organic inputs (Seneviratne et al., 1998; Lehmann et al., 1999). There is need therefore, for more research to establish the patterns in which nitrogen (in form of nitrate) is leached down the soil profile under different management practices, different agroecological zones and with organic inputs of different quality.

2.4.3. Volatilization

Nitrogen loss in the form of ammonia gas and its volatilization is mainly a soil surface phenomenon that is more pronounced in alkaline

environments (Glasener and Palm, 1995; Singh and Vaje, 1998). Loomis and Connor (1992) noted that at pH 5.0 and below, about 0.004% of the nitrogen is present as free NH_3 but that fraction increases approximately 10-fold with each unit increase in pH. Thus at pH 9.0, about 40% of the total nitrogen available in form of NH_3 is volatilized. Kumar et al. (1994) noted considerable reduction in NH_3 losses by application of *Sesbania aculeata* leaves as compared to mineral fertilizer application. Glasener and Palm (1995) found a maximum of 11.8% N loss via volatilization on a soil with pH 4.5. This was reduced to zero with incorporation of the organic materials.

Research need

The nutrient uptake and loss pathways highlighted above such as crop harvesting and runoff have been noted to be the principal ways through which about 89% of the N applied in the soil is lost (Peoples et al., 1995). Most annual crops are capable of recovering only about 20-50% of the N applied (Paroda et al., 1994) or lower (Mugendi et al., 2000) depending on the form in which the fertilizer is applied (inorganic or organic). These losses influence the performance of organic resources compared to inorganic nutrient sources. More research is needed to establish the amount of N lost through each of the pathways and work on ways and means of minimising the same.

CHAPTER THREE

3.0 RESEARCH METHODOLOGY

3.1 Site Description

The experiment was carried out at the National Agricultural Research Laboratories (NARL), Kabete, Kenya. The station is located at 36° 46'E and 01° 15'S and an altitude of 1650 m above sea level. The soils are mainly Humic Nitisols (FAO–UNESCO-classification, 1990) that are deep and well weathered. The soil pH is 5.4, total N 1.35g kg⁻¹, extractable P 27mg kg⁻¹, carbon 1.6%, exchangeable Ca, Mg, and K (cmol kg⁻¹) 5.8, 1.7, and 0.7 respectively, clay 40%, sand 23%, and silt 37%. The mean annual rainfall is about 950 mm received in two distinct rainy seasons; the long rains (LR) received mid March to June and the short rains (SR) received mid October to December (Appendix 4). The average monthly maximum and minimum temperature is 23.8°C and 12.6°C respectively.

3.2 Experimental design and treatments

The experimental research was designed and established by Tropical Soil Biology and Fertility (TSBF) programme in 1999 with the aim of determining fertilizer equivalency values based on high quality organic materials (Table 3.1a & b). The experiment was a completely randomised block design (CRBD) with 10 treatments (Table 3.2) replicated 4 times (appendix 1). The plot size was 5.25 m by 5 m with an interplot spacing of 0.75 m. Schedule of activities done during the study period is shown in appendix 2.

Table 3.1a: Chemical properties for three selected plant materials used (1999 short rains) at NARL, Kabete, Kenya

Sample	%N	%P	%Ca	%K	%Mg	%PP	%Lignin
Tithonia	4.7	0.5	3.0	5.1	0.2	2.5	5.2
Senna	3.7	0.2	0.9	2.0	0.2	3.4	10.7
Calliandra	3.2	0.1	1.1	1.0	0.3	9.9	14.4
sed	0.2	0.03	0.3	0.3	0.1	1.0	1.8

Table 3.1b: Chemical properties for three selected plant materials used (2000 long rains) at NARL, Kabete, Kenya

Sample	%N	%P	%Ca	%K	%Mg	%PP	%Lignin
Tithonia	4.0	0.4	2.2	5.5	0.4	1.9	9.3
Senna	3.1	0.1	0.9	1.8	0.2	1.8	10.9
Calliandra	2.4	0.1	1.1	0.7	0.3	12.4	17.5
sed	0.2	0.03	0.3	0.3	0.1	1.0	1.8

Abbreviations: PP= Polyphenols

Sed = Standard error deviation

(Source: This study, unpublished data)

Table 3.2: Experimental Treatments for the experimental trial at NARL Kabete, Kenya.

Trt.	Inorganic N (Kg ha ⁻¹)	Organic N (kg ha ⁻¹)
1. * (Control)	0	0
2.	30	30 (50% TD)
3.	0	60 (100% TD)
4. *	60	0
5.	30	30 (50% SS)
6.	0	60 (100% SS)
7.	30	30 (50% CC)
8.	0	60 (100% CC)
9. *	35	0
10. *	100	0

* These are the treatments that were used in plotting of the response curve, which was used in the calculation of the nitrogen fertilizer equivalency values of the three organic inputs. The percentages (%) refer to the specific amount of nitrogen (N) that was applied as organic or inorganic source. In this experiment, the rate of N applied for the combined nutrient sources was 60 kg N ha⁻¹ (100%) and this was added every season.

3.2.1 Plant material selection

The selection of *Tithonia diversifolia* (TD), *Senna spectabilis* (SS) and *Calliandra calothyrsus* (CC) as the organic N sources was based on their contrasting qualities with respect to polyphenols and rates of decomposition (Gachengo et al., 1999). *Calliandra calothyrsus* (11.1% polyphenol on average) had the highest polyphenol quantity followed by *Senna spectabilis* with an average of 2.6% and *Tithonia diversifolia* had the lowest polyphenol content (2.2%) (Mutuo et al., 1999). Lignin contents also decreased in the same order i.e. *Calliandra calothyrsus*, *Senna spectabilis*, and *Tithonia diversifolia* (14.4%, 10.7% and 5.2% respectively). Therefore, due to the high polyphenol and lignin contents in calliandra (Lehmann et al., 1999), the decomposition rate is lower than in tithonia whose polyphenol and lignin contents are low hence decomposes at a faster rate than calliandra (Palm et al., 2001). Decomposition rate in senna biomass is moderate because its lignin and polyphenol contents are intermediate to those of tithonia and calliandra. The chemical characteristics of these three organic inputs used for the two cropping seasons are shown in Tables 3.1a & b.

3.2.2 Experimental Treatments

Collection of the materials was done by hand at the same location for both seasons, i.e., along Thika road (Githurai area) for tithonia, and Muguga for senna and calliandra. The leaves included the petioles, and in the case of senna and calliandra, they also included the rachis since these two have compound leaves. The calculation of the application amount of organic

materials (that would give 60 kg N ha⁻¹) (Table 3.2) was done on dry matter basis giving 1.3 t ha⁻¹, 1.8 t ha⁻¹ and 1.9 t ha⁻¹ for tithonia, senna and calliandra respectively.

3.4 Field Methods

3.4.1 Application of N sources and planting

Tilling was done at 10 cm depth using hand hoes in both seasons before planting. Organic materials (freshly collected leaves of *Tithonia diversifolia*, *Senna spectabilis* and *Calliandra calothyrsus*) were applied each season, broadcasted and incorporated by hand in the top 10 cm of soil prior to planting. Urea was applied according to normal practice (split application); a third of the total amount applied before planting while two thirds was applied five weeks after planting. Maize (*Zea mays* L.), hybrid 511 and hybrid 512 for season one and season two respectively, was planted at the spacing of 75 cm by 25 cm (giving a population of 53,333 plants per hectare). This gave seven rows per plot each containing 20 holes totaling to 140 plants per plot.

3.4.2 Trial Management

Since organic materials supply other macronutrients like potassium (K) and phosphorous (P) which ultimately affect maize yields (Jama et al., 2000), both nutrients were applied in all the plots in non-limiting quantities (100 kg P ha⁻¹ and 100 kg K ha⁻¹), in each season as a way of eliminating these confounding effects. This way, it was assumed that nitrogen (N) was the only

macronutrient limiting maize yields. The phosphorous and potassium fertilizers used were triple super phosphate (TSP) and muriate of potash (MOP) respectively.

3.4.3 N availability and losses

3.4.3.1 Soil sampling

Soil N dynamics, both in terms of N availability in the topsoil and N movement through the profile were determined by consecutive soil samples through the cropping season.

Soil was sampled at 0-10 cm depth in all plots twice in each season (before treatment application and at harvesting). In addition to this, three treatments (control, tithonia and urea) were sampled one and four week(s) after planting. Deeper sampling was also done in these three selected treatments at tassling stage and at the end of each season. These treatments were sampled upto 300 cm depth at the intervals of 0-10 cm, 10-30 cm, 30-60 cm, 60-90 cm, 90-120 cm, 120-150 cm, 150-180 cm and 180-300 cm. This was done to enable comparison of changes in mineral N at different soil profiles with time. All soil samples were taken for soil moisture content, extractable NH_4^+ and NO_3^- determination. In determining the amount of N leached down the soil profile, soil sampled from treatments 1, 3 and 4 at depth upto 300 cm was analyzed for extractable nitrate and ammonium. This enabled determination of N-loss through leaching in organic (TD) and urea treatments.

3.4.3.2 Gas sampling

Nitrous oxide emissions were determined in selected treatments (1, 3 and 4) before planting, one week after planting, and four weeks after planting. This was to enable comparison of nitrogen loss in gaseous form in *Tithonia diversifolia* and urea treatments.

Polyvinylchloride (pvc) chambers with internal diameter of 30.5 cm and a height of 10 cm were used for measuring gas fluxes. The top of each chamber had a brass-sampling valve fitted with a teflon septa. A base was constructed using pvc tubes about 6 cm in height where one end was expanded to enable the chamber to fit tightly. The bases were driven to a depth of 3 cm in the soil 24 hours before gas sampling to ensure that disturbed soil had settled. At the beginning of each sampling period the chamber was placed into the permanent pvc base. A hole was opened in the chamber's top during placement to avoid creating overpressure, a rubber bung was placed in the hole once the chamber was situated in the permanent base. Samples were collected from the chamber headspace with 50 mL polypropylene syringes at 0, 10, 20, and 40 minutes following chamber closure. Thirty mL of each sample was injected into 20 mL evacuated glass vials (Labco Exetainer). The vials sampled were properly labeled with plot descriptions and time of sampling and then sent to USDA/ARS laboratory in Fort Collins, CO, USA for N₂O analysis which was done using gas chromatography method. Data entry sheet for the gas sampling is shown in appendix 3.

3.4.3.3 Maize harvesting

Maize was harvested about six weeks before maturity for season one (due to poor rainfall distribution), while for season two harvesting was done at maturity and net plot yield considered. Harvesting area was determined separately for the two seasons. In the first season, harvesting was done on whole plots with two outer rows and two outer plants being left out to minimize edge effects. Thus, harvesting area was 9.0 m² (out of the total area of 26.25 m²). In the second season, one guard row on each side and two outer plants on each row were left out to eliminate edge effects. This gave a harvest area of 15.0 m².

During the second season, which was relatively better, the cobs in the harvested area were separated from the stover in the standing crop. The cobs from each plot were put in a bag and total fresh weight taken. Fresh weight of the subsample was determined then dried at 60°C to attain constant weight. To obtain the net grain yield, the grains were separated from the core by hand shelling then each subsample weighed separately. The stover was cut at ground level and total fresh weight taken then sorted according to sizes (small, medium and large). A plant was picked from each class to form a subsample. The fresh weight of the subsample was recorded then dried at 60°C for about 3 days until a constant weight was attained.

Total yield was determined as follows:

$$\text{Yield (t/ha)} = [10 \times (\text{TFW} \times \text{SSDW})] / (\text{Ha} \times \text{SSFw})$$

Where: TFW= Total fresh weight (kg)

SSDW= Sub-sample dry weight (g)

HA= Harvest area (m²)

SSFW= Sub-sample fresh weight (g)

The grain yield on dry matter basis was determined as:

$$\text{Grain yield (t/ha)} = \text{Yield} \times (\text{GDW} / \text{SSDW})$$

Where: Yield = Total yield calculated (t/ha)

GDW = Grain dry weight (g)

After harvesting, all the maize stover was removed from the experimental plots to ensure that no nutrients were returned to the plots with the stover so as to eliminate the confounding effects of adding a material of different quality and decomposition pattern.

3.5 Laboratory methods

3.5.1 Soil extraction

Soil extraction was done by shaking about 20 g of soil in 125 ml bottles for 1 hour in 100 mls of 2N KCl (ICRAF, 1995). The extract was filtered through whatman paper (no. 5). The filtrates were then analyzed for extractable nitrate by cadmium (Cd) reduction column method (Dorich and Nelson, 1984; Anderson and Ingram, 1993; ICRAF, 1995) and for extractable ammonium using colorimetric method (ICRAF, 1995).

3.5.1.1 Determination of extracted soil ammonium and nitrate

Ammonium-N concentration in the soil was calculated as follows:

$$\text{EXANMGKG} = \frac{(\text{EXACONC} - \text{EXABLNK}) \{100 + (\text{EXNSLWT} - \text{EXNDSWT})\}}{\text{EXNDSWT}}$$

Where: EXANMGKG = Ammonium concentration in soil (mg N/kg)
EXACONC = Ammonium concentration for sample (mg N/L)

EXABLNK = Ammonium concentration for blank (mg N/L)
 EXNDSWT = Dry weight of extracted soil (g)

Nitrate-N concentration in the soil was calculated as follows:

$$\text{EXNNMGKG} = \frac{(\text{EXNCONC} - \text{EXNBLNK}) \{100 + (\text{EXNSLWT} - \text{EXNDSWT})\}}{\text{EXNDSWT}}$$

Where: EXNNMGKG = Nitrate concentration in soil (mg N/kg)
 EXNCONC = Nitrate concentration for sample (mg N/L)
 EXNBLNK = Nitrate concentration for blank (mg N/L)
 EXNDSWT = Dry weight of extracted soil (g)

3.5.2 Soil moisture content determination

About 40 g of the soil sample was dried in an oven at 105°C for 24 hours then the dry weight of the samples taken. The moisture content was calculated using the following formula:

$$\% \text{ Moisture content} = \frac{\text{Sample fresh weight} - \text{Sample dry weight}}{\text{Sample Dry weight}} \times 100 \%$$

The moisture content so determined, was then used in the calculation of mineral N (ammonium-N and nitrate-N) content in the soil that had been extracted in 100 mls of 2N KCl as indicated above.

3.5.3 Gas analysis

Gas samples obtained from the field as explained earlier in section 3.4.3.2, were analyzed for nitrous oxide (N₂O) using gas chromatography (GC) method with electron capture detector (ECD) (Matson and Harriss, 1995). Calculation of N₂O fluxes in organic and inorganic treatments was done using the procedure described below.

Gas concentrations in parts per million (ppm) were plotted against time (0, 10, 20, and 40 minutes) for each chamber. The four replicates were plotted in one graph. The out-liers were eliminated where necessary to obtain an R^2 of the fitted line of above 0.7. Using the slopes (D_y) of the lines (concentration versus time), the fluxes were calculated as follows:

$$N_2O \text{ Flux} = D_y \times 7027.2$$

Where: D_y is the slope and
7027.2 is a constant.

The above calculations assumed a standard pressure (1 atm.) and standard temperature of 20°C or 293°K, therefore, corrections for pressure and temperature were made.

$$\text{Flux (corrected)} = \text{Gas flux} \times \frac{[\text{Pressure (bars)}/1.013]}{[\text{Temperature (°K)}/293]}$$

Matson and Harriss (1995) method was adopted in this study.

3.5.4 Plant sample analysis

Plant samples were oven-dried at 60°C for 48 hours then ground to pass through a 1.0 mm sieve and analyzed for total N, P, K, Ca, and Mg by Kjeldahl digestion with concentrated sulfuric acid (Anderson and Ingram, 1993; ICRAF, 1995). Nitrogen and phosphorus were determined colorimetrically (Parkinson and Allen, 1975) while potassium was by flame photometry (Anderson and Ingram, 1993). Magnesium and calcium was by atomic absorption spectrophotometer at wavelength of 2852 and 4227 respectively. Determination of lignin was done using the acid detergent fiber

(ADF) as described by Van Soest (1963). Total soluble polyphenols were analyzed by extraction using 50% aqueous methanol. The plant material to extractant ratio was 0.1 g / 50 ml and phenols were analyzed colorimetrically using the Folin-Ciocalteu reagent as described by Constantinides and Fownes (1994).

3.6 Data analysis

3.6.1 Fertilizer equivalency value

Fertilizer equivalencies (FE) of organic materials were obtained by comparing the yield from the organic material treatments to that of the nitrogen (N) response curve (Mutuo et al., 1999). Since the response assumed a quadratic function with the equation $Y = aFE^2 + bFE + c$, the following formula for solving quadratic equations was used:

$$FE = \frac{-b \pm \sqrt{(b^2 - 4ac)}}{2a}$$

Where a, b, and c are constants, with values -0.0001, 0.0252, and 1.8297 respectively for season one (Figure 4.1) and -0.0001, 0.0284, and 2.0827 respectively for season two (Figure 4.2).

In order to compare the fertilizer equivalencies of organic materials, the fertilizer equivalency (FE) % values were calculated according to the method employed by Mutuo et al. (1999)

$$FE (\%) = \frac{FE \times 100}{N \text{ applied}}$$

Where: N applied = actual amount of N applied.

3.6.2 Combined organic-inorganic N sources

A comparison on the effects of the various combinations of organic and inorganic N sources on soil mineral N for the different sampling dates and maize yield was done.

3.6.3 Maize yields

To compare treatment effects on maize grain yield, yields were converted to relative increase compared to the control using a method employed by Gachengo et al. (1999)

$$\text{Yield increase (\%)} = \frac{(\text{Yield}_{\text{treatment}} - \text{yield}_{\text{control}})}{\text{Yield}_{\text{control}}} \times 100$$

3.6.4 Nitrogen uptake

Nitrogen uptake by the maize crop was determined by multiplying the grain, stover and core (husk) yields with the nitrogen concentration in the specific components. Analysis was done on grain and stover samples for total N by the above described methods. The nitrogen concentration in the core was estimated from the values obtained from the stover samples. This is because, earlier research by Gachengo (unpublished data and personal communication) revealed that the nutrient contents in the stover were almost similar to concentrations of the same nutrients in the core. Mugendi (1997) also observed the same in his study in the subhumid highlands of Kenya.

Nitrogen recovery was determined as shown below:

$$\text{Nitrogen recovery (\%)} = \frac{(\text{Nitrogen uptake}_{\text{treatment}} - \text{Nitrogen uptake}_{\text{control}})}{\text{Amount of nitrogen applied}} \times 100$$

3.6.5 Statistical comparisons

Genstat 5 for windows (Release 4.1) computer package was used for statistical analysis. Treatment effects on soil N availability, N leaching, nitrous oxide emissions and maize yield were analyzed using analysis of variance (ANOVA). Treatment means found to be significantly different from each other were separated by Least Significant Differences (LSD) at $P \leq 0.05$.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.0 Introduction

This chapter presents the results for determination of the fertilizer equivalency values for *Tithonia diversifolia*, *Senna spectabilis* and *Calliandra calothyrsus* and their effect in combination with inorganic N source on maize yield and soil mineral N. The results on the effect of organic and inorganic nutrient sources on N losses and N use efficiency by maize are also included in this chapter. Analytical data obtained is summarized in tables and figures in this chapter and in the appendices.

The chapter comprises of three main sections, each of which summarizes the study findings and discussions as per the three specific objectives highlighted in section 1.5 of chapter one.

4.1 Nitrogen fertilizer equivalencies of tithonia, calliandra and senna

The first objective in this study was to establish the fertilizer equivalency values for tithonia, calliandra, and senna. The study sought to attain this by investigating the performance of maize crop supplied with green leaves from the organics as compared to maize grown with urea as N source. Results obtained from the first season showed that maize biomass yields were 3.3, 3.6 and 4.6 t ha⁻¹ for calliandra, tithonia and senna treatments respectively compared to 1.8 t ha⁻¹ obtained from control. As shown in Figure 4.1, these yields were higher than the biomass yields from any of the inorganic N source

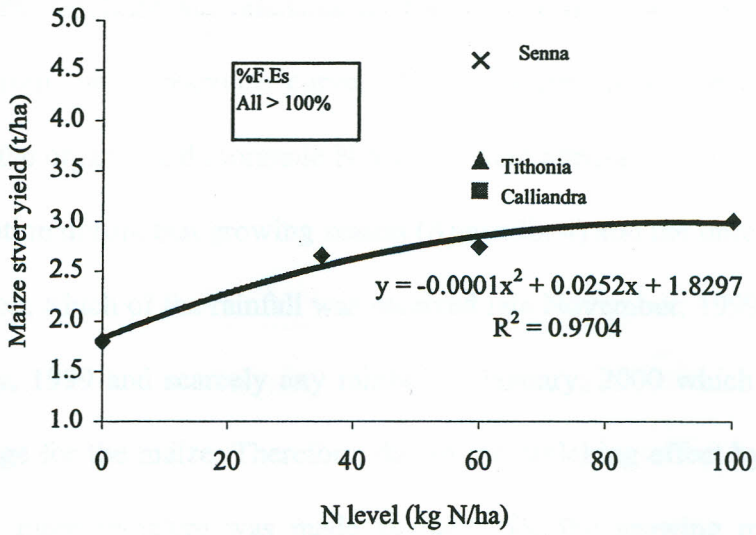


Figure 4.1: Maize biomass yield response to levels of N in 1999 short rain season at NARL-Kabete, Kenya

treatments whose highest yield was only 3.0 t ha^{-1} . Thus, the values for the yields obtained from the three organic materials fell high above the response curve. Hence, the fertilizer equivalencies for the organic materials could not be estimated from the N response curve. These differences in the yields obtained from the organic and inorganic N sources were attributed to the poor rainfall distribution during that growing season (Appendix 4) and the timing of the N application. Much of the rainfall was received late November, 1999 and early December, 1999 and scarcely any rainfall in January, 2000 which was the tussling stage for the maize. Therefore, due to the mulching effect by the organic inputs, more moisture was made available for the growing maize unlike in the inorganic treatments. Also, the fact that all the 60 kg N from the organics was applied when there was moisture (at planting) unlike for urea which was applied in split (20 kg N at planting and 40 kg N applied after five weeks) could also be a partial explanation for the better performance of the maize crop supplied with the organics. This is mainly because the application of the second split of the urea was followed by a dry spell. Hence, the growing maize crop might not have utilized this portion of the urea, thus leading to the low maize biomass yields from urea treatment. The relatively high biomass yield from organic treatments could also be due to other positive effects of the organic materials on soil physical and chemical properties (Clien and Avnimelech, 1986; Wallace, 1996; Mutuo et al., 1999).

A better maize performance was observed during the second season in the urea treatments. Results obtained showed that, maize grain yields from the organic treatments were 3.6 , 3.1 and 3.0 t ha^{-1} for tithonia, calliandra and

senna respectively compared to the highest yields from urea treatments of about 3.6 t ha⁻¹ (Figure 4.2). This gave fertilizer equivalency values of 130%, 72% and 68% for tithonia, calliandra and senna (Table 4.1). The implication was that tithonia biomass performed better than an equivalent amount of inorganic fertilizer in improving maize grain yield while calliandra and senna performed relatively lower to an equivalent amount of inorganic N source. The high fertilizer equivalency value for *Tithonia diversifolia* compared to the other two organic materials (*Senna spectabilis* and *Calliandra calothyrsus*) could be attributed to its low polyphenol content (2.2%) compared to senna (2.6%) and calliandra (11.1%). Hence, decomposition rate and subsequent N release is higher in tithonia green biomass (Gachengo et al., 1999) as compared to senna and calliandra (Lehmann et al., 1995). The N content in the material also influence decomposition and N release as Mutuo et al. (1999) noted in their trials in Western Kenya. The conclusion was that fertilizer equivalency value of organic materials is proportional to the N content. However, in the present study, the fertilizer equivalency values for senna and calliandra (68% and 72% respectively) did not differ significantly despite the different N content in the two organic materials (3.1 and 2.4%). This could be an indication of more conspicuous residual effect (from season one) in the calliandra treatment than in senna treatment.

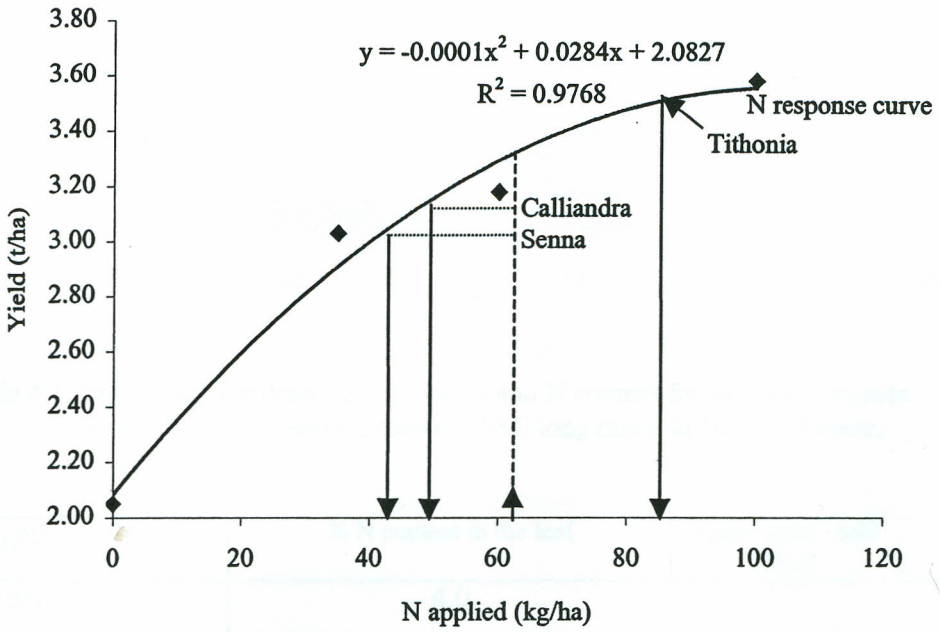


Figure 4.2: Maize grain yield response to N levels during 2000 long rains at NARL-Kabete, Kenya

Table 4.1: Percentage fertilizer equivalencies and N content for the three organic inputs during the second season (2000 long rains) at NARL, Kabete, Kenya.

Organic material	% N content in the leaf	Maize grain yield (t/ha)	%F. E
Tithonia	4.0	3.5	130
Calliandra	2.4	3.1	72
Senna	3.1	3.0	68
sed	0.2	0.3	N/A

F.E: Fertilizer equivalency

Fertilizer equivalency values for tithonia and calliandra were almost twice the values reported by Mutuo et al. (1999) for the same organic materials in their trial in Western Kenya. This could be due to the difference in the climatic conditions at both regions (Western Kenya and Kabete), especially rainfall distribution during both growing seasons. The Central region (Kabete trial site) was characterized by poor rainfall distribution during the two seasons when this research was carried out.

As per the study findings, tithonia green biomass can be recommended therefore for direct application while senna green biomass can be applied in combination with inorganic fertilizer. Calliandra leaf biomass on the other hand may not be recommended for direct application due to the high polyphenol content (11.1%) as compared to the critical level of 4.0% and also because of its low nitrogen content (2.4% N). Therefore, as suggested in the organic matter management decision tree (Delve et al., 2000; Palm et al., 2001), calliandra leaf biomass may give better results when mixed with inorganic N fertilizer.

4.2 Effects of N sources on maize performance

The second objective in the study was to determine the effect of inorganic and organic nitrogen sources on maize yields as well as nitrogen use efficiency. This objective was tackled in two portions, one of which investigated the effect of the different N sources on maize grain and biomass yields and the other that sought to establish how the different N sources influenced N use efficiency by maize crop.

4.2.1 Grain and biomass yields as influenced by the N source

The hypothesis the study sought to test in the first part of the second objective was that maize yields were dependent on the N source. In an endeavor to establish the validity of this hypothesis, data was obtained from maize crop grown under different N sources for two distinct seasons.

The study findings revealed that maize yields were dependent on the N source (Figure 4.3 and Figure 4.4). In season one, results showed that biomass yield obtained from a combination of either of the three organic inputs with inorganic N source differed significantly ($P \leq 0.05$) from biomass yield obtained from sole application of inorganic N source (Figure 4.3). It was also found that maize biomass yield obtained from tithonia + urea treatment was significantly higher compared to maize biomass yield obtained from sole tithonia and sole urea treatments. Approximately twice as much maize biomass yield was obtained with combination of tithonia and urea as compared to urea applied alone. This could be an indication of better results in combining organic and inorganic N source, which could be attributed to better synchrony of nutrient availability to maize crop demand. Separate application of either tithonia or urea did not show significant differences.

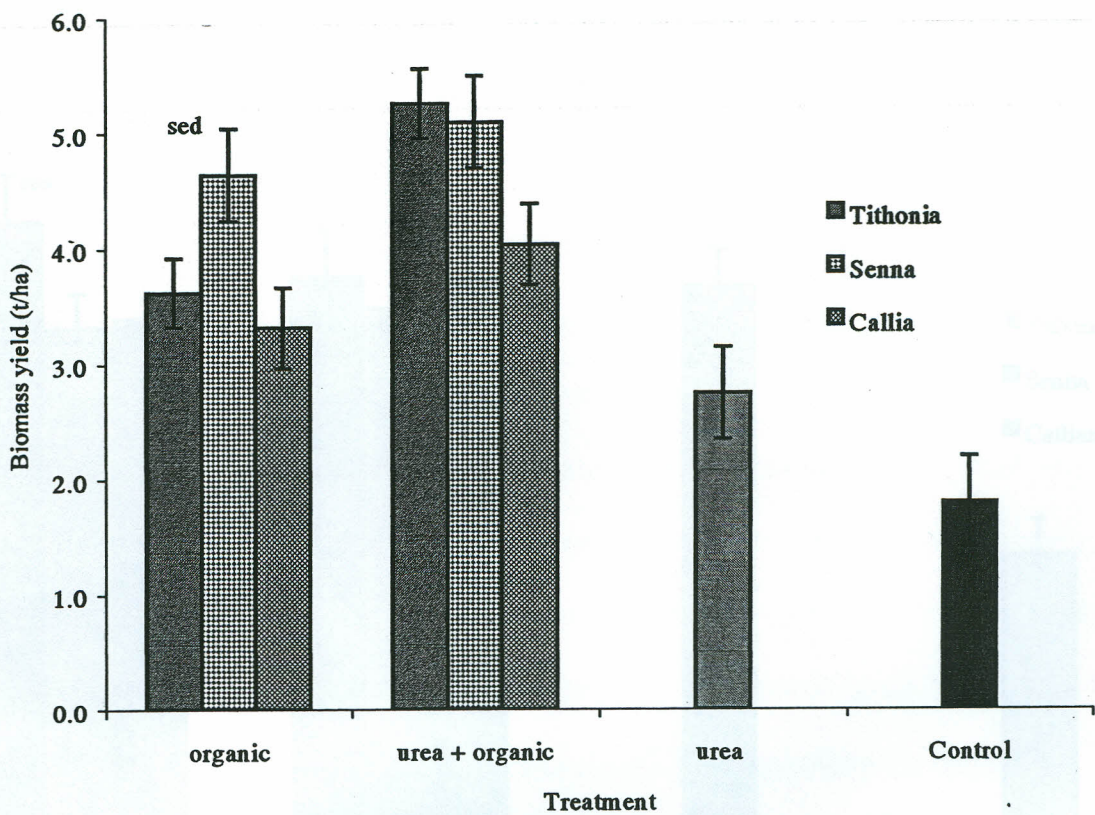


Figure 4.3: Effect of combining organic-inorganic N sources on maize biomass yield during the short rains season (1999) at NARL, Kabete, Kenya.

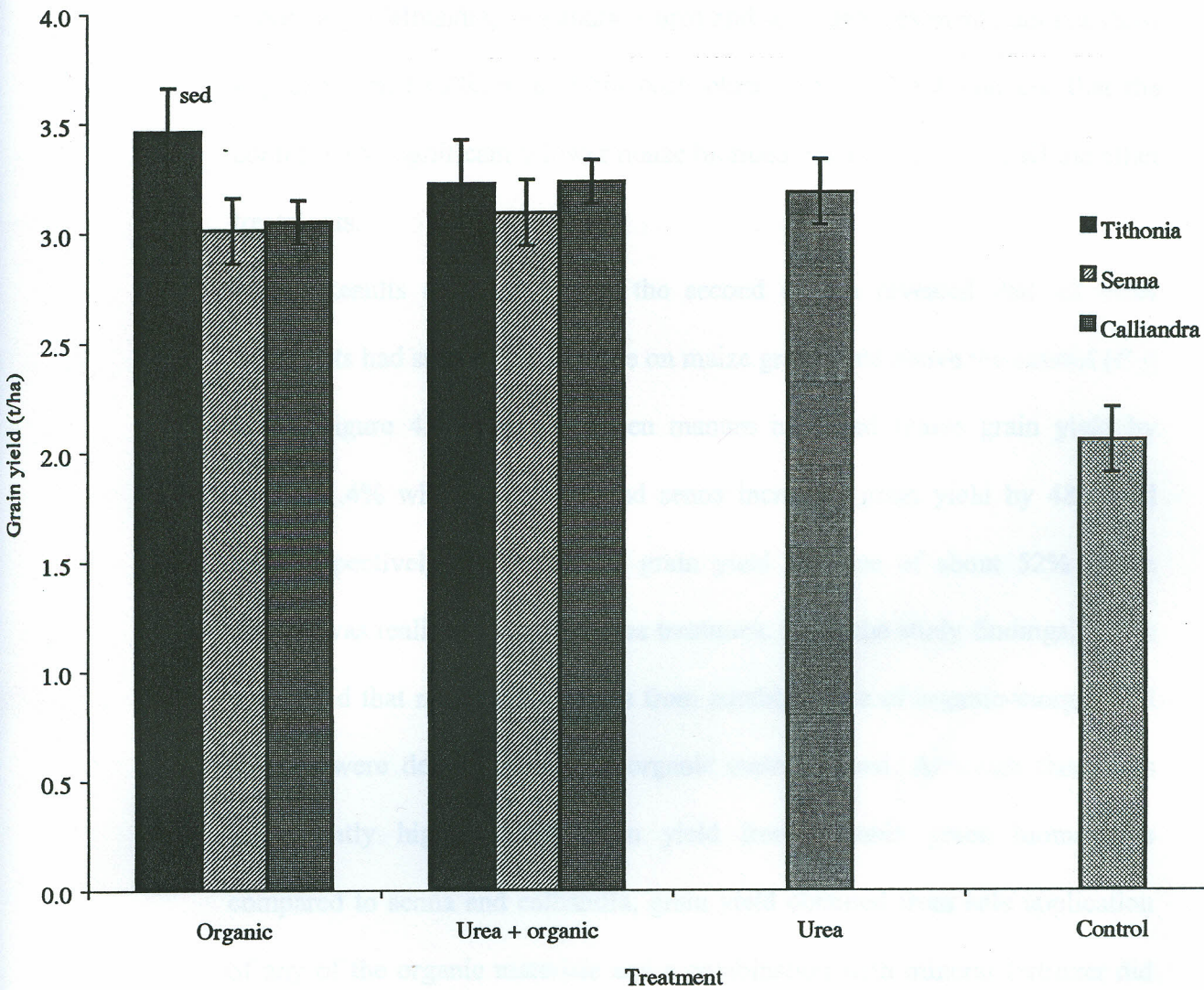


Figure 4.4: Effect of combining organic-inorganic N sources on maize grain yield during the long rains season (2000) at NARL, Kabete, Kenya.

Sole application of senna green biomass and a combination of the same with urea had significantly higher maize biomass yield than urea applied separately. Calliandra, calliandra + urea and sole urea treatments did not show any significant differences from each other. It was also found out that the control gave significantly lower maize biomass yield compared to all the other treatments.

Results obtained during the second season revealed that all other treatments had significant increase on maize grain yield above the control ($P \leq 0.05$) (Figure 4.4). Tithonia green manure increased maize grain yield by about 71.4% while calliandra and senna increased grain yield by 48% and 43% respectively. A percentage grain yield increase of about 52% above control was realized from sole urea treatment. From the study findings, it was also noted that maize grain yields from combined use of organic-inorganic N sources were dependent on the organic material used. Although there was significantly higher maize grain yield from tithonia green biomass as compared to senna and calliandra, grain yield obtained from sole application of any of the organic materials and a combination with mineral fertilizer did not significantly differ from each other. Maize grain obtained from urea treatment did not differ from all the other treatments.

Tithonia combined with urea gave higher yield than urea applied separately while maize grain yield from application of *Senna spectabilis* leaves in combination with inorganic fertilizer was higher than the grain yield resulting from application of sole *Senna spectabilis* leaves. This was also true with calliandra green biomass whose combination with inorganic fertilizer

gave higher maize grain yield than each applied separately. This could be attributed to the immediate availability of N from urea and its delayed release from the organic material hence synchronizing its release (in the urea + calliandra treatment) with maize demand. Similar results were reported by Jama et al. (2000) who observed higher maize yields obtained from a combination of tithonia and phosphorus fertilizer in their work in Western Kenya. Other researchers have observed greater maize production through application of high-quality organic inputs like tithonia in combination with inorganic fertilizer as compared to sole application of mineral fertilizers (Gachengo, 1996; Palm et al., 1997).

The relatively better results realized from tithonia sole application than a combination with mineral N source and sole application of urea could still be attributed to other indirect effects to the soil such as moisture retention (Wallace, 1996; Lehmann et al., 1999) and addition of micronutrients (Mutuo et al., 1999). Nziguheba (2001), also reported increase in maize growth with application of tithonia green biomass which (in addition to increased N availability), was attributed to increased labile P as compared to sole application of inorganic inputs.

As noted also in season one, time of application might have as well played a major role in maize performance. All the tithonia green biomass was applied at once at planting when there was rain while only one third of the urea was applied at planting. Two thirds of the urea was applied five weeks later, which was followed by a dry spell, hence, insufficient amounts of the urea N were available to the growing crop.

Lower maize grain yields obtained from sole application of either calliandra or senna, could be attributed to N immobilization or reduced N release as Mwale et al. (2000a) also noted in their study at Chalimbana, Zambia. Other researchers also observed that, large portion of N from a slowly decomposing biomass may be incorporated into soil organic matter fractions (Lehmann et al., 1999) or immobilized into forms not readily available to annual crops (Mugendi et al., 1999). Therefore tithonia green biomass can be recommended for direct incorporation for soil fertility improvement while senna and calliandra green biomass can give better results when applied in combination with inorganic fertilizer (Delve et al., 2000; Palm et al., 2001), to overcome the deleterious effects.

4.2.2 Nitrogen uptake and total %N recovery by maize

The second part of the second objective in the study was to investigate nitrogen uptake and percentage nitrogen recovery by maize. Due to the high costs involved in the laboratory analyses, this objective was achieved by analyzing maize yields obtained from four selected treatments (control, tithonia, urea, and tithonia + urea) for total nitrogen. The results revealed that, nitrogen concentrations in the grain, stover and core yields differed significantly ($P \leq 0.05$) between the different treatments (Table 4.2). Nitrogen uptake ranged from 93.3 to 131.9 kg ha⁻¹. From the study findings, it was noted that the inorganic fertilizer applied treatment gave the highest N uptake while control had the lowest. Tithonia + urea and urea treatments were significantly higher compared to the control. Above ground yield from urea

sole application had about 131.9 kg ha⁻¹ total N uptake while tithonia + urea gave 114.3 kg ha⁻¹. This relatively high N uptake from the two treatments, could be attributed to the readily available N from the urea. The N uptake by maize that received tithonia green biomass alone as N source was about 97.6 kg ha⁻¹, which was not significantly different from the control.

Table 4.2: Nitrogen added, total aboveground nitrogen uptake, and nitrogen recovery by maize crop (1999/2000) at NARL, Kabete, Kenya.

Treatment	N applied (kg N ha ⁻¹)	Nitrogen uptake (kg ha ⁻¹)	%N		Total % N recovery
			Grain	Stover	
Control	0	93.3	1.7	0.63	N/A
Tithonia + Urea	60	114.3	1.9	0.9	35
Tithonia	60	97.6	1.8	0.8	7.2
Urea	60	131.9	2.0	1.1	64.3
sed	N/A	16.4	-	-	N/A

The apparent percentage N recovery by maize crop that received sole tithonia green biomass was found to be 7.2% while 35% was recovered in tithonia + urea treatment. Sole urea treatment had a 64.3% nitrogen recovery. However, these values might not have reflected the actual N recoveries by the maize. This is because the material used was not labeled hence it was not possible to ascertain the contribution of the applied nitrogen from different sources, either in organic or in inorganic form. Therefore, calculated total %N recovery values obtained in the study were meant to be estimates to the actual recoveries.

Nitrogen recovery by the maize crop that received sole application of urea and the one that received a combination (inorganic-organic N source), was significantly higher compared to nitrogen recovered by maize that received sole tithonia green biomass. The high N recoveries by maize crop planted in sole urea and tithonia + urea applications were an indication that there was less N loss from soil-plant system. Therefore, the growing maize crop took up a large percentage of the N supplied by either the inorganic or inorganic-organic inputs.

From the study, it was also noted that, grain yield accounted for a greater portion of the recovered N than either stover yield or the core. This was also noted by Mugendi et al. (2000) in their work in the subhumid highlands of Kenya.

Other researchers working on different N sources (organic inputs and inorganic inputs) also reported a percentage N recovery ranging from 25% to 111% (Westerman et al., 1972; Kruijs et al., 1988; Christianson et al., 1990; Gachengo et al., 1999). In this study, nitrogen recovery values from tithonia green biomass was found to be relatively lower than the values Gachengo et al. (1999) observed using the same organic material in a study in Western Kenya. This could be due to differences in environmental conditions especially rainfall distribution between the two sites. However, the N recovery value from inorganic fertilizer (urea) agrees with the findings of Chabrol et al. (1988) in a study in Bedfordshire, England as well as what Mugendi et al. (1999) found out in their studies in the subhumid highlands of Kenya.

4.3 Soil mineral N and N losses as influenced by the N source

The third objective in the study was to determine the effect of organic and inorganic N sources on soil mineral N as well as to establish the influence of the N source on nitrogen losses through denitrification and leaching. Therefore, this objective was tackled in three parts, each of which formed a sub section as discussed below.

4.3.1 Effect of N source on soil mineral N at different stages of maize growth after treatment application

Nitrogen being a macronutrient required for plant growth, its availability to plants is determined by several factors. One of these factors is the form in which it is been applied into the soil. Thus the first part of the third objective in this study was to determine how organic and inorganic nitrogen sources influenced N availability to maize at different stages of growth.

4.3.1.1 Soil mineral N content one week after treatment application

The study findings indicated significant treatment differences in mineral N content during the first week after application (at $P \leq 0.05$) (Table 4.3). Mineral N content was highest in urea treatment, which had about 53.7 mg kg⁻¹ and lowest in control (20.4 mg kg⁻¹). Tithonia treatment had about 27.5 mg kg⁻¹ which was less than half of what Gachengo et al. (1999) reported using the same organic material. This is attributed to the difference in the rate at which the N was applied. In this study, the N was applied at 60 kg ha⁻¹ while Gachengo et al. (1999) applied N was at the rate of 189 kg ha⁻¹. The time of

the soil sampling also influenced the amount of mineral N in the soil (in this study, soil was sampled at one week after application while Gachengo et al. (1999) did their sampling at three weeks after application).

4.3.1.2 Soil mineral N content four weeks after treatment application

The study revealed significant differences among treatments ($P \leq 0.05$) four weeks after application (Table 4.3). Urea treatment had significantly higher mineral N content (25.3 mg kg^{-1}) compared to tithonia (19.4 mg kg^{-1}) treatment and control (12.8 mg kg^{-1}). The relatively higher mineral N content in urea treatment as compared to tithonia treatment and control indicated higher risk of leaching in the urea treatment. While on the other hand it could imply that more N was available in the urea treatment for crop uptake. Considering that only one third of the mineral fertilizer had been applied at this stage (two thirds to be applied in a weeks' time), the results from this study depict that high amounts of mineral N might be available to the growing crop at a stage it does not require such great amounts, thus implying lack of synchrony.

Table 4.3: Treatment effects on topsoil mineral N at different stages of maize growth at NARL Kabete, Kenya.

Treatment	N rate (kg N ha ⁻¹)	Mineral N (mg N kg ⁻¹ of soil)		
		One week after application	Four weeks after application	Nine weeks after application
Control	0	20.4	12.8	7.2
Tithonia	60	27.5	19.4	13.3
Urea	20	53.7	25.3	7.6
S.e.d	N/A	2.8	2.8	2.5

4.3.1.3 Mineral N content at tussling stage

The mineral N content significantly differed ($P \leq 0.05$) between the different treatments at tussling stage (about nine weeks after treatment application) (Table 4.3). Green tithonia biomass treatment had about 13.3 mg kg⁻¹ of mineral N while the mineral N content in the urea treatment was 7.6 mg kg⁻¹ and 7.2 mg kg⁻¹ in the control. The high mineral N content in the tithonia treatment at tussling stage could be due to the completely decomposed organic material and the subsequent nitrogen release and this can be an advantage to the growing maize crop which is at its peak demand.

4.3.1.4 Treatment effects on soil mineral N at the end of the season

Soil mineral N content at the end of the season is an indicator of how much N was available to the growing crop but was not utilized and neither was it lost from the soil-plant system. This being the case, the study sought to investigate the residual mineral N in the soil even after crop harvest in the

different treatments. It was found out that soil mineral nitrogen content differed significantly ($P \leq 0.05$) depending on the N source applied as different treatments at the end of the first season (1999 short rains) (Figure 4.5). The mineral N content in the different treatments was in the order of Urea > urea + tithonia > tithonia > urea + calliandra > control > urea + senna > senna > calliandra.

Urea had the highest amount of mineral N (11.4 mg kg^{-1}) while sole application of calliandra green biomass gave the lowest amount of mineral N

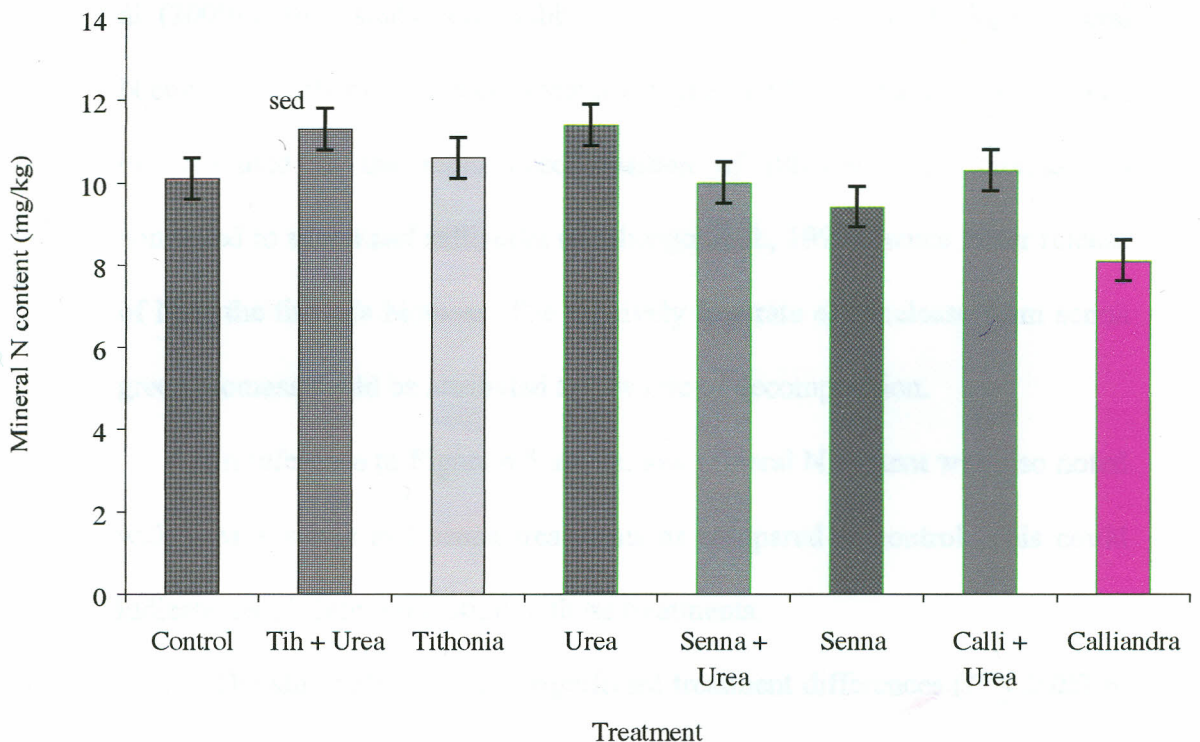


Figure 4.5: Treatment effect on soil mineral N content at the top 10 cm at the end of 1999 short rains season at NARL, Kabete, Kenya.

(8.1 mg kg⁻¹). Urea, tithonia + urea, tithonia, and calliandra + urea treatments indicated significantly higher mineral N content compared to sole application of calliandra.

The low soil mineral N content in calliandra could be attributed to the high polyphenol (11.1%) and lignin content (15.5%) found in the leaves as shown in Table 3.1(a) and Table 3.1(b). The polyphenol content is more than double the critical value (4.0%) for N release to occur (Delve et al., 2000; Palm et al., 2001). Thus calliandra leaf biomass decomposed at a relatively slow rate hence slow release of N leading to net N immobilization in the calliandra treatment. The same observation has been reported by Mugendi et al. (2000) in their study in the subhumid highlands of Kenya. The high mineral N content in tithonia treatment indicated higher net N-mineralization. This can be attributed to the rapid decomposition of tithonia green biomass as compared to senna and calliandra (Gachengo et al., 1999), hence faster release of N in the tithonia biomass. The relatively low rate of N release from senna green biomass could be attributed to low rate of decomposition.

In reference to Figure 4.5 above, low mineral N content was also noted with urea + senna and senna treatments as compared to control. This could indicate net N- immobilization in these treatments.

The study also revealed significant treatment differences ($P \leq 0.05$) in mineral N content at the end of the second season (2000 long rains) (Figure 4.6). Tithonia green biomass combined with inorganic N source (urea) gave the highest amount of mineral N (10.3 mg kg⁻¹), while control gave the lowest mineral N content (3.9 mg kg⁻¹).

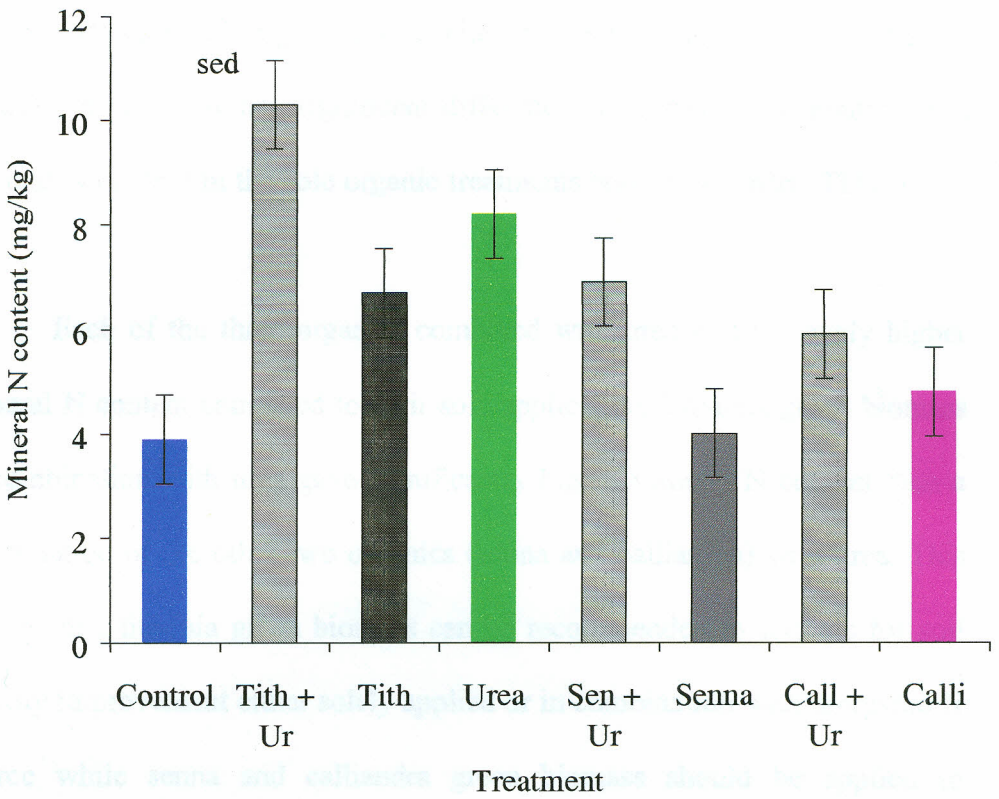


Figure 4.6 : Treatment effect on soil mineral N at the end of 2000 long rains season at NARL, Kabete, Kenya.

Results also indicated that the separate application of the different N sources (organic or inorganic) had significantly different levels of influence on mineral N content in the soil. This was dependent on the specific N source. Urea had the highest mineral N content (8.2 mg kg^{-1}) followed by tithonia sole application with 6.7 mg kg^{-1} . The other two organic inputs (calliandra and senna) did not show any significant difference compared to the control. The mineral N content in the sole organic treatments was in the order: TD > CC > SS.

Each of the three organics combined with urea had relatively higher mineral N content compared to their sole application. Tithonia green biomass in combination with urea gave significantly higher mineral N content than a combination of the other two organics (senna and calliandra) with urea. This implies that tithonia green biomass can be recommended to farmers for soil fertility improvement either solely applied or in combination with inorganic N source while senna and calliandra green biomass should be applied in combination with inorganic fertilizer to minimize N immobilization.

Lower levels of $\text{NH}_4^+\text{-N}$ compared to $\text{NO}_3^-\text{-N}$ concentrations were noted in this study. Similar results were obtained by Thonissen et al. (2000) in their studies in Asia, Taiwan and Philippines. This could suggest that N is rapidly transformed from $\text{NH}_4^+\text{-N}$ to $\text{NO}_3^-\text{-N}$ following mineralization of the organic inputs (Shepherd et al., 2000).

The mineral N content was found to be relatively higher in the first season compared to the second season for all treatments including the control. This may have been due to the poor performance of the maize crop in season

one, which was caused by poor rainfall distribution during this season hence little of the mineral N was utilized by the growing maize crop or lost via leaching. Most of the mineral N released from the organic or inorganic N source was therefore still available in the soil at the end of the season. The relatively good maize performance during the second season shows that most of the mineral N from the decomposing biomass was available to the growing crop hence lower mineral N content was left in the soil at the end of the season as compared to season one.

4.3.2 Nitrogen losses through gaseous emissions as influenced by nitrogen source

The second part of the third objective was to determine the influence of organic and inorganic nitrogen sources on losses on nitrogen through gaseous emissions. Emphasis here was laid on nitrous oxide emissions. The time variations in nitrous oxide emissions within each treatment were also investigated.

4.3.2.1 Periodic variation in nitrous oxide emissions

The study findings revealed that there was variation in nitrous oxide emissions between the different sampling periods (Table 4.4) for the three treatments. However, this was significant only for tithonia treatment whose range was as low as $-0.3 \mu\text{g N m}^{-2} \text{hr}^{-1}$ (before treatment application) and as high as $12.3 \mu\text{g N m}^{-2} \text{hr}^{-1}$ (four weeks after application).

Table 4.4: Treatment effects on N₂O fluxes at different stages of maize growth (2000) in N1 experiment Kabete, Kenya.

Treatment	N rate (kg N ha ⁻¹)	Nitrous oxide (N ₂ O) flux (µg/m ² /hr).			
		BP	1 WAP	4 WAP	sed
Control	0	1.7	1.2	7.3	5.6
Tithonia	60	-0.3	2.4	12.3	2.7
Urea	20	0.6	2.9	1.3	4.4
sed	N/A	4.0	1.6	4.7	-

Abbreviations:

BP = Before planting (treatment application)

WAP = Week after planting

Sed = Standard error deviation

4.3.2.2 Influence of organic and inorganic N sources on nitrous oxide emissions

There were no significant treatment differences ($P < 0.05$) in nitrous oxide fluxes before treatment application and one week after application (Table 4.4). The amount of N₂O emitted from tithonia treatment one week after treatment application was about 2.4 µg m⁻² hr⁻¹ while N₂O emission in urea treatment was 2.9 µg m⁻² hr⁻¹ and only 1.2 µg m⁻² hr⁻¹ for control. However, considering the rate at which N was applied (60 kg N ha⁻¹ and 20 kg N ha⁻¹ for tithonia and urea respectively), urea treatment emitted N₂O at a higher rate compared to tithonia treatment on a per unit N added basis.

At four weeks after treatment application, there was a significantly higher N₂O emission from organic (*Tithonia diversifolia*) treatment compared to the urea treatment (Table 4.4). The rate of N₂O emission in tithonia

treatment was $12.3 \mu\text{g m}^{-2} \text{hr}^{-1}$ while urea treatment emitted at the rate of about $1.3 \mu\text{g m}^{-2} \text{hr}^{-1}$. The relatively lower N_2O emissions in urea treatment could be attributed to split application of the mineral fertilizer whereby only one third of the fertilizer was applied at planting. The high nitrous oxide emissions observed in tithonia treatment at this stage of maize growth could be attributed to the rapid decomposition of the high quality green biomass. Similar results were reported by Palm et al. (1997). These researchers observed relatively large amounts of N losses from sole application of high quality organic materials as compared to mineral fertilizer alone. Therefore, a better option could be the use of high quality organics as partial substitution for inorganic fertilizers. Thus, farmers could be encouraged to use high quality organic materials in combination with inorganic fertilizer.

The relatively higher N_2O emissions in the organic treatment as compared to fertilizer treatment could, however be attributed to the incorporation of the organics, which promote high levels of nitrate and available carbon in the soil enhancing denitrification (Janzen and Schaalje, 1992). Xu et al. (1993) and Jones et al. (1997) arrived at the same conclusion when they observed higher losses of N through denitrification with incorporated material as compared to surface application.

4.3.3 Leaching of mineral N as influenced by organic and inorganic N sources

In the third part of the third objective the study sort to investigate the influence of inorganic and organic N sources on N loss through leaching. This

particular aspect was investigated at tussling stage (about nine weeks after treatment application) and at the end of the season. To tackle this objective, three treatments (control, urea and tithonia) were selected whereby soil was sampled at different depths down the profile.

4.3.3.1 Effect of organic and inorganic N sources on mineral N leaching at tussling stage

Soil mineral N content at tussling stage increased down the profile (Figure 4.7). This was evident in the three treatments investigated in the study. Urea and tithonia treatments exhibited significantly higher mineral N content compared to the control at depth upto 20 cm. This could be attributed to the washing down of the mineral N applied as inorganic or organic in nitrate form (Loomis and Connor, 1992) from the top most soil accumulating in the sub soil. However, beyond this depth, there were no significant treatment differences. This was an indication that there was no significant leaching of the added N during this period of the growing season from the topsoil to the lower layers beyond 20 cm. This could be attributed to the sampling time, which was preceded by a dry spell of more than a month (Appendix 4).

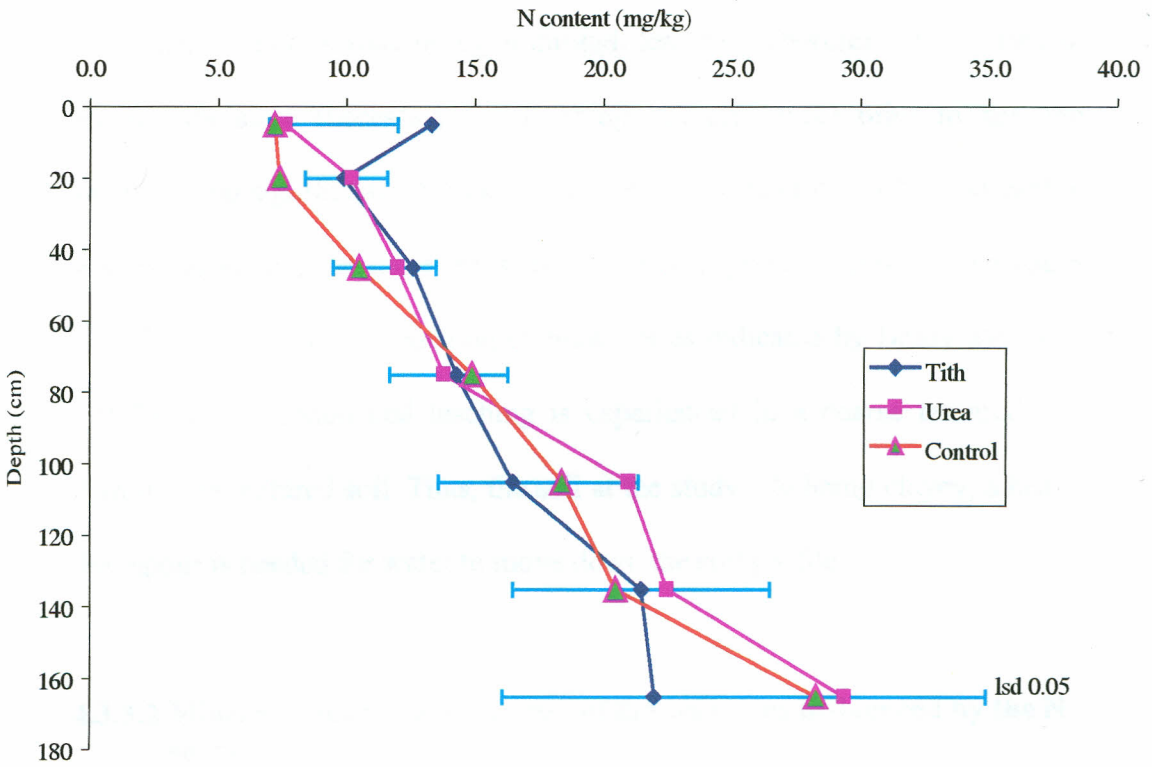


Figure 4.7: Mineral N dynamics down the soil profile at tusing stage in 1999 short rain season at NARL, Kabete, Kenya.

As Brady and Weil (1999) indicated, precipitation is a major factor influencing loss of nitrate nitrogen through leaching. Therefore, due to lack of enough moisture (necessary for leaching to take place) prior to the soil sampling, no significant difference in mineral N content down the soil profile was noted among the three treatments. The soil type also might have had a significant influence on leaching of nitrate-N as indicated by Brady and Weil (1999). More pronounced leaching is experienced in a coarse textured soil than in fine textured soil. Thus, the soil at the study site being clayey, a heavy downpour is needed for water to move down the soil profile.

4.3.3.2 Mineral N leaching at the end of the season as influenced by the N source

In endeavor to establish how mineral nitrogen had been leached down the soil profile even after crop harvest, mineral N content was determined for soil sampled at different depths for the three selected treatments (tithonia, urea, and control).

Findings from this study at the end of the first season revealed that urea treatment had significantly higher mineral N content compared to control and tithonia treatments in the subsoil (Figure 4.8). This was more conspicuous at the depth between 20 and 50 cm and could be attributed to leaching of the urea N down the soil profile. The mineral N content in the tithonia treatment did not significantly differ from the control. The high content of mineral N in urea treatment could be attributed to the second split (40 kg N ha^{-1}) which had been applied five weeks after planting and then followed by a dry spell.

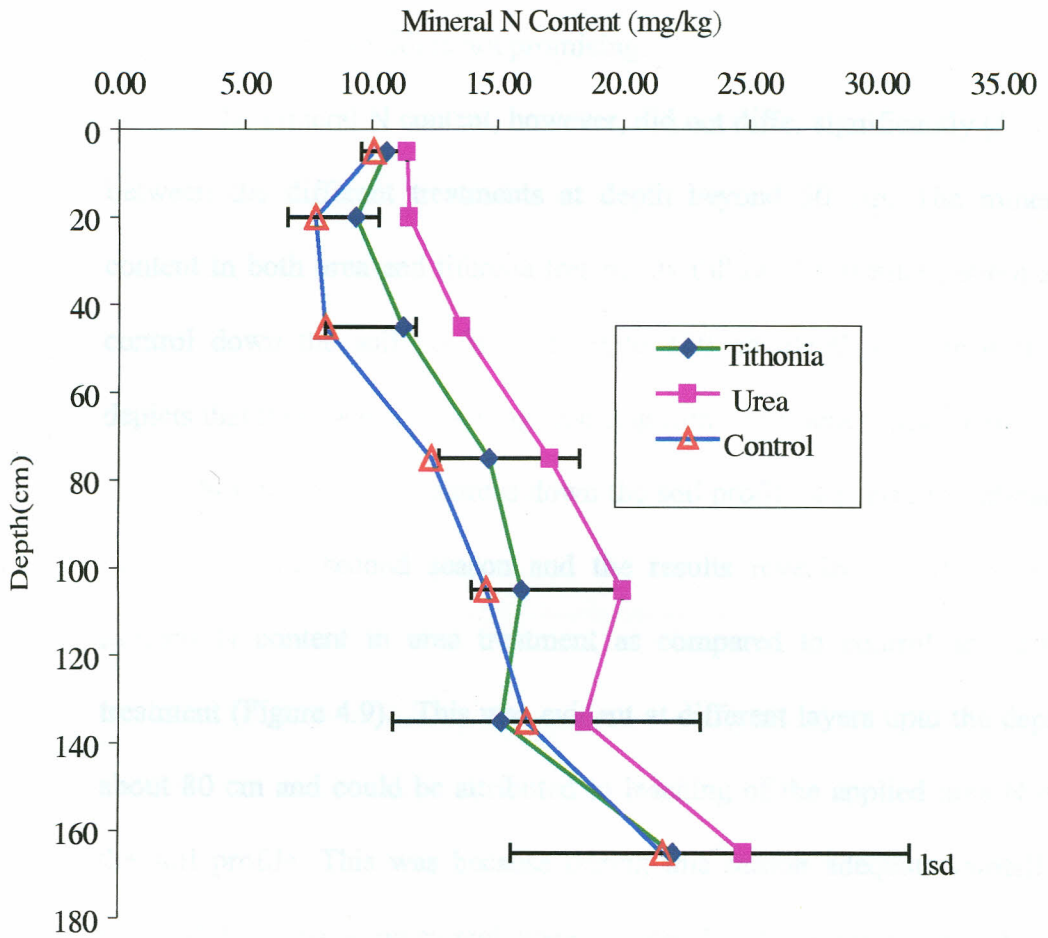


Figure 4.8: N Dynamics down the soil profile- End of 1999 short rain season at NARL, Kabete, Kenya.

Therefore, there is a high possibility that the growing maize crop did not utilize this portion of the mineral fertilizer N hence, a good amount of it was still available in the soil at the end of the season. This could result to leaching of the nitrate N at the onset of the rains (Hagedorn et al., 1997) in the following season. It may be advisable for farmers to avoid this late split application if the rainfall is not promising.

The mineral N content, however, did not differ significantly ($P \leq 0.05$) between the different treatments at depth beyond 50 cm. The mineral N content in both urea and tithonia treatments followed a similar pattern as the control down the soil profile even upto 170 cm depth (Figure 4.8). This depicts that there was no leaching resulting from treatment application.

Soil mineral N dynamics down the soil profile was also investigated at the end of the second season and the results revealed significantly high mineral N content in urea treatment as compared to control and tithonia treatment (Figure 4.9). This was evident at different layers upto the depth of about 80 cm and could be attributed to leaching of the applied urea N down the soil profile. This was because during this season adequate rainfall was received thus, providing enough water to percolate down the soil profile hence washing down of the soil-loosely held nitrate-N to lower layers (Singh and Vaje, 1998). At depth lower than 80 cm, no significant treatment differences were noted in the mineral N content.

The relatively lower mineral N content in tithonia treatment as compared to urea treatment down the soil profile was an indication of lower N leaching when tithonia green biomass is used as a nitrogen source instead of

urea. Therefore, farmers could be encouraged to use tithonia green biomass as a strategy for lower N losses through leaching.

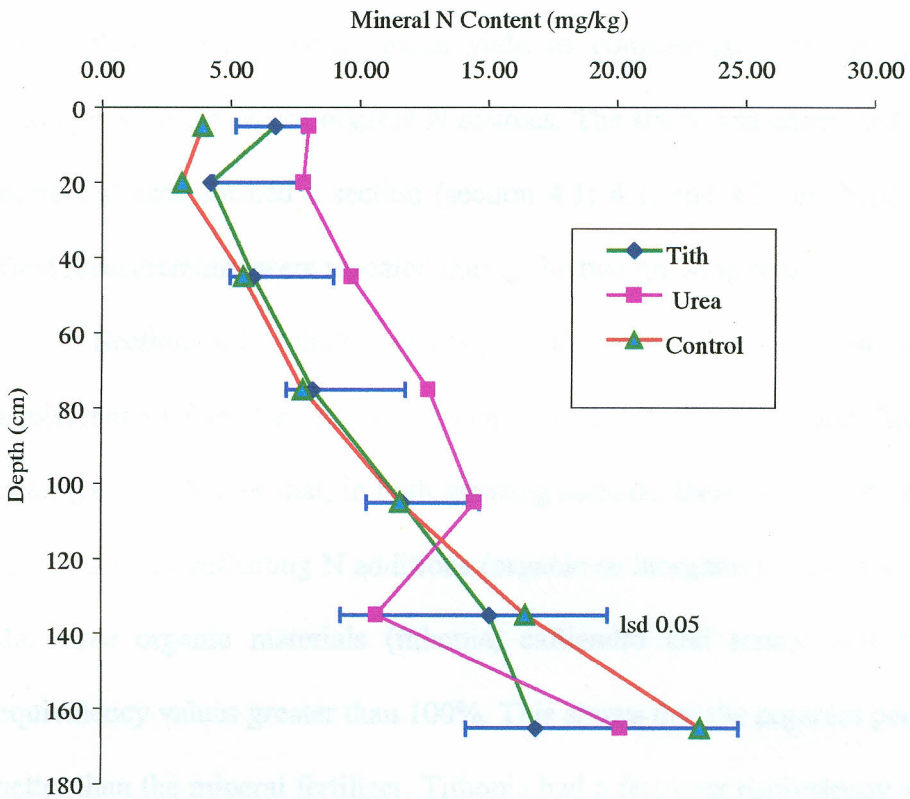


Figure 4.9: N Dynamics down the soil profile - End of 2000 long rain season at NARL, Kabete, Kenya.

CHAPTER FIVE

5.0 CONCLUSIONS AND RECOMMENDATIONS

The main or primary objective of this study was to determine the fertilizer equivalency values for organic materials with contrasting qualities. This was aimed at establishing the quantity of an organic material that has the same effect on improving maize yield as commercial fertilizer and offer guidelines on the use of organic N sources. The study was composed of three parts and each formed a section (section 4.1; 4.2; and 4.3) in chapter 4. All field measurements were repeated during the two growing seasons.

Section 4.1 which reports on the respective nitrogen fertilizer equivalency values for *Tithonia diversifolia*, *Senna spectabilis* and *Calliandra calothyrsus* indicates that, in both growing seasons, there were relatively high yield response reflecting N additions (organic or inorganic). In season one, all the three organic materials (tithonia, calliandra and senna) had fertilizer equivalency values greater than 100%. This shows that the organics performed better than the mineral fertilizer. Tithonia had a fertilizer equivalency value of 130% in the second season while calliandra and senna had 72% and 68% respectively. The extent to which an organic material will perform comparable to mineral fertilizer, is dependent on several factors especially the quality of the organic materials, climatic factors and site characteristics.

The secondary objectives of the results reported in section 4.2 was to investigate the effect of organic, inorganic and organic + inorganic nutrient sources on maize grain and biomass yields and nitrogen use efficiency by maize crop. Maize crop supplied with sole urea was found to recover nitrogen

at a higher rate though higher biomass and grain yields were obtained from tithonia sole application. It is evident that the effect of external inputs (combined with organics) on crop N use efficiency is dependent on the organic material used and climatic conditions (especially rainfall amount) prevailing throughout the growing period of the annual crop. Organic inputs assist in the synchronization of nutrient release and the nutrient uptake by the growing crop.

In section 4.3, a secondary objective investigated was that of partial substitution of inorganic N source with organic N sources. Results obtained showed that it could be a better option in reducing N losses through denitrification. The results presented in the same section depicts that organic inputs (especially high quality), positively influenced the soil mineral N content as well as reducing N leaching. Therefore, from the study findings, it could be concluded that the use of high quality organic inputs could help in enhancing the synchrony of applied N with crop demand.

The following recommendations can be drawn based on the findings from this research:

(a) Merits of the use of the organics

- 1) *Tithonia diversifolia* can be used as a source of nitrogen in place of mineral fertilizer and smallholder farmers should be encouraged to use tithonia green biomass for annual crops especially in areas of inadequate rainfall. *Senna spectabilis* and *Calliandra calothyrsus* green biomass should be recommended for use in combination with inorganic N source for better results.

- 2) A similar research should be carried out for other organic materials and at different agroecological zones.
 - 3) More research is needed to establish other specific beneficial effects of organic inputs on annual crop yields.
- (b) Limitations in the use of organics
- 1) Large quantities are required and associate labor demand.
 - 2) Variable quality constraining the use predictability with respect to the Organic Resource Database (ORD) decision tree.
 - 3) There are often little economic returns when the organics are not used on high value crops.
 - 4) Limited information about the right proportions of application.

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APPENDICES

Appendix 1

Experimental layout of N1 experiment at NARL-Kabete.

101 T3 R1	102 T9 R1	103 T7 R1	104 T6 R1	105 T2 R1
106 T4 R1	107 T1 R1	108 T8 R1	109 T5 R1	110 T10 R1
201 T8 R2	202 T2 R2	203 T9 R2	204 T1 R2	205 T6 R2
206 T4 R2	207 T7 R2	208 T10 R2	209 T5 R2	210 T3 R2
301 T2 R3	302 T7 R3	303 T3 R3	304 T10 R3	305 T1 R3
306 T5 R3	307 T8 R3	308 T4 R3	309 T9 R3	310 T6 R3
401 T5 R4	402 T2 R4	403 T6 R4	404 T7 R4	405 T3 R4
406 T8 R4	407 T9 R4	408 T4 R4	409 T1 R4	410 T10 R4

Treatments

1= Control
 2= 50% Urea, 50% TD
 3= 0% Urea, 100% TD
 4= 100% Urea
 5= 50% Urea, 50%SS

6= 0% Urea, 100% SS
 7= 50% Urea, 50% CC
 8= 0% Urea, 100% CC
 9= 35 kg N/ha
 10= 100 kg N/ha

Key

Plot size: 5.25 * 5 m
 Inter-plot spacing = 0.75 m

Appendix 2 Work Plan

SEASON 1	
19/11/99	Tillage - disc
22-23/11/99	Collection of materials
	Application of the material (broadcasting)
24/11/99	Incorporation of the material (to 15cm)
	Fertilization
	Planting
25/11/99	Planting cover crop
	Soil Sampling
30/11/99	Trenching for erosion control
21-22/12/99	1 st Weeding
23/12/99	Thinning and counting thinning density
29/12/99	Top-dressing with urea (5 weeks after planting)
31/1/00	Soil sampling
9/3/00	Gas sampling in treatments 1,3,4. Soil sampling in treatments 1,3,4 at 0-10cm depth
10/3/00	Harvesting
13/3/00	Soil sampling in all plots at 0-10 cm depth.
14 – 18/3/00	Soil sampling in treatments 1,3,4, and 10 at depths 10-30cm , 30-60cm, 60-90cm, 90-120cm, 120-150cm, 150-180cm, and 180-300cm

SEASON 2

10/4/00	Collection of material Trenching
11/4/00	Application of organic material and inorganic fertilizer (Urea)
12/4/00	Planting of test crop and cover crop
20/4/00	Gas sampling in treatments 1,3, and 4
20/4/00	Soil sampling in treatments 1,3, and 4 at 0-10 cm depth
18/5/00	1 st weeding . Thinning and counting thinning density.
23/5/00	Gas sampling in treatments 1,3, and 4. Top-dressing with urea (6 weeks after Planting). Soil sampling at 0-10 cm depth in treat- ments 1,3, and 4.
18/6/00	2 nd weeding
July, 2000	Laboratory analysis of soil samples at ICRAF.
13 th September,2000 at	Harvesting and soil sampling in all plots 0-10cm depth
13 th -15 th September, 2000	Soil sampling in treatments 1,3, and 4 at depths 0-10cm, 10-30 cm, 30-60 cm, 60-90 90-120 cm, 120-150 cm, 150-180 cm, 180-300 cm.
As from October, 2000	Data analysis and compilation.

Appendix 3

SITE _____ DATE _____

LAND-USE: _____ AMBIENT TEMP.: _____

CHAMBER NO.: _____ PRESSURE: _____

CHAMBER HEIGHT (cm) 1. _____ 2. _____ 3. _____ 4. _____

TIME (Min.)	INTERVAL	VIAL	TIME	CHAMBER TEMPERATURE	SOIL TEMPERATURE
0				X	
10				X	
20				X	
40					

CHAMBER NO.: _____

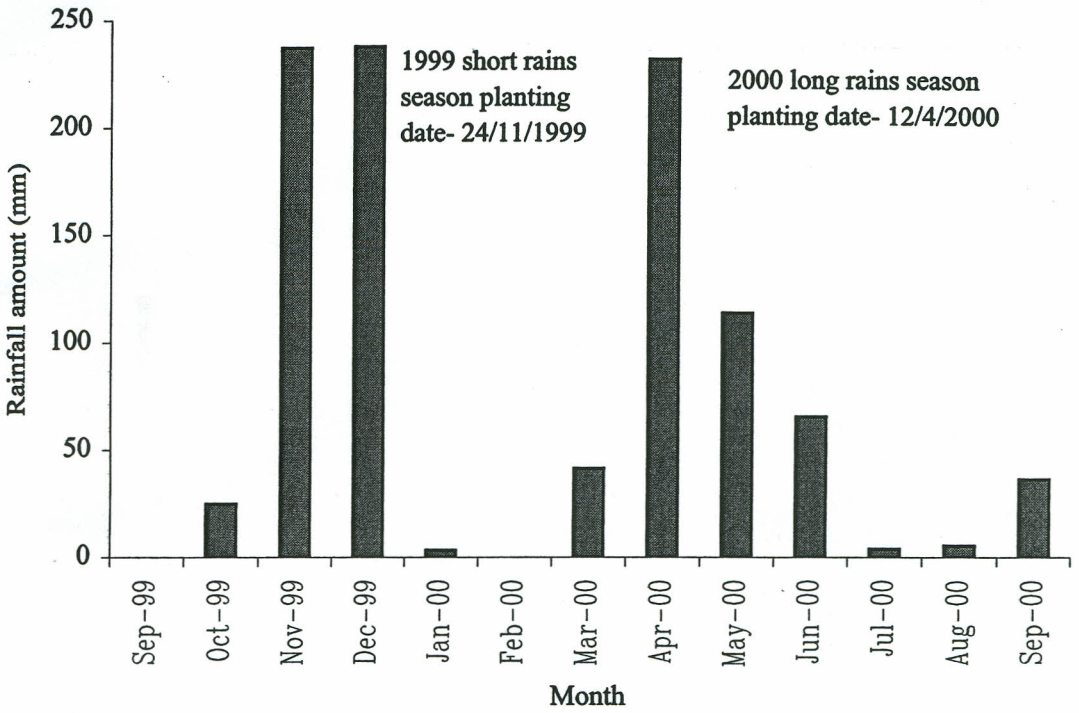
CHAMBER HEIGHT (cm) 1. _____ 2. _____ 3. _____ 4. _____

TIME (Min.)	INTERVAL	VIAL	TIME	CHAMBER TEMPERATURE	SOIL TEMPERATURE
0				X	
10				X	
20				X	
40					

CHAMBER NO.: _____

CHAMBER HEIGHT (cm) 1. _____ 2. _____ 3. _____ 4. _____

TIME (Min.)	INTERVAL	VIAL	TIME	CHAMBER TEMPERATURE	SOIL TEMPERATURE
0				X	
10				X	
20				X	
40					



Appendix 4: Rainfall data (mm) for 1999/2000 at the study site, NARL, Kabete, Kenya

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