SOIL FERTILITY TECHNOLOGIES FOR INCREASED FOOD PRODUCTION IN CHUKA, MERU SOUTH DISTRICT, KENYA

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DECLARATION

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DEDICATION

To my dear mum and dad for their encouragement, dedication and the many sacrifices they have made towards my education “Without you I wouldn’t have come this far”. To my dear husband, for his support and understanding during the study period. Lastly to my brothers and sisters who have continued to cheer me up even when things were not very good.

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ABSTRACT

The high population pressure in Chuka has led to continuous cultivation with minimal additional of inputs, leading to soil nutrient depletion. Research work has reported positive results from the use of manure and biomass from tithonia, calliandra, leucaena, mucuna and crotalaria for soil fertility replenishment. In relation to this a multidisciplinary farmers participatory trial was established in Chuka Division, Meru District, to offer small-scale resource poor farmers feasible soil nutrient replenishment technologies.

The experiment was set up in a randomized complete block design with 14 nutrient replenishment treatments (technologies) replicated thrice. At the beginning and at the end of the study soil was sampled at 0-15 cm depth and the samples analysed for pH, Ca, Mg, K, C, N, and P. At the end of the 2000/2001 short rains season and 2001 long rains season soil samples were taken at 0-30, 30-100 and 100-150 cm, for nitrate and ammonium analysis. All the treatments received an equivalent of 60 kg N ha^{-1} except the herbaceous legume treatments where the amount of N was determined by the amount of the biomass harvested and incorporated and the absolute control treatment that received no inputs. Net benefit and benefit-cost analysis were conducted using farm gate prices.

The results indicate that soil fertility increased slightly in all the treatments (except the control) over the two years of the study period. The average maize grain yield across the treatments was 1.1, 5.4, 3.5 and 4.0 Mg ha^{-1} during the 2000 long rains, 2000/2001 short rains, 2001 long rains and 2001/2002 short rains seasons respectively. The poor yields in the 2000 long rains and 2001 long rains seasons were attributed to the poor rainfall received in these two seasons. On average tithonia with half recommended rate of inorganic fertilizer recorded the highest (4.8 Mg ha^{-1}) maize yield followed by sole tithonia (4.7 Mg ha^{-1}).

The highest average concentration (144.8 and 115.5 kg N ha^{-1}) of mineral N was recorded at the 30-100 cm soil depth at the end of both the 2000/2001 short rains and 2001 long rains respectively. The lowest average concentration (67.1 kg N ha^{-1}) was recorded in the 100-150 cm soil depth during the 2000/2001 short rains while during the 2001 long rains the 0-30 cm depth recorded the lowest concentration (52.3 kg N ha^{-1}). The residual mineral N in the 100-150 cm soil depth doubled at the end of the long rains 2001 compared to what was present at the end of short rains 2000/2001 season in all the treatments. This shows that there is a substantial amount of mineral-N that is being leached below the rooting systems of maize.

Sole tithonia was ranked as the best treatment, while, the control was ranked as the poorest treatment by both the farmers and future farmers (students). The treatment ranking by both groups was closely related to the actual maize grain yields attained later at the end of the season. Out of the 171 farmers who attended the 3rd field day, 153 farmers (90%) indicated willingness to take the technologies to their farms. Sole leucaena and calliandra were the most cost effective technologies with a benefit/cost ratio (BCR) of 7.3 while sole tithonia followed closely with a (BCR of 6.9) through out the four seasons.

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ACRONYMS

ANOVA	Analysis of Variance
ICRAF	International Centre for Research in Agroforestry
UM2-UM3	Upper midland 2 to upper midland 3
Var. H513	Variety Hybrid 513

CHAPTER ONE

INTRODUCTION

1.1 Background of the study

Declining soil fertility is a major impediment to the growth of agriculture and the reason for slow growth in food production in sub-Saharan Africa (Sanchez et al., 1995). Annual net nutrient depletion exceeds 30 kg ha^{-1} of N and 20 kg ha^{-1} of K for arable land in Kenya (Smaling, 1993). In many parts of the tropics and particularly tropical Africa, nitrogen is the most limiting nutrient to crop production (Sanchez et al., 1997).

Chuka Division in Meru South District is generally densely populated with more than 647 persons per km^{-2} (Government of Kenya, 2001). The high population pressure has led to the replacement of traditional systems of shifting cultivation with continuous cultivation and unsustainable fallow systems, leading to soil nutrient depletion (Ikombo, 1984). The use of commercial fertilizers has generally been restricted to only a few farms with high endowment of resources. The majority of the smallholder farmers lack the financial resources to purchase sufficient fertilizers to replace the soil nutrients depleted through crop harvesting. As a result, soil fertility has continued to decline and the productivity of the land has declined drastically (Ikombo, 1984; Muriithi et al., 1994; Kapkiyai et al., 1998).

Given the above situation, it was important to access locally available soil fertility improvement technologies, which are affordable to smallholder farmers. This study therefore sought to introduce different locally available technologies in the Meru South District, which could be used by smallholder farmers in curbing the problem of nutrient depletion.

1.2 Statement of the research problem

The declining crop yields consequent to high population pressure has been a major problem experienced by smallholder farmers in Chuka Division, Meru South District, who are faced with the challenge of producing adequate food to feed this high and rapidly growing population. The major factor contributing to reduced productivity is soil impoverishment caused by continuous cropping without addition of adequate fertilizers and manures (Kapkiyai et al., 1998), and nutrient loss through soil erosion and leaching. The use of inorganic fertilizers is as low as less than 20 kg N and 10 kg P ha^{-1} (Muriithi et al., 1994). The amount is inadequate - below the recommended level of 60 kg N ha^{-1}, to meet the crop nutrient requirement for optimum crop productivity in the area. Kihanda (1996) reported that less than 25% maize growers in the central highlands of Kenya use inorganic fertilizers. Wokabi (1994) reported that, though high yielding maize varieties have been developed with yield potentials of 7-12 Mg ha^{-1}, maize yields at the farm level hardly exceed 1.5 Mg ha^{-1}. Surveys carried out in the area indicate that farmers are fully aware of the declining soil fertility (as expressed by declining crop yields), but in most cases they do not have readily available resources to replenish soil fertility (Muriithi et al., 1994; Mugendi, unpublished data).

This calls for the development of improved integrated nutrient replenishment approaches so as to meet the need for adequate food production. The purpose of this study was therefore to address the constraint of declining soil fertility, using locally available nutrient replenishment technologies.

1.3 Research questions

The study sought to answer the following questions:

1. What are the effects of the different soil-incorporated organics (with and without inorganic fertilizers) on soil chemical properties and maize yields?
2. What is the magnitude of nitrogen leaching in the soils in this area?

3. What are the economic costs and benefits of each of the proposed integrated nutrient replenishment technology?

1.4 Objectives

The main objective of the study was to increase food production by encouraging the adoption of integrated nutrient replenishment technologies that are capable of improving soil fertility status in the smallholder systems in the central highlands of Kenya. To achieve this objective the study sought to address the following specific objectives:

1. To compare and contrast the effects of different soil-incorporated organic inputs on soil chemical properties and maize yields.
2. To assess the rate of nitrogen leaching in the soils in this area.
3. To evaluate the economic implications of different proposed nutrient replenishment technologies.

1.5 Research hypotheses

The hypotheses tested in the study were:

1. Soil-incorporated organic inputs have a positive effect on soil chemical properties and maize yields.
2. The magnitude of nitrogen leaching in the soils in this area is high.
3. There are differences in the economic benefits of the different proposed nutrient replenishment technologies.

1.6 Research rationale

Soil fertility decline is a major limiting factor in food production in Chuka Division, Meru south District. Most of the smallholder farmers are not endowed with resources to enable them to apply the recommended rates of inorganic fertilizers to curb the decline in soil fertility. Therefore, there is need to introduce other soil nutrient replenishment technologies that can supplement inorganic fertilizers in order to meet the food production needs of the rapidly growing population. There are diverse organic sources of nutrients that are locally available to the farmers; these include leguminous tree species, farmyard manure, and herbaceous legumes, which can be used to alleviate the problem of nutrient depletion in the area.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

Soil fertility, which is a measure of the health of soils, declines when its nutrient content diminishes, and/or when its physical, chemical, and biological make up changes in ways that lower its ability to support and nourish plants (Donovan and Casey, 1998). Declining soil fertility in smallholder farms is a fundamental impediment to agricultural growth in food production in sub-Saharan Africa and soil fertility replenishment should be considered as an investment in natural resource capital (Sanchez et al., 1995). Africa is losing 4.4 million Mg N, 0.5 million Mg P, and 3 million Mg K every year from its cultivated land. These rates are several times higher than Africa's annual fertilizer consumption, (excluding South Africa) of 0.8 million Mg N, 0.26 million Mg P, and 0.2 million Mg K (FAO, 1995).

Several decades of nutrient depletion have transformed originally fertile lands to infertile ones, for instance, a long term trial in Kabete, Kenya, indicates that a fertile, red soil lost about 1 Mg ha^{-1} of soil organic N and 100 kg P ha^{-1} of soil organic P during 18 years of continuous maize-common bean rotation in the absence of nutrient inputs (Sanchez et al., 1997). During this period maize yields without N and P fertilizer inputs decreased from 3 to 1 Mg ha^{-1} (Swift et al., 1994; Kapkiyai, 1996; Bekunda et al., 1997; Sanchez et al., 1997).

Many interrelated factors, both natural and management of soils cause soil fertility decline. This decline may occur through leaching, soil erosion, and crop harvesting (Donovan and Casey, 1998). Unless the nutrients are replenished through the use of organic or mineral fertilizers, or partially returned through crop residues, or rebuilt more comprehensively through traditional fallow systems that allow restoration of nutrients and reconstruction of soil organic matter, soil nutrient levels and general health decline continuously (Donovan and Casey, 1998).

The two most widespread limiting nutrients to food production in Africa are N and P, in that order, for instance in a series of fertilizer trials conducted throughout the Kenyan highlands, N and P deficiencies were reported in 57 and 26% of the cases, respectively (KARI, 1994). In most smallholder farms these deficiencies are replenished through the use of inorganic fertilizers and cattle manure. However, the use of inorganic fertilizers in the central highlands is as low as less than 20 kg N and 10 kg P ha^{-1} (Muriithi et al., 1994). This is due to the high cost of inorganic fertilizers as well as the low quantity and quality of the manure used (Kihanda, 1996). The amount of N supplied is thus below the recommended level of 60 kg N ha^{-1}, to meet the crop nutrient requirement for an optimum crop production in the area. Thus other low-cost sources of soil fertility replenishment need to be sought.

There are various organic sources of nutrients in the central highlands of Kenya that can be utilized by farmers. These include, farmyard manure, *Tithonia diversifolia*, *Leucaena leucocephala*, *Calliandra calothyrsus*, *Mucuna pruriens* and *Crotalaria ochroleuca*. Organic and inorganic nutrient sources can also be combined. The sections below give introductory background of these nutrient replenishment approaches.

2.2 Farm yard manure

Farmyard manure is common in the central highlands of Kenya and it has been estimated that more than 75% of the farmers growing maize use farmyard manure (Maize Data Base, 1993). Kanampiu and Irungu (1992) reported an application of 4-10 Mg of farmyard manure in the central highlands of Kenya. Manures have the advantage of supplying essential plant nutrients either directly or indirectly by alleviating aluminium toxicity or by producing organic acids, thereby increasing nutrient availability especially

P in high P-fixing soils (Nziguheba et al., 1998). The study area is characterized with low pH and high exchangeable aluminium which reduces crop productivity (FURP, 1987) and the use of farmyard manure which has been demonstrated to reduce exchangeable aluminium in acid soils (Hue and Amien, 1989) could be appropriate in rectifying this problem. The reduction of aluminium by farmyard manure is considered to occur through aluminium precipitation or chelation on organic colloids or by complexation of soluble aluminium by organic molecules, especially organic acids (Hue and Amien, 1989). Other effects of farmyard manure include the improvement of soil structure and subsequent soil permeability, water holding capacity and soil aeration, supply of organic substances that are not directly nutritional but have influence on crop growth, and increased soil microbial activity (Opperman et al., 1989).

A major characteristic of farmyard manure is its variability in chemical composition which is influenced by the quality of the feed given to the animal, storage and handling of the manure (Van Faassen and Van Dijk, 1987; Murwira et al., 1995; Probert et al., 1995). For example, Kwaye (1980) reported that when manure was stored in heaps or in pits until application, the buried manure had substantially greater contents of N, P and K. Nzuma and Murwira (2000) further reported that manures stored in pits had significantly higher N content compared to the manure stored in heaps. This could be due to the large ammonia losses that occurred throughout the decomposition period, which was associated with alkaline conditions possibly due to mineralization of N and transformation of NH_4-N under aerobic conditions. Another factor that might have influenced volatilization was a faster reduction in moisture content in aerobic systems (heap) possibly induced by exposure of manure to windy and high temperature conditions and better aeration resulting in drying and the consequent volatile losses. The value of manure as a source of N ranges from high-quality manure that increases crop yields to low-quality manure that depresses crop yields due to N immobilization, with a critical threshold value of 1.25% N (12.5 g N kg^{-1}; Mugwira and Mukurumbira, 1986).

Yield responses to manure can be seen in crops for several years after application when the manure is supplied in sufficiently large amounts (Mugwira and Murwira, 1997). The study therefore sought to establish the maize productivity over time in response to manure application at the recommended rate of N in Chuka.

2.3 Biomass transfer

This technology involves ex-situ production of biomass away from the cropping land in designated areas or hedges or around or within the farm. The biomass is then harvested and applied as mulch or incorporated into the soil before and/or after the crop is planted. In this technology the interactions between the components is only through the nutrient release from applied mulch and the uptake by the crop. The system eliminates competition but often requires substantial labor inputs during biomass transfer activities.

2.3.1. *Tithonia diversifolia*

Recent research by the Kenya Agricultural Research Institute (KARI), Kenya Forestry Research Institute (KEFRI), Tropical Soil Biology and fertility Programme (TSBF) and International Center for Research in Agroforestry (ICRAF) in western Kenya has dramatically raised the awareness and expectations of tithonia green biomass for soil nutrient replenishment (Niang et al., 1996). *Tithonia diversifolia* commonly known as Mexican sunflower, is a non-N_2-fixing shrub of the family Asteraceae, which grows 1 to 3 m in height. It commonly grows along fields and farm boundaries as well as along roads and it produces large quantities of leaf biomass and tolerates regular pruning (Buresh and Niang, 1997). Tithonia which is not a N fixing shrub accumulates as much N in its leaves as N-fixing legumes, presumably because of its greater root volume and ability to scavenge nutrients from the soil (Szott et al., 1991; Gachengo, 1996).

Gachengo (1996) identified green biomass from tithonia-grown ex-situ and transferred into a field as an effective source of nutrients for maize. It was as effective in supplying N, P, and K to maize as an equivalent amount of commercial NPK fertilizer. Maize yields in some cases were also higher with tithonia biomass than commercial fertilizer. Tithonia applied at 2 Mg ha^{-1} on a dry weight basis contains about 60 kg N ha^{-1}, 5 kg P ha^{-1} and 60 kg K ha^{-1}. Tithonia decomposes and releases its nutrients rapidly. Gachengo et al. (1999) reported a half-life of about one week for the disappearance of dry matter in the rainy season in western Kenya. Phosphorus release from tithonia green biomass is rapid, and it supplies plant available P at least as effective as an equivalent amount of P from soluble fertilizer (Nziguheba et al., 1998).

Jama et al. (1999), reported that green biomass of tithonia is high in nutrients, averaging about 3.5% N, 0.37% P, and 4.1% K on a dry matter basis. Thus, tithonia green biomass has relatively high macronutrient contents as compared to green biomass of other shrubs and trees. The N concentrations in tithonia are comparable to those found in N_2-fixing leguminous shrubs and trees, whereas the P and K concentrations are higher than those typically found in shrubs and trees.

Mutuo et al. (2000) reported that 5 Mg ha^{-1} of tithonia had higher residual effects (50% yield increase) than other treatments that had yield increases of about 30% above the control in western Kenya. Application of 5 Mg ha^{-1} from tithonia biomass gave significantly higher yield (5.7 Mg ha^{-1}) than sole application of fertilizer (4.7 Mg ha^{-1}) (Nziguheba and Mutuo, 2000). The sustainability of tithonia use by farmers to recycle nutrients in farming systems can be however limited by the long-term availability of the plant material and intensive labor involved in biomass collection, processing and application (Jama et al., 1999; Mutuo et al., 2000).

2.3.2 *Leucaena leucocephalla and Calliandra calothyrsus*

The properties of leucaena that make it a useful agroforestry tree in improvement of soil fertility include; high biomass production about 10-25 Mg dry matter ha^{-1} yr^{-1}, high nitrogen fixation of about 100-500 kg N ha^{-1} yr^{-1} (Young, 1989), high level of nitrogen in leaves of about 2.5-4.0% (Young, 1989; Delve et al., 2000) and thus high rate of return in litter or pruning. It also contains substantial content of other nutrients in leaves; about 0.28% P, 2.5% K, and 1.49% Ca (Young, 1989). In addition to providing nitrogen, the application of leucaena biomass greatly increases the availability of phosphorus and exchangeable potassium in the soil. It is a fast growing tree that withstands lopping, coppicing and pollarding (ICRAF, 1992).

Calliandra produces high yields of protein rich leaf material that are suitable as green manure (Gutteridge and Shelton, 1994). It is a fast growing tree on good sites, it withstands lopping, and coppicing. Although the tree coppices well, stand vigor declines with time (ICRAF, 1992). Fresh pruning of calliandra have been used as green manure. It has the ability to decrease soil bulk density, increase soil porosity and availability of water in soil (Liyanage and Abeysoma, 1996), therefore, the improvement of the soil physical conditions is pronounced with calliandra. IITA (1987/8) estimated the nutrients from calliandra pruning as 169 kg N, 8 kg P, 83 kg K, 423 kg Ca and 26 kg Mg ha^{-1} yr^{-1}.

Mugendi et al. (1999) reported that calliandra and leucaena green biomass (with or without fertilizer) had significant increase in maize grain yields as compared to the inorganic fertilizer. With biomass incorporation, an average of 4.1 Mg ha^{-1} of maize grain per season was obtained, compared to 3.3 Mg ha^{-1} obtained from the application of the recommended level of inorganic fertilizer and 3.1 Mg ha^{-1} per season for the absolute control. The rate of soil fertility decline was reduced with the application of biomass, with total soil nitrogen increasing by 1-8%, however, without the application of biomass total soil nitrogen declined by 2-4%. Mafongoya and Nair (1997) reported a maize grain yield of 5.6 Mg ha^{-1} with application of leucaena biomass compared with 1.1 Mg ha^{-1} from the control in Zimbabwe.

These organic materials have shown impressive results in the on-station trials but little research has been carried out on-farm, this study therefore sought to take these technologies on-farm and assess their effects on maize grain yield and soil chemical properties.

2.4 Herbaceous legumes

Legumes enrich the soil by biological atmospheric nitrogen fixation and can replace nitrogen fertilizers, wholly or in part. Biological nitrogen fixation is the process by which atmospheric dinitrogen is converted to a biologically useful form of ammonia nitrogen through a reduction reaction (Loomis and Connor, 1992). The reduced form of fixed nitrogen is readily available for crop uptake. The fixed nitrogen is assimilated into plant parts and then released into the soil through litter-fall, green manure, roots and nodule decay. There are various factors that affect the legume symbiotic fixation in the soil and hence the overall beneficial effects from nitrogen fixation. These factors include the presence of appropriate rhizobia, deficiency of plant nutrients other than nitrogen, soil acidity and aluminium toxicity, water stress, temperature among others (Loomis and Connor, 1992; Sanchez et al., 1997).

Biological N fixation from legumes can sustain tropical agriculture at moderate levels of output (Giller et al., 1994; 1997; Giller, 2002; Bekunda et al., 1997). As much as 30-60 kg N ha^{-1} yr^{-1} is reported to be added to the soil by legumes (Reinjntjes et al., 1992). Sanginga et al. (1996) reported that across all cropping systems (mixed and mono cropping) *Mucuna pruriens* derived an average of 70% of its N from atmospheric nitrogen (estimate made by the ^{15}N isotope dilution method), representing 167 kg N ha^{-1}

per 12 weeks in the field. Mucuna accumulated in 12 weeks about 313 kg N ha^{-1} as either a sole crop or 160 kg N ha^{-1} when mixed/intercropped with maize respectively (Sanginga et al., 1996).

Herbaceous legumes also improve the yield of food crop through weed suppression, soil erosion control and production of fast decomposing residues that release nutrients to the subsequent crop. Tian and Kang (1998) argue that contribution of legumes to soil improvement and crop production depends primarily on biomass production (which controls nutrient cycling) and chemical composition (which controls residue decomposition and nutrient release). Gitari et al. (1998) reported that mucuna biomass accumulation in a maize intercrop could reach an average of 8.1 Mg ha^{-1} when rains were favorable.

Ile et al. (1996) reported doubling of maize grain yields using mucuna biomass. Incorporating mucuna biomass into the soil has been found to increase maize grain yields by 46% above farmer practice in the central highlands of Kenya (Gitari et al., 1998), while Gachene et al. (1999) reported maize yield of 88% and 107% higher than the control after incorporating mucuna and crotalaria respectively. In western Kenya, Ojiem and Okwuosa (1998) reported an increase of maize grain yield in the range of 2.2 to 2.4 Mg ha^{-1} above farmers' own practice. In Uganda, Fischler (1999) obtained maize grain yield increase of 39% using *Crotalaria ochroleuca* green manure.

The Legume Screening network Research Project identified mucuna (*Mucuna pruriens*; velvet bean) and crotalaria (*Crotalaria ochroleuca*; Tanzanian sunnhemp) as some of the most promising legumes in the central highlands of Kenya (Embu) in terms of biomass production, nodulation and nitrogen fixation, ground cover, pests and disease resistance (Gitari et al., 1997). Although inoculation with appropriate rhizobia may increase the level of nodulation, mucuna and crotalaria produce effective nodules, in the central highlands of Kenya in the absence of any external inoculation (Mureithi and Gachene, 1998).

Most of the legume work in the central highlands of Kenya has only been carried out in the research stations. The study thus sought to assist in the introduction of these legumes in the farming systems (farmer's field) and to establish their effects on soil nutrient composition and maize grain yield. It is also important to establish whether they would do as well in Chuka as they have done in Embu where the research has been done.

2.5 Organic and inorganic nutrient combinations

While fertilizer, used effectively is essential to attain sustainable agricultural growth, technologies that use organic resources are also essential and in some cases more appropriate and feasible for resource-poor farming system. Traditional organic materials such as crop residues and animal manure, however, cannot by themselves reverse soil fertility decline because they are not available in sufficient quantities in most farms. Low nutrient content and high labor demand in their processing and application also limit their use (Palm et al., 1997).

Technologies that combine mineral fertilizers with organic nutrient sources can be considered as a better option in increasing fertilizer use efficiency, reducing risks of acidification, and providing a more balanced supply of nutrients (Donovan and Casey, 1998). Combination of organic and inorganic nutrient sources has been shown to result into synergy and improved synchronization of nutrient release and uptake by crop (Palm et al., 1997) leading to higher yields; especially when the levels of inorganic used are relatively low as is the case in smallholder farms of central Kenya (Kapkiyai et al., 1998; 1999). The practice may hold the key to effective soil fertility management in Meru South District of Kenya.

Studies by Tian et al. (1993), show that nutrient uptake and grain yield of the crop was higher when nitrogen was partially applied as prunings, indicating the importance of the combined addition of plant residue and fertilizer N for improving crop production. Gachengo (1996) reported that mixing of tithonia with inorganic P resulted in significant maize grain yield increase (2.42 Mg ha^{-1}) as compared to the sum of the maize grain yields of inorganic P alone and tithonia alone (1.27 Mg ha^{-1}). Gachengo et al. (1999); Jama et al. (1999); Mutuo et al. (2000) and Nziguheba and Mutuo (2000) also reported the same trend with tithonia integrated with inorganic fertilizer. Maize yields were increased with increasing rates of farmyard manure application, however, maize grain yields above 3.5 Mg ha^{-1} were only obtained when both farmyard manure and NP fertilizers were applied (Kihanda, 1996). Suggestions have been made to incorporate FYM with inorganic fertilizers so as to boost production (Kihanda, 1996; Kapkiyai et al., 1999; Kibunja and Gikonyo 2000). Leucaena biomass combined with inorganic fertilizer gave higher crop yields as compared to sole use of inorganic fertilizer or sole leucaena biomass (Cotejo, 1982; Chagas, 1983; Palled et al., 1997; Escalanda and Ratilla, 1998; Mugendi et al., 1999). Gichuru and Kana (1989) and Mugendi et al. (1999) also observed the same trend with calliandra biomass.

Literature has clearly indicated that the integration of organic and inorganic sources of nutrients perform better than the sole application of either. The study therefore sought to integrate different sources of organics and inorganic fertilizer to establish their performance in Chuka and to encourage farmers to adopt them.

2.6 Nitrogen uptake

The amount of nutrients recovered from the soil by any crop will always depend on the yield got from that particular crop (Sanchez et al., 1997; Halvorson et al., 2001). This implies that an increase in yield will result in an increase in the removal of soil nutrients.

High rates of nutrient uptake are maintained when other factors like solar radiation, water and other nutrients are not limiting (Wild and Jones, 1988). Ayub (2000) observed that the greatest uptake of nitrogen occurs during the period of the highest growth rates but the concentration of N in plant tissues may decrease as plant biomass increases. Hence N mineralized late in the growing season may not be effectively utilized and could reduce use efficiencies. Tian et al. (1993) and Tian and Kang (1998) reported that nutrient uptake and grain yield of the crop was higher when nitrogen was partially applied as prunings, indicating the importance of the combined addition of plant residues and fertilizer N for improving crop production. Halvorson et al. (2001) reported that nitrogen removal in the grain increased with increasing N rate in most years.

2.7 Residual mineral nitrogen

The global cycle of nitrogen has been altered by human activity to a greater extent than of any other element. The production of N fertilizers, cultivation of legumes, and incidental fixation by combustion together transfer more N from the atmosphere into biologically available forms than is fixed by natural processes combined (Soon et al., 2001). Improper utilization of N fertilizers lead to eutrophication and increased nitrate contamination in surface and ground waters which could lead to a variety of human and animal health problems (Heathwaite et al., 1993; Nieder et al., 1995).

Inorganic nitrogen (ammonium and nitrate) released from soil organic matter mineralization may be taken up by plants, lost from the soil system through leaching and denitrification or retained in the soil profile (Shepherd et al., 2000; Halvorson et al., 2001; Randall and Mulla, 2001; Dana et al., 2002). Nitrate leaching is an important pathway of loss in cultivated agricultural lands. Nitrate is loosely held by soil particles and can easily be washed down the soil profile (Loomis and Connor, 1992; Randall and Mulla, 2001; Dana et al., 2002). Wild (1972) reported that leaching of mineralized NO^{-}_{3}-N is not as rapid as that of NO^-_3-N applied as fertilizer due to the time taken for the NO^-_3-N to diffuse to the large pores and channels through which water drains preferentially. In acid soils leaching of NO^-_3-N is retarded due to retention of NO^-_3 ions by positive charges (Wild, 1972; Wong et al., 1987; Hartemink et al., 1996). Nitrate losses from crop root zones normally range from 2 to 100 kg N ha^{-1} yr^{-1} (Wild and Cameron, 1980), however, losses of 170 kg N ha^{-1} yr^{-1} of soil and fertilizer N have been measured in freshly cultivated soils in humid tropics (Van der kruijs et al., 1988).

Non-point loss of NO^-_3-N is caused by a combination of various factors as outlined here. Leaching is highly dependent on soil type, for instance, Nieder et al. (1995) reported an average annual leaching rate for heavier arable soils to be estimated at 16 kg NO^-_3-N ha^{-1} and for arable sandy soils 63 kg NO^-_3-N ha^{-1} (i.e., the lighter soils the higher the leaching potential). It is also affected by rainfall intensity/pattern, amount of nitrogen applied and the time of application (Kolenbrander, 1981, Shepherd et al., 2000; Randall and Mulla, 2001; Dana et al., 2002). Continuity of soil cover (Kolenbrander, 1981; Halvorson et al., 2001; Soon et al., 2001; Dana et al., 2002) as well as the soil organic matter levels, tillage, and crop selection (Dana et al., 2002) also affect the rate on N leaching.

In the subhumid to humid tropics, precipitation rates usually exceed potential evapotranspiration rates during part of the growing season, which favor water flow through the crop root zone (Shepherd et al., 2000; Dana et al., 2002). Acid tropic soils with variable charge are further prone to N leaching, because they have stable aggregation that promotes rapid drainage and movement of N (Sollins et al., 1988). Plant N uptake is often limited in such soils by P deficiency and Al-toxic sub soils, which limit root growth (Van Noordwijk, 1989) thus limiting N uptake, which enhances N leaching.

Soil NO^-_3-N can be derived from both organic and inorganic N. Whether the N source is animal manure, organic residues or inorganic fertilizers, over-application or illtimed application of either can provide too much plant-available N and increase the potential for NO^-_3-N leaching (Hatfield and Cambardella, 2001). Balancing the amount of N needed for optimum plant growth while minimizing the NO^-_3-N that is transported to ground and subsurface waters remains a major challenge for everyone attempting to understand and improve agricultural nutrient use efficiency (Dana et al., 2002). There is increased concern about nitrate concentrations in receiving waters at a regional scale related to land cultivation, not only in high-input farming systems (Heathwaite et al., 1993), but also in low-input tropical farming systems (Bullock et al., 1995). Nitrate N concentrations in excess of 10 mg L^{-1} in drinking water may pose health risks to humans and livestock (USDA, 1991) and have cost some communities millions of dollars for their removal or to provide alternate drinking water sources (Dana et al., 2002). The mineral N below the rooting zone of plants is not available to the plants (Mugendi et al., 2000; Delgado et al., 2001; Paramasivam et al., 2001; Dana et al., 2002) and thus it is prone to leaching into ground water, therefore careful management of soil fertility inputs needs to be put into place. Some strategies for improved nitrogen management are discussed briefly in the following sections:

- *Timing of application and nitrogen rates*

The challenge is to manipulate N availability before, during and after peak crop demand. The risk of N losses due to leaching, denitrification, volatilization and immobilization increases as the time between N application and crop uptake increases (Delgado et al., 2001; Randall and Mulla, 2001; Dana et al., 2002). This is true for residue N as well as applied N (Magdoff, 1991, Karlen et al., 1998), especially in years that do not produce optimal yields (Power et al., 1998). Limiting the amount of inorganic N within the soil at the end of a growing season and before the next crop has established an extensive root system is a key factor for reducing N losses (Randall and Mulla, 2001; Dana et al., 2002). Power et al. (2000) and Randall and Mulla (2001), noted that soils are seldom uniform throughout a field, so applying sufficient fertilizer N to assure high yields for more productive areas of the field often results in over-fertilization of the less productive areas. This may lead to greater nitrate leaching, particularly in those areas of the field that are more susceptible to leaching (Dana et al., 2002). Several studies have found large differences in crop yield and crop N response within individual fields (Kitchen et al., 1995; Vetch et al., 1995), confirming the need for reliable methods to generate site-specific N recommendations (Hergert et al., 1997; Delgado et al., 2001; Randall and Mulla, 2001). Split application of inorganic fertilizer has also been reported to reduce nitrate leaching (Delgado et al., 2001; Randall and Mulla, 2001; Paramasivam et al., 2001). However, Baker and Melvin (1994) reported that losses of nitrate were higher for split application compared with a pre-plant application for continuous corn.

- *Diversified crop rotations*

Changing from continuous maize to maize-soybean rotation has been shown to reduce nitrate leaching although the amount of reduction may be minimal, depending on climatic conditions (Randall et al., 1997; Randall and Mulla, 2001). Including perennial legume or non-legume crops in rotations has also been shown to decrease nitrate losses. Mugendi et al. (2000) reported that treatments without tree hedges recorded higher amounts of mineral-N in the 100-300 cm depth averaging 330-660 kg N ha^{-1} whereas soils in treatments with tree hedges (*Leucaena leucocephala* and *Calliandra calothyrsus*) recorded an average of 22-66 kg N ha^{-1} in the same depth indicating that trees are capable of intercepting and recapturing the crop-inaccessible nutrients, below the roots of the annual crops by the action of their deep roots. This could be as a result of longer growing seasons and greater annual evapotranspiration in fields with perennials because both of these processes contribute to greater N uptake and less drainage than in fields with only annual crops (Randall and Mulla, 2001; Dana et al., 2002).

- *Cover crops and green manure*

Cover crops have been shown to reduce the potential for nitrate leaching from farm fields (Magdoff, 1991; Kuo et al., 1997; Staver and Brinsfield, 1998) by mimicking natural ecosystems. They function by accumulating the inorganic soil N between main crop seasons and holding it in an organic form, thus preventing it from leaching (Magdoff, 1991; Staver and Brinsfield, 1998). The N is subsequently released to the next crop as the cover crop residue decomposes. In studies reviewed by Meisinger et al. (1991) cover crops reduced both the mass of N leached and nitrate concentration of leachate by 20-80% compared with no cover crop control.

Gunnar and Helena (2000) also noted that careful integration of organic with inorganic sources of N were important in reducing the rate of N leaching.

There is insufficient documented literature on nitrogen leaching in the study area, thus, there is need for more research to establish the quantity of nitrate leached from the plant-soil system. The literature review indicates that different soil nutrient management strategies affect the rate of nitrogen leaching differently. The current study having different soil nutrient replenishment technologies sought to establish whether they have the potential of reducing the magnitude of nitrate leached down the soil profile as shown in other studies.

2.8 Economic Analysis

For farmers to accept any new technology, the returns to the new technology must be superior to those achieved through the existing technologies. The adoption of any new technology depends on farmer's perceptions of the financial benefits, particularly when additional labor is required in the establishment and management of these technologies. In their study in western Kenya, Jama et al. (1997) reported that added costs were lowest for manure, intermediate for inorganic sources and highest for calliandra biomass. Net benefits were positive for inorganic sources and manure but frequently negative for calliandra (biomass transfer). The negative benefits for the organic sources (biomass transfer) reflect the high labor requirements (Sanchez et al., 1997; Jama et al., 1998a).

The use of tithonia is economically more attractive with high than low-valued crops. Jama et al. (1999) concluded that its potential was greatest on small landholdings with nearby production of tithonia biomass and with ample, low-cost labor for cutting and carrying the biomass. Studies by Mutuo et al. (2000) ranked cost of application of tithonia biomass as the most expensive, however, about a third of the farmers did not consider tithonia treatments costly probably because of low valuation of their time and labor and the inability to assign a market value for tithonia. Since most of the organic biomass used to replenish soil nutrients currently do not have market values, the economic analysis is relative depending on the costing. For instance, Jama et al. (1997) reported that the added costs for calliandra biomass were much greater when calliandra was valued at the opportunity cost of dairy concentrate than at the cost of production. Most studies on the use of organic inputs are invariably unaccompanied by economic (costs and returns) analysis, this study therefore sought to determine the economical feasibility of the various soil fertility replenishment technologies that were to be introduced in the area.

CHAPTER THREE

RESEARCH DESIGN AND METHODOLOGY

3.1 Introduction

3.1.1 Study Area

The study was conducted in Kirege, Chuka Division, Meru South District, Kenya. According to Jaetzold and Schemindt (1983), the area is in upper midlands 2 and 3 (UM2 and UM3) with an altitude of approximately 1500 m above sea level, annual mean temperature of about 20^0 C and annual rainfall varying from 1200 to 1500 mm. The rainfall is bimodal, falling in two seasons, the long rains (LR) lasting from March through June and short rains (SR) from October through December (Jaetzold and Schemindt, 1983). About 65% of the rains come during the long rainy season. The main food crop is maize. The soils are Humic Nitisols, deep, well weathered with moderate to high inherent fertility (Jaetzold and Schemindt, 1983).

3.1.2 Choice of the site

The choice of the district was based on the fact that not much of the soil fertility related research activities have been conducted in this district compared to Embu District where the KARI Regional Center and National Agroforestry Research Project are located. In addition, much research work has been done in the research stations but these technologies have not reached the farmers who are supposed to be the beneficiaries of this work. The experiment sought to bring these technologies close to the farmers to help facilitate adoption. The experiment was located in Kirege primary school, which is a public property thus accessible to all the farmers as a demonstration site.

3.2 Experimental Design and management

The experiment was established in March 2000 on a farm with poor and impoverished soils and laid out as a randomized complete block design (RCBD) with 3 replicates (Appendix 1) with plot sizes of 6 m x 4.5 m. The test crop, maize (*Zea mays* L, var. H513) was planted at a spacing of 0.75 m and 0.5 m inter- and intra-row, respectively. Three (3) seeds were sown per hole and thinned four weeks later to 2 plants. Thirteen external soil fertility amendment inputs (Table 1) were applied to give an equivalent amount of 60 kg N ha^{-1} with the exception of the herbaceous legume treatments where by the amount of N was determined by the amount of the biomass harvested and incorporated (Table 2) in the respective treatments. The fourteenth treatment was the absolute control (no soil fertility enhancement input) representing farmers on the lower end of resource endowment.

TABLE 1: Experimental treatments: Soil applied fertility amendment inputs and their N contribution at Chuka

No	Treatment	Amount of N supplied (kg ha^{-1})	
		Organic	Inorganic
1	Mucuna	-	-
2	Crotalaria	-	-
3	Mucuna + 30 kg N ha^{-1}	-	30
4	Crotalaria + 30 kg N ha^{-1}	-	30
5	Cattle manure	60	-
6	Tithonia diversifolia	60	-
7	*Calliandra calothyrsus*	60	-
8	*Leucaena trichadra*	60	-
9	Cattle manure + 30 kg N ha^{-1}	30	30
10	Tithonia + 30 kg N ha^{-1}	30	30
11	Calliandra + 30 kg N ha^{-1}	30	30
12	Leucaena + 30 kg N ha^{-1}	30	30
13	Recommended rate of fertilizer	-	60
14	Control	-	-

Two rows of herbaceous legumes were planted between two rows of maize plants two weeks after maize was planted. The legumes were left to stay in the field (after maize was harvested) till land preparation for the next season when they were harvested, weighed, chopped and incorporated into the soil to a depth of 15 cm. The weight of the herbaceous legume biomass applied during the second, third and fourth seasons is shown in Table 2.

TABLE 2: Herbaceous legumes incorporated in the 2000/2001 short rains, 2001 long rains and 2001/2002 short rains seasons in Chuka

Treatment	**2000/2001 short rains season**		**2001 long rains season**		**2001/2002 short rains season**	
	Biomass incorp. (Mg ha^{-1})	N equivalence (kg ha^{-1})	Biomass incorp. (Mg ha^{-1})	N equivalence (kg ha^{-1})	Biomass incorp. (Mg ha^{-1})	N equivalence (kg ha^{-1})
Mucuna	0.2	5.9	3.7	110	0.18	5.3
Crotalaria	0.3	9.0	5.6	168	0.02	0.6
Mucuna + 30 kg N/ha	0.3	8.8	4.1	120	0.14	4.1
Crotalaria + 30 kg N/ha	0.1	3.0	5.4	162	0.04	0.1
SED	**0.2**	**6.0**	**0.6**	**21.2**	**0.1**	**1.6**

The other organic materials (biomass transfer) were applied and incorporated into the soil to a depth of 15 cm during land preparation in the four seasons. The average nutrient composition of the organic inputs that were incorporated in the four seasons is as shown in Table 3.

TABLE 3: Average nutrient composition (%) of organic materials applied in the Soil during the 2000 long rains, 2000/2001 short rains, 2001 long rains and 2001/2002 short rains seasons at Chuka

Treatment	**N**	**P**	**Ca**	**Mg**	**K**	**Ash**
Cattle manure	1.4	0.2	1.0	0.4	1.8	46.1
Tithonia	3.0	0.2	2.2	0.6	2.9	13.2
Calliandra	3.3	0.2	0.9	0.4	1.1	5.8
Leucaena	3.8	0.2	1.4	0.4	1.8	8.7
SED	**0.11**	**0.004**	**0.03**	**0.01**	**0.05**	**0.28**

The compound fertilizer NPK (23:23:0) was the source of inorganic N and was applied at sowing during the four seasons. Other agronomic procedures for maize production were appropriately followed after planting. During the first season, a general P deficiency was noted, thus a uniform top dressing for P, as triple super phosphate (TSP), was applied during the 2000/2001 short rains, 2001 long rains and 2001/2002 short rains seasons.

3.3 Sampling

Initial soil sampling was carried out in March 2000 just before the experiment was established while the final sampling was carried out in March 2002, two years after the establishment of the experiment.

3.3.1 Soil

For the initial and final sampling, soil samples were collected with an Eldelman auger at 0-15 cm for analyses of soil N, K, P, C, Mg, Ca, and pH. Soil samples were taken at 8 different spots per plot and then bulked to one sample. At the end of the 2000/2001 short rains and 2001 long rains seasons soil samples were collected at 0-30 cm, 30-100 cm and 100-150 cm, for mineral N (ammonium and nitrate) determination to enable comparison of leaching in the different treatments. At 0-30 cm soil depth, soil auguring was done at six spots per plot and then bulked to one sample, while four spots were augured and bulked per plot for the 30-100 and 100-150 cm soil depth. The soil was then sub-sampled after thorough mixing.

3.3.2 Organic materials

Sub-samples of all the organic amendments were collected randomly at the beginning of each season and analyzed for N, P, K, Ca and Mg to determine their quality. Maize grain and stover were also collected randomly from each plot at the end of the 2001 long rains and 2001/2002 short rains seasons and analyzed for N.

3.3.3 Maize plant height

Maize heights were taken at 4, 8, 16 and 20 weeks after planting during the 2001/2002 short rains season and 20 weeks after planting during the 2001 long rains season. The height of every 4th maize plant was taken systematically leaving out the guard rows in all the plots.

3.3.4 Phosphorus deficiency

The plant response to P deficiency was visually scored 50 days after the crop emergence using a scale of 1-4 during the 2000 long rains season where:

- 1 - no plant P-deficiency
- 2 – mild plant P-deficiency
- 3 – medium plant P-deficiency
- 4 - severe plant P-deficiency

3.3.5 Maize harvesting

Maize grain and stover were harvested at maturity from a net area of 21.0 m^2 after leaving out one row on each side of the plot and the first and last maize plants on each row to minimize the edge effect. The cobs in each plot were separated from the stover and then the fresh weight determined. The cobs in each plot were then air dried to 12.5% moisture content. The maize grains were then separated from the core through hand shelling and then weighed to give the net grain weight. The maize stovers were cut at ground level and the total fresh weight determined. After harvesting all the maize stovers were removed from the experimental plots to ensure that they did not return any nutrients to the experimental plots.

3.4 Farmers' Field days

In order to achieve the adoption of the technologies, full involvement of the farmers from the initial stages of experimentation was necessary. The trial was therefore located on a school farm to facilitate accessibility to farmers considering that the school is a public property. A farmers' field day was then held in each growing season at the grain filling stage where farmers and future farmers (students) qualitatively (visually) evaluated the treatments. During the 2000/2001 short rains season farmers evaluated the trial using 1-5 ranking criteria, where:

1 – poorest performance
5 – best performance

In the 2001/2002 short rains season, farmers and students evaluated the treatments using the following criteria:

Height – 1 = short, 2 = medium, 3 = tall
Cob size – 1 = small, 2 = medium, 3 = large
Vigor – 1 = poor, 2 = good, 3 = very good
Colour – 1 = yellow, 2 = green, 3 = deep green

The farmers were also asked to select the technologies they wished to take to their farms during these sessions.

3.5 Laboratory analysis

3.5.1 Soil analysis

Soil samples were analyzed for N, P, K, Ca, Mg, pH, ammonium and nitrate using the ICRAF Laboratory Methods of Soil and Plant Analysis (ICRAF, 1995).

3.5.1.1 Soil moisture content

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 determined. The soil moisture content was then calculated using the formula in Appendix 2.

3.5.1.2 Soil pH

Ten milligrams of soil was scooped and added to 60 milli-liter (mL) bottle then 25 mL distilled water was added with a dispenser. The solution was then stirred for 10 minutes and then let to stand for 20 minutes. Immediately before measuring the pH of each sample, the sample was stirred for 5 seconds with a glass rod. The soil was allowed to settle for 30 seconds and then the electrode immersed into 60 mL bottle with soil and pH reading was recorded after reading stabilized (about 30 seconds to 1 minute). The electrode was then removed from the bottle, rinsed with distilled water. All the samples were treated the same way.

3.5.1.3 Exchangeable Acidity

The 2.5 mL spoon was tarred with holder on balance and 2.5 mL of soil was scooped. The spoon with soil and holder were then weighed and the weight recorded. The soil was then added to 60 mL bottle and 25 mL 1 *N* potassium chloride added with a multiple dispenser and then stirred for 10 minutes. The solution was then filtered by gravity through whatman No. 5 filter paper. Ten mL of the filtrate extract and 15 mL deionised water were then dispensed in a 60 mL bottle and 2 drops of phenolphthalein indicator added. The solution was then titrated with standardized sodium hydroxide until a pale pink colour appeared and persisted for 15 to 30 seconds and the volume of the sodium hydroxide recorded to 0.05 mL. The exchangeable acidity was then calculated using the formula in Appendix 2.

3.5.1.4 Extractable soil nitrate and ammonium

Twenty (20) g of field moist soil was extracted using 100 ml 2 *N* KCl by shaking for one hour at 150 reciprocations per minute. This was followed by gravimetric filtration through a pre-washed whatman No.5 paper. The resulting extract was analyzed first for ammonium using calorimetric method, followed by extractable nitrate which was analyzed using cadmium reduction with subsequent calorimetric determination (Dorich and Nelson, 1984; Anderson and Ingram, 1993). To determine ammonium concentration, 2.0 mL of the extract was transferred into labeled test tubes. Five mL of reagent N1 (68 g sodium salicylate + 50 g sodium citrate + 50 g sodium tartrate + 0.24 g sodium nitroprusside mixed with deionised water to make to 2 liters) and 5 mL of reagent N2 (60 g sodium hydroxide + 20 mL sodium hypochlorite + deionised water to make to 2 liters) were then added to each sample, mixed well and left for one hour for full colour development. The absorbance was then read at 655 nm using a spectrophotometer. For nitrate determination, 1 mL concentrated ammonium chloride was added into the Cd column and 3 mL of sample pipetted into the column and the solution was then drained (into a test tube containing 5 mL sulphanilic acid reagent) almost to the top of the granules, leaving 2 mm of the solution on top. The reservoir was then rinsed with approximately 2 mL dilute ammonium chloride solution and again drained into the test tube almost to the top of granules leaving 2 mm solution on top. Forty five (45) mL of dilute ammonium chloride was then added to the reservoir and drained within 25 - 30 seconds leaving approximately 2 mm of the solution on top of the column. The test tube was then removed, stoppered and shaken well and let to stand for at least 5 minutes after which 5 mL of 5-amino-2-naphthalene sulphonilic acid (5-2 ANSA) solution was added, stoppered well and shaken. The solution was let to stand for 30 minutes and the absorbance read at 525 nm using a spectrophotometer. The soil extractable nitrate and ammonium was then calculated using the formula in Appendix 2.

3.5.1.5 Total nitrogen and phosphorus

Total nitrogen and phosphorus were analysed following the Kjeldahl method (Anderson and Ingram, 1993). About 0.4 g of soil was ground to pass 0.3 mm mesh and then digested with 7.5 mL of the digestion mixture (selenium powder + conc. sulphuric acid + salicylic acid) and let to stand overnight. The following day the solution was heated at 100° C for one hour and then allowed to cool, then 1 mL aliquots of 30% hydrogen peroxide was added to the solution and the temperature raised to 250°C, heated for one hour, then raised to 330° C and heated for two hours. The solution was allowed to cool, then 70 mL of deionised water added and allowed to settle overnight. For nitrogen analysis 5.0 mL of N1 reagent was added to 0.2 mL of the digested solution in a test tube and left for 15 minutes, 5.0 mL of reagent N2 was then added to the solution, mixed well and left for one hour for colour development. The sample concentration was then read at 655 nm using a spectrophotometer. For phosphorus analysis, 4.0 mL ascorbic acid solution and 3.0 mL molybdate were added to 0.5 mL of the digested solution, mixed well and then left for one and a half hours for colour development. The concentration was then read at 880 nm using a spectrophotometer. The total N and P were then calculated using the formula in Appendix 2.

3.5.1.6 Exchangeable Calcium and Magnesium

For exchangeable calcium and magnesium determination, the 2.5 mL spoon was tarred with holder on the balance. The soil sample was then scooped to fill the spoon, then weighed and the weight recorded. The soil was put in a clean 60 mL bottle and extracted for calcium and magnesium using 2 *N* KCl for 10 minutes and then filtered with whatman No. 5 filter paper. Two mL of filtered extract were then diluted with 8 mL deionised water and 10 mL of lanthanum solution using a multiple dispenser. The concentration of calcium and magnesium was then read using the atomic absorption spectrophotometer at 422.7 nm and 285.2 nm respectively. The concentration was then calculated using the formula in Appendix 2.

3.5.1.7 Extractable Potassium

To determine extractable potassium, 2.5 mL of soil sample was scooped as described above in the exchangeable calcium and magnesium determination. The soil was the added to 60 mL bottle and 25 mL extracting solution was added to bottle with a multiple dispenser. The solution was stirred for 10 minutes then filtered by gravity through whatman No.5 filter paper into clean 60 mL bottles. For K determination 2 mL filtered sample and 8 mL distilled water were transferred to clean 60 mL bottle and swirled gently to mix. The filter selector was set in the flame photometer to the required "K'' position and the concentration read.

3.5.1.8 Total organic Carbon

About 1.0 g soil sample ground to pass through a 0.3 mm mesh was weighed and put in a test tube and 2 mL-deionised water added into the soil sample. Ten mL 5% potassium dichromate solution and 5 mL concentrated sulphuric acid were then added consecutively and the mixture was then digested at 150° C for 30 minutes. The mixture was then allowed to cool and 50 mL 0.4% barium chloride added to it, it was then shaken and allowed to stand overnight. The concentration was read at 600 nm on the spectrophotometer and total organic carbon was then calculated using the formula in Appendix 2.

3.5.2 Organic materials analysis

The sub samples of all organic materials were oven-dried at 60° C for 48 hours, then ground to pass through a 1.0-mm sieve and analyzed for nitrogen, potassium, phosphorus, calcium and magnesium by Kjeldahl digestion (Anderson and Ingram, 1993). One gram of the ground sample was digested with digestion mixture (1 g selenium powder + 1 litre conc. sulphuric acid + 7.2 g salicylic acid + 30% solution hydrogen peroxide) overnight. The following day the mixture was heated at 200° C for half an hour after which the temperature was raised to 250°C, then heated for another half an hour, before being raised to 330° C and heated for another three hours. The mixture was allowed to cool, after which it was made to 50 mL mark with deionised water, mixed well and allowed to settle overnight.

For nitrogen analysis 5.0 mL of reagent N1 (68 g sodium salicylate + 50 g sodium citrate + 50 g sodium tartrate + 0.24 g sodium nitroprusside mixed with deionised water to make to 2 litres) was added to 0.2 mL of the digested sample and left for 15 minutes, then 5.0 mL of reagent N2 (60 g sodium hydroxide + 20 mL sodium hypochlorite + deionised water to make to 2 litres) added and left for one hour for colour development. The sample absorbance was read at 655 nm using the spectrophotometer. For phosphorus analysis 4.0 mL ascorbic acid solution and 3.0 mL molybdate were added to 0.5 mL of the digested sample and then left for one and a half hours for colour development. The concentration was then read at 880 nm using a spectrophotometer. For potassium analysis, 2 mL of the digested sample was mixed with 8 mL of deionised water. The filter selector was set in the flame photometer to the required "K" position and the concentration was read (Dorich and Nelson, 1984). For calcium and magnesium 2 mL of the extract, 8 mL of deionised water and 10 mL of 0.2% lanthanum solution were dispensed into a bottle and the concentration read using the atomic absorption spectrophotometer at 422.7 nm and 285.2 nm respectively. The plant N, P, K, Ca and Mg were then calculated using the formulas in Appendix 2.

3.6 Statistical data analysis

Data on the organic inputs nutrient composition, soil properties, maize yields, maize plant height, maize tissue nitrogen concentration, and residual mineral N was subjected to ANOVA using Genstat 5 for windows (Release 4.1) computer package. Data on farmers' evaluation and adoption was analysed using Excel.

3.7 Economic analysis

Average costs were used for operations unaffected by technologies such as land preparation and sowing. Where the operations were affected by different technologies, as was the case for input collection and application, harvesting and threshing of maize, the costing was worked out as per the technologies. The cost-benefit analysis was calculated using the farm gate prices of the various inputs, however, all the organic amendments (except manure) did not have a set price in the area. Thus, these organic inputs were costed in terms of the labor involved in their harvesting and preparation for incorporation and transportation costs (biomass transfer). Maize price was an average of its market price during harvest in the area. Maize yields on an air-dry basis (12.5% moisture content) were used in the economic analysis. Maize stover had a market value in the area as it is used as feedstuff for livestock.

The assumptions made during the cost-benefit analysis were that:

- All the organic materials are locally available in the farmers' fields,
- Labor is not hired, but from the household.

The information used for cost-benefit analysis in this study was collected at the specific time of each activity in the course of each season. The data was mainly from farmers and agro-input stockists.

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1 Soil Properties

The table below shows the chemical composition of the soils at Chuka at the beginning of the experiment in March 2000 (Table 4).

Table 4: Soil chemical properties at the beginning of the Experiment (March 2000) at Chuka

Treat[1]	**pH**	**Ca**	**Mg**	**K**	**C**	**Total N**	**Total P**
		Exchangeable (cmol/kg)			**........... g/kg ....**		
1	5.6	5.6	1.6	0.31	18.3	2.46	1.10
2	5.1	2.9	1.1	0.30	18.9	2.42	0.98
3	5.1	2.7	1.1	0.30	17.4	2.40	1.00
4	5.1	2.5	1.0	0.26	18.7	2.45	1.02
5	5.2	3.1	1.1	0.33	16.8	2.38	1.01
6	5.4	4.0	1.5	0.34	16.5	2.33	1.13
7	5.2	3.1	1.4	0.22	18.9	2.49	1.09
8	5.1	2.4	0.9	0.26	16.9	2.49	1.02
9	5.6	5.1	1.6	0.48	18.2	2.41	1.09
10	5.8	5.6	1.5	0.38	17.1	2.38	1.11
11	5.0	2.6	1.0	0.31	19.2	2.52	1.01
12	5.2	3.4	1.4	0.29	16.7	2.30	1.09
13	5.3	3.4	1.3	0.35	18.7	2.49	1.06
14	5.2	2.8	1.1	0.38	16.6	2.25	1.00
SED	**0.3**	**1.1**	**0.2**	**0.10**	**1.9**	**0.02**	**0.45**

Treat[1] = Treatment (1= mucuna; 2 = crotalaria; 3 = mucuna + ½ fert; 4 = crotalaria + ½ fert; 5 = manure; 6 = manure + ½ fert; 7 = tithonia; 8 = calliandra; 9 = leucaena; 10 = tithonia + ½ fert; 11 = calliandra + ½ fert; 12 = leucaena + ½ fert; 13 = rec fert; 14 = control)

After two years of continuous cultivation and application of inputs, various changes were observed in the different soil parameters as shown in Tables 5 and 6 below.

Table 5: Soil chemical properties at the end of the experiment (March 2002) at Chuka

Treat^1	**pH**	**Ca**	**Mg**	**K**	**C**	**Total N**	**Total P**
		Exchangeable (cmol/kg)			**............ g/kg ....**		
1	5.5	6.5	1.7	0.25	20.1	2.27	1.00
2	4.7	3.8	1.2	0.19	21.4	2.44	1.00
3	4.8	4.0	1.2	0.36	20.5	2.27	1.03
4	4.9	5.1	1.6	0.43	21.6	2.40	1.03
5	5.5	6.3	2.3	0.86	21.5	2.52	1.04
6	5.3	5.5	2.2	0.69	18.7	2.40	1.03
7	4.8	3.9	1.6	0.46	20.8	2.37	0.96
8	4.9	4.6	1.6	0.30	22.5	2.35	0.88
9	5.3	5.9	1.7	0.56	20.8	2.07	0.81
10	5.3	5.7	1.9	0.56	20.3	2.37	1.18
11	4.5	2.9	1.0	0.23	22.8	2.41	0.92
12	4.7	3.8	1.4	0.34	19.5	2.22	0.93
13	4.6	3.5	1.2	0.29	19.3	2.14	0.85
14	4.7	3.6	1.1	0.28	16.5	1.91	0.87
SED	**0.2**	**1.0**	**0.2**	**0.11**	**1.9**	**0.25**	**0.09**

Treat^1 = Treatment (1= mucuna; 2 = crotalaria; 3 = mucuna + ½ fert; 4 = crotalaria + ½ fert; 5 = manure; 6 = manure + ½ fert; 7 = tithonia; 8 = calliandra; 9 = leucaena; 10 = tithonia + ½ fert; 11 = calliandra + ½ fert; 12 = leucaena + ½ fert; 13 = rec fert; 14 = control)

All the treatments showed a decline in soil pH after the two years with the exception of manure treatment (Treatment 5), which recorded an increase (0.3) (Table 4 and 5). The decline ranged from –0.7 to –0.1. The treatments that had integration of inorganic and organic materials had the highest decline in soil pH. Exchangeable calcium increased in all the treatments over the two years and exchangeable magnesium increased in all the treatments with the exception of calliandra with half recommended rate of inorganic fertilizer (Treatment 11), leucaena with half recommended rate of inorganic fertilizer (Treatment 12), recommended rate of inorganic fertilizer (Treatment 13) and the control (Treatment 14) which remained constant (Table 6).

Table 6: Percentage change in soil chemical properties after two years in Chuka

Treat[1]	**Ca**	**Mg**	**K**	**C**	**Total N**	**Total P**
	Exchangeable (cmol/kg)			**……….. g/kg ………..**		
1	16.2	6.3	-19.4	9.8	-7.7	-9.1
2	31.0	9.1	-36.7	13.2	0.8	20.4
3	48.1	9.1	20	17.8	-5.4	3.0
4	104.0	60	65.4	15.5	-2.0	1.0
5	103.2	109.1	160.6	28.0	5.9	3.0
6	37.5	77.8	102.9	13.3	-3.0	-8.8
7	25.8	14.3	109.1	10.1	-4.8	-11.9
8	116.7	77.8	15.4	33.1	-5.6	-13.7
9	15.7	6.3	16.7	14.3	-14.1	-25.7
10	1.8	26.7	47.4	18.7	-0.42	-6.3
11	11.5	0.0	-25.8	15.8	-4.4	-8.9
12	11.8	0.0	17.2	16.8	-3.5	-14.7
13	2.9	7.7	-17.1	3.2	-14.0	-19.8
14	0.0	0.0	-26.3	-0.6	-15.1	-13.0
SED	**88.5**	**15.5**	**35.1**	**7.6**	**9.2**	**10.9**

Treat[1] = Treatment (1= mucuna; 2 = crotalaria; 3 = mucuna + ½ fert; 4 = crotalaria + ½ fert; 5 = manure; 6 = manure + ½ fert; 7 = tithonia; 8 = calliandra; 9 = leucaena; 10 = tithonia + ½ fert; 11 = calliandra + ½ fert; 12 = leucaena + ½ fert; 13 = rec fert; 14 = control)

Exchangeable potassium also increased in all the treatments except for sole mucuna (Treatment 1), sole crotalaria (Treatment 2), calliandra with half recommended rate of inorganic fertilizer (Treatment 11), recommended rate of inorganic fertilizer (Treatment 13) and the control (Treatment 14), which recorded a reduction. Organic carbon increased in all the treatments except in the control where it decreased slightly (-

0.6%) (Table 6). Total N decreased in all the treatments except in the sole crotalaria (Treatment 2) and sole manure (Treatment 5) treatments where it increased slightly. Total P also decreased in all the treatments with the exception of sole crotalaria (Treatment 2), mucuna with half recommended rate of inorganic fertilizer (Treatment 3), crotalaria with half recommended rate of inorganic fertilizer (Treatment 4) and sole manure (Treatment 5) that registered an increase (Table 6).

In general these results corroborates those of Kang (1993), Schroth et al. (1993), and Mugendi et al. (1999) who reported a general reduction in pH, total N and total P after input applications and continuous cropping over time and also with Chang et al. (1991), Schlegel (1992), Tian (1993), Gao and Chang (1996), Clark et al. (1998), and Eghball (2002) who reported a general increase in organic carbon, exchangeable Ca, Mg and K, after application of various inputs over time. Changes in soil properties under organically and conventionally managed farming systems have been found to be more variable, perhaps due to differences in climate, crop rotation, soil type, or length of time a soil has been under a particular management (Drinkwater et al., 1995; Werner, 1997).

The soil pH decline in all treatments with the exception of sole manure treatment, could be due to export of crop products, nitrification, and nitrate leaching (Section 4.5) which leads to soil acidification (Helyar and Porter, 1989). The higher pH decrease in the integrations of organics and inorganics compared to the sole applications of organic inputs could be as a result of the H^+, which are added on the cation exchange complex of soils from the inorganic fertilizer (Tisdale et al., 1993). The pH increase with manure treatment (Treatment 5) corresponds with findings by Eghball (2002) and could be attributed to the reduction of exchangeable aluminium in acid soils (Ahmad and Tan, 1986; Hue and Amien, 1989), which is considered to occur through aluminium precipitation or chelation on organic colloids or by complexation of soluble aluminium by organic molecules, especially organic acids (Hue and Amien, 1989). Indeed, the manure treatment was the only treatment that consistently showed an increase in all the other soil nutrients, corroborating results reported by Chang et al. (1991), Schlegel (1992), Gao and Chang (1996), Eghball and Power (1999), and Eghball (2002) who observed an increment of nutrients after manure application over time. Manures have the advantage of supplying essential plant nutrients either directly or indirectly by alleviating aluminium toxicity or by producing organic acids, thereby increasing nutrient availability (Nziguheba et al., 1998).

All the organic materials had a higher positive contribution to soil carbon in comparison to the inorganic fertilizer and the control. This agrees with Eghball (2002), who observed an increase in soil organic carbon after four years of manure application where about 25% C was retained in the soil carbon pool, however, he observed no significant difference in soil carbon with the inorganic fertilizer application. This was because, whereas the organic materials had a major impact on mineralization rates by increasing soil C directly, the effect of inorganic fertilizer N was less pronounced since it was increased C only indirectly by improving plant growth (Glendining et al., 1992; Antil et al., 2001).

4.4 Phosphorus deficiency

The results of the plant response to P deficiency visually scored at 50 days after crop emergence is reported in Table 7. The phenomena differed significantly ($P = 0.05$) among treatments with plants that received tithonia plus 30 kg N and P ha^{-1} having the lowest average value score of 1.0 (no P-deficiency) while the highest mean score of 3.0 (medium P-deficiency) was observed in the control, tithonia, calliandra and calliandra plus 30 kg N and P ha^{-1} treatments.

Table 7: P deficiency of maize plants 50 days after emergence during the 2000 long rains season at Chuka

Treatment	**Scored plant P deficiency (50 days after emergence)**
Cattle manure	2.3
Tithonia	3.0
Calliandra	3.0
Leucaena	2.0
Cattle manure + 30 kg N ha^{-1}	1.6
Tithonia + 30 kg N ha^{-1}	1.0
Calliandra + 30 kg N ha^{-1}	3.0
Leucaena + 30 kg N ha^{-1}	2.3
60 kg N ha^{-1}	1.3
Control	3.0
SED	**0.5**
CV%	**31.9**

The high P-deficiency symptoms observed in some organic treatments could have been as a result of the low P concentration in the organic materials that were applied (Table 3) compared to the recommended rate of P application in the area (60 kg ha^{-1}). The low moisture in the soil during this season could have worsened the situation as this could have meant that most of the organic materials did not fully decompose in time, thus P was not released from these organics for plant utilization. This shows that the sole organic inputs cannot by themselves be options to curbing P deficiency in the soil but should be integrated with inorganic sources of P as reported by Palm (1995). This was well illustrated in the case of tithonia, which showed a high P deficiency (3.0) with sole tithonia application but showed no P deficiency (1.0) when integrated with the inorganic fertilizer that contained 30 kg P and N. Nziguheba et al. (1998) reported that tithonia biomass could slightly reduce P adsorption and increase soil biological activity, which might enhance availability of P and other nutrients. These results are consistent with those of other studies by Gachengo (1996) and Mutuo et al. (2000).

After the 2000 long rains season, it was resolved that sufficient blanket basal application of P (as TSP) would always be applied to all the treatments to avoid confounding effects of P and N deficiencies since the study was more geared into working at N dynamics in the soil.

4.3 Maize grain yield

The average maize grain yields in the different treatments across the four seasons are presented in Table 8. Tithonia with half recommended rate of inorganic fertilizer recorded the highest maize grain yield of 4.8 Mg ha^{-1} followed closely by sole tithonia (4.7 Mg ha^{1}). Sole crotalaria recorded the lowest maize grain yields across the treatments and seasons with 1.7 Mg ha^{-1} followed closely by the control with 2.0 Mg ha^{-1} (Table 8).

TABLE 8: Maize yields (Mg ha^{-1}) under different technologies during the 2000 long rains, 2000/2001 short rains, 2001 long rains and 2001/2002 short rains seasons at Chuka

Treatment	**............... Seasons ....**				
	.... Grain weight (Mg ha^{-1})				
	2000 long rains	**2000/2001 short rains**	**2001 long rains**	**2001/2002 short rains**	**Mean**
Mucuna	1.3	4.0	2.4	3.7	**2.6**
Crotalaria	0.9	2.1	1.9	1.8	**1.7**
Mucuna + 30 kg N ha^{-1}	1.4	4.4	3.2	2.7	**2.9**
Crotalaria + 30 kg N ha^{-1}	1.4	3.4	2.4	3.2	**2.6**
Cattle manure	1.2	6.7	3.7	4.6	**4.1**
Cattle manure + 30 kg N ha^{-1}	1.2	6.5	4.9	2.9	**3.9**
Tithonia	1.2	6.6	4.3	6.5	**4.7**
Calliandra	0.7	6.0	2.8	4.5	**3.5**
Leucaena	1.0	6.1	4.0	5.8	**4.2**
Tithonia + 30 kg N ha^{-1}	1.3	6.8	5.4	5.6	**4.8**
Calliandra + 30 kg N ha^{-1}	1.1	5.8	4.3	5.1	**4.1**
Leucaena + 30 kg N ha^{-1}	1.3	6.1	3.7	4.4	**3.9**
60 kg N ha^{-1}	1.4	6.3	5.0	3.2	**4.0**
Control	0.6	4.6	1.2	1.5	**2.0**
SED	**0.2**	**0.4**	**0.7**	**0.7**	**0.5**

The low maize grain yields in calliandra treatment during the 2000 long rains season could be attributed to the lower rate of decomposition and mineralization of calliandra biomass that is brought about by its high polyphenol content that is known to bind with N lowering the decomposition rate and N release (Chesson, 1997). The situation could have been exacerbated by the low soil moisture content resulting from the low rainfall (126 mm received in the first 20 days of the season) and the P deficiency that were reported during this season. The higher maize grain yield with the inorganic fertilizer in this season could be due to the readily available N compared to the N from organic inputs which must first decompose and mineralize before the N is made available to the plant. Rains that stopped very early in the season could have meant that the organics did not have sufficient water (moisture) to decompose and mineralize and even if they did, water was not available for the mineralized nutrients to be taken up by the plants. During this season the additional benefits in the treatments with sole herbaceous legumes in contrast to the absolute control could have been from the nitrogen fixation by the legumes, weed suppression, and shading that could have improved the soil moisture retention in the soil. The herbaceous legumes had a very poor germination during this season thus they posed very low competition with maize crop.

The better performance of tithonia during the 2000/2001 short rains season could be attributed to the faster release of nutrients from the tithonia leaf biomass (Gachengo et al., 1999). The integration of tithonia with 30 kg N ha^{-1}, sole tithonia, sole cattle manure and cattle manure with 30 kg N ha^{-1} had higher yields than the recommended rate of inorganic fertilizer. This could be due to the provision of additional physical, chemical and biological benefits (besides N) by the organic materials (Hatfield and Cambardella, 2001) or due to the prevention of other nutrient deficiencies and/or enhanced nutrient fluxes (Sanchez and Jama, 2002). The lower yields with the herbaceous legumes compared to the control during this season could have been as a result of competition from the herbaceous legumes and the low biomass produced in the 2000 long rains season (incorporated during this season) which had low biomass thus low N concentration (Table 2) as a result of the low rainfall and the P deficiency reported during the 2000 long rains season. Tian and Kang (1998) reported that phosphorus plays a role in influencing N content of legumes, as P is known to have an important effect on legume N fixation.

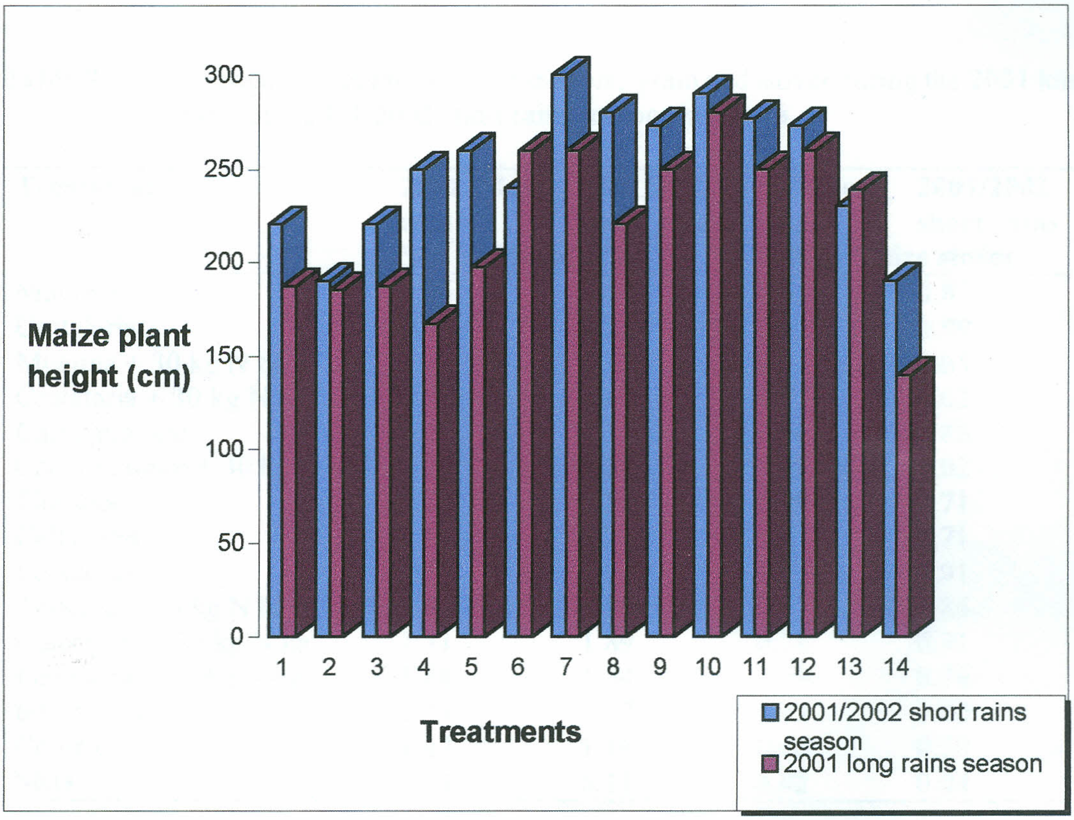
In the 2001 long rains season the herbaceous legumes performed significantly better than the control. This was as a result of the high amount of biomass that was harvested during the previous season (2000/2001 short rains) (Table 2).

During the 2001/2002 short rains season the herbaceous legumes especially the crotalaria germinated well and the biomass was high and it had even choked some maize plants. This may have resulted to the low maize grain yields (Table 8) as a result of severe competition from the legumes. Yields from cattle manure treatments in 2001/2002 short rains season were poor as compared to the 2000/2001 short rains season. This was as a result of long duration of storage compared to the previous season. The open and long storage time (about 9 months) of the manure could have led to the loss of nutrients leading to low quality manure. Nzuma and Murirwa (2000) reported that aerobically manure composts had lower total N values due to large ammonia losses that occurred throughout the decomposition period.

On average the integration of organic and inorganic nutrient sources of N gave higher maize grain yields as compared to the sole application of organic materials during the four seasons of the study. These results concur with results by Gachengo (1996), Kihanda (1996), Niang et al. (1996), Mugendi et al. (1999), Mutuo et al. (2000), and Nziguheba et al. (2000) on the integration of organic and inorganic soil fertility inputs. Integration of inorganic and organic nutrient inputs can be considered as a better option in increasing fertilizer use efficiency and providing a more balanced supply of nutrients (Palm et al., 1997; Donovan and Casey, 1998; Iwuafor et al., 2002; Vanlauwe et al., 2002). Kapkiyai et al. (1998) reported that combination of organic and inorganic nutrient sources has been shown to result into synergy and improved synchronization of nutrient release and uptake by plants (leading to higher yields). However, during the 2001 long rains season the sole application of leucaena performed better (not significantly different) than the integration with inorganic fertilizer and on the other hand, during the 2001/2002 short rains season most of the treatments without integration (Mucuna, manure, tithonia and leucaena) performed significantly better than with the integration. This could have been as a result of residue effects of the organic inputs from the previous seasons, since sole applied treatments received twice as much biomass compared to those treatments that were integrated.

The lower maize grain yield in the 2000 and 2001 long rains seasons could be associated with the low precipitation averaging 126 mm in the 2000 long rains season with most of it being recorded within the first three weeks of the season and the P deficiency reported during that season. During the 2001 long rains season an average of 431 mm was recorded with 86% of the rains being received within the first two weeks of the season (Appendix 4). This low and poorly distributed rainfall could have reduced the availability of nutrients to the maize plants. However, the 2000/2001 short rains and 2001/2002 short rains seasons were characterized by high precipitation (average 698 and 806 mm respectively) that was recorded throughout the season (Appendix 4) and this could have led to increased soil moisture content and N mineralization leading to the higher maize grain yield (Table 8). Soil moisture content has been reported to influence N mineralization and availability (Schomberg et al., 1994; Vanghn and Evanylo, 1998; Soon et al., 2001) and subsequent maize growth and N uptake (Clark et al., 1995; 1997; Soon et al., 2001).

Plant height is an important parameter in determining the final plant yields. The results on maize height (Appendix 3) show that maize plant height affected the maize grain yield as illustrated in Figure 1, where the maize plants in the 2001/2002 short rains season were slightly taller than those of the 2001 long rains season. A similar pattern was also observed with maize yields in the two seasons with the 2001/2002 short rains season having slightly higher yields than the 2001 long rains season (Table 8).



Treatment (1= mucuna; 2 = crotalaria; 3 = mucuna + ½ fert; 4 = crotalaria + ½ fert; 5 = manure; 6 = manure + ½ fert; 7 = tithonia; 8 = calliandra; 9 = leucaena; 10 = tithonia + ½ fert; 11 = calliandra + ½ fert; 12 = leucaena + ½ fert; 13 = rec fert; 14 = control)

Figure 1: Maize plant height during the 2001 long rains and 2001/2002 short rains seasons at harvest in Chuka

4.4 Nitrogen concentration in maize plant tissue

The results for the N concentration in maize plant tissue for the 2001 long rains and 2001/2002 short rains seasons are presented in Table 9. It was observed that tithonia with half recommended rate of inorganic fertilizer recorded the highest N (1.81%) concentration in maize grain while leucaena with half recommended rate of inorganic fertilizer reported the highest N (1.09%) concentration in the maize stover during the 2001 long rains season. The control reported the lowest N (1.47% and 0.48%) concentration in the maize grain and stover respectively during the same season.

Table 9: Nitrogen concentration (%) in maize grain and stover during the 2001 long rains and 2001/2002 short rains seasons in Chuka

Treatment	**2001 long rains**	**2001/2002 short rains**	**2001 long rains**	**2001/2002 short rains**
	%N in Maize grain		**%N in Maize stover**	
Mucuna	1.56	1.17	0.65	0.87
Crotalaria	1.65	1.27	0.61	0.99
Mucuna + 30 kg N ha^{-1}	1.61	1.17	0.51	0.65
Crotalaria + 30 kg N ha^{-1}	1.72	1.41	0.75	0.62
Cattle manure	1.52	1.31	0.56	0.88
Cattle manure + 30 kg N ha^{-1}	1.70	1.36	0.49	1.02
Tithonia	1.74	1.55	0.59	0.71
Calliandra	1.63	1.24	0.61	0.71
Leucaena	1.66	1.56	0.57	0.91
Tithonia + 30 kg N ha^{-1}	1.81	1.58	0.57	0.84
Calliandra + 30 kg N ha^{-1}	1.71	1.89	0.78	0.91
Leucaena + 30 kg N ha^{-1}	1.68	1.54	1.09	0.76
60 kg N ha^{-1}	1.77	1.17	0.69	1.00
Control	1.47	1.16	0.48	0.50
SED	**0.04**	**0.12**	**0.02**	**0.04**

In the 2001/2002 short rains season, calliandra with half recommended rate of inorganic fertilizer treatment recorded the highest N (1.89%) concentration in the maize grain while manure with half recommended rate of inorganic fertilizer recorded the highest N (1.02%) concentration in the maize stover. Control treatment recorded the lowest N

(1.16% and 0.50%) concentration in both the maize grain and stover respectively (Table 9).

During the two seasons, the N concentration in the maize grain was higher in the treatments with integration of organic and inorganic sources of N compared to the sole organic application. These results agree with Tian et al. (1993), and Tian and Kang (1998) who reported that nutrient uptake was higher when nitrogen was partially applied as prunings, indicating the importance of the combined addition of plant residue and inorganic fertilizer N for improving crop production. Maize in the treatments that received leucaena biomass recorded higher N concentration than those that received calliandra biomass, this concurs with what Mugendi et al. (2000) observed in their study. This could be attributed to the lower rate of decomposition and mineralization of calliandra biomass. Indeed, Lehmann et al. (1995) reported that only 52% of calliandra N had been released by the time of maximum N demand by maize. Hence, N mineralized late in the growing season may not be effectively utilized and could reduce nutrient use efficiencies.

4.5 Residual Mineral N

The bulk (almost 90%) of residual mineral-N found in the soil in all the treatments during both the 2000/2001 short rains and 2001 long rains seasons was in the form of nitrate-N, with ammonium-N contributing less than 10% in most cases as exemplified by the data from the 2000/2001 short rains presented in Table 10. This could be as a result of the rapid conversion of ammonia to nitrate following mineralization of inputs in the soil.

TABLE 10: Treatment effects on soil nitrate and ammonium (kg ha^{-1}) at 0-30 cm soil depth after the 2000/2001 short rains in Chuka

Treatment	**Nitrate**	**Ammonium**
Mucuna	47.1	5.6
Crotalaria	80.0	9.3
Mucuna + 30 kg N ha^{-1}	52.5	6.4
Crotalaria + 30 kg N ha^{-1}	70.4	8.5
Cattle manure	73.3	4.4
Cattle manure + 30 kg N ha^{-1}	61.9	2.8
Tithonia	60.0	7.8
Calliandra	57.6	6.4
Leucaena	66.7	10.9
Tithonia + 30 kg N ha^{-1}	63.6	14.2
Calliandra + 30 kg N ha^{-1}	80.8	6.3
Leucaena + 30 kg N ha^{-1}	80.1	17.6
60 kg N ha^{-1}	47.8	3.6
Control	46.7	5.0
SED	**10.1**	**4.4**

At the end of 2000/2001 short rains season soil samples at 30-100 and 100-150 cm depth were only taken for some representative treatments due to the cost of analyzing the soil for residual mineral-N (Table 11). The results show that there was a significant difference ($P<0.05$) in residual mineral-N among treatments and depth at the end of this season.

TABLE 11: Treatment effects on soil mineral-N (kg ha^{-1}) at different soil depths at the end of 2000/2001 short rains at Chuka

Treatment	**0-30 cm**	**30-100 cm**	**100-150 cm**
Mucuna	52.7	56.9	93.6
Crotalaria	89.3	-	-
Mucuna + 30 kg N ha^{-1}	58.9	85.0	29.5
Crotalaria + 30 kg N ha^{-1}	78.9	-	-
Cattle manure	77.7	143.4	38.2
Cattle manure + 30 kg N ha^{-1}	64.7	70.6	44.1
Tithonia	67.8	282.8	94.2
Calliandra	64.1	-	-
Leucaena	77.5	104.4	43.2
Tithonia + 30 kg N ha^{-1}	77.7	131.9	84.2
Calliandra + 30 kg N ha^{-1}	87.1	-	-
Leucaena + 30 kg N ha^{-1}	97.7	207.2	87.0
60 kg N ha^{-1}	51.4	56.4	49.8
Control	51.7	161.5	95.8
SED	**10.6**	**28.5**	**15.6**

At 0-30 cm depth leucaena with 30 kg N ha^{-1} recorded the highest (97.7 kg N ha^{-1}) residual mineral N while recommended level of inorganic fertilizer recorded the lowest (51.4 kg N ha^{-1}) residual mineral N during this season (Table 11). All the treatments were higher in residual mineral N than the control with the exception of the recommended level of inorganic fertilizer in the 0-30 cm depth during this season. At 30-100 cm depth sole tithonia recorded the highest (282.8 kg N ha^{-1}) concentration of residual mineral N while the recommended rate of inorganic fertilizer recorded the lowest (56.4 kg N ha^{-1}) in the same depth. In the 100-150 cm depth the control had the highest concentration (95.8 kg N ha^{-1}) while mucuna with half recommended rate of inorganic fertilizer had the least concentration (29.5 kg N ha^{-1}).

The above observations changed slightly in the season that followed (end of the 2001 long rains). During this season, mucuna with half recommended rate of inorganic fertilizer recorded the highest (84.2 kg N ha^{-1}) level of residual mineral-N while sole mucuna intercrop recorded the lowest (32.4 kg N ha^{-1}) at 0-30 cm depth (Table 12).

TABLE 12: Treatment effects on soil mineral N (kg ha^{-1}) at different soil depths at the end of the long rains 2001 at Chuka

Treatment	0-30 cm	30-100 cm	100-150 cm
Mucuna	32.4	63.9	40.3
Crotalaria	33.6	102.1	94.4
Mucuna + 30 kg N ha^{-1}	84.2	168.9	120.3
Crotalaria + 30 kg N ha^{-1}	73.1	240.3	158.6
Cattle manure	78.6	158.9	87.6
Cattle manure + 30 kg N ha^{-1}	59.7	88.8	118.3
Tithonia	60.4	74.7	87.3
Calliandra	71.8	119.7	204.2
Leucaena	78.6	158.4	103.4
Tithonia + 30 kg N ha^{-1}	72.1	113.5	167.7
Calliandra + 30 kg N ha^{-1}	80.3	224.9	190.3
Leucaena + 30 kg N ha^{-1}	75.2	117.1	153.8
60 kg N ha^{-1}	54.0	107.8	65.3
Control	48.8	95.8	147.2
SED	**11.4**	**69.7**	**58.1**

In the 30-100 cm soil depth crotalaria with half recommended rate of inorganic fertilizer recorded the highest (240.3 kg N ha^{-1}) mineral N concentration while sole mucuna intercrop reported the lowest concentration (63.9 kg N ha^{-1}). At 100-150 cm depth sole calliandra recorded the highest mineral N (204 kg N ha^{-1}) whereas sole mucuna intercrop recorded the lowest concentration (40.3 kg N ha^{-1}) followed by recommended rate of inorganic fertilizer (65.3 kg N ha^{-1}) (Table 12).

The highest average concentration of mineral N was recorded at the 30-100 cm soil depth at the end of both the 2000/2001 short rains and 2001 long rains respectively, whereas the lowest was recorded in the 100-150 cm soil depth during the 2000/2001 short rains and the 0-30 cm depth during the 2001 long rains respectively. On average, treatments with integration of inorganic and organic inputs tended to record higher concentrations of mineral N compared to other treatments especially in the deeper soil layers.

A bulge in mineral N was observed at the 30-100 cm depth in all the treatments during the end of the 2000/2001 short rains (Figure 2) and at the end of the 2001 long rains (Figure 3). However, no bulge was observed in manure with half recommended rate of inorganic fertilizer, leucaena with half recommended rate of inorganic fertilizer, tithonia and control treatments during the 2001 long rains (Figure 3).

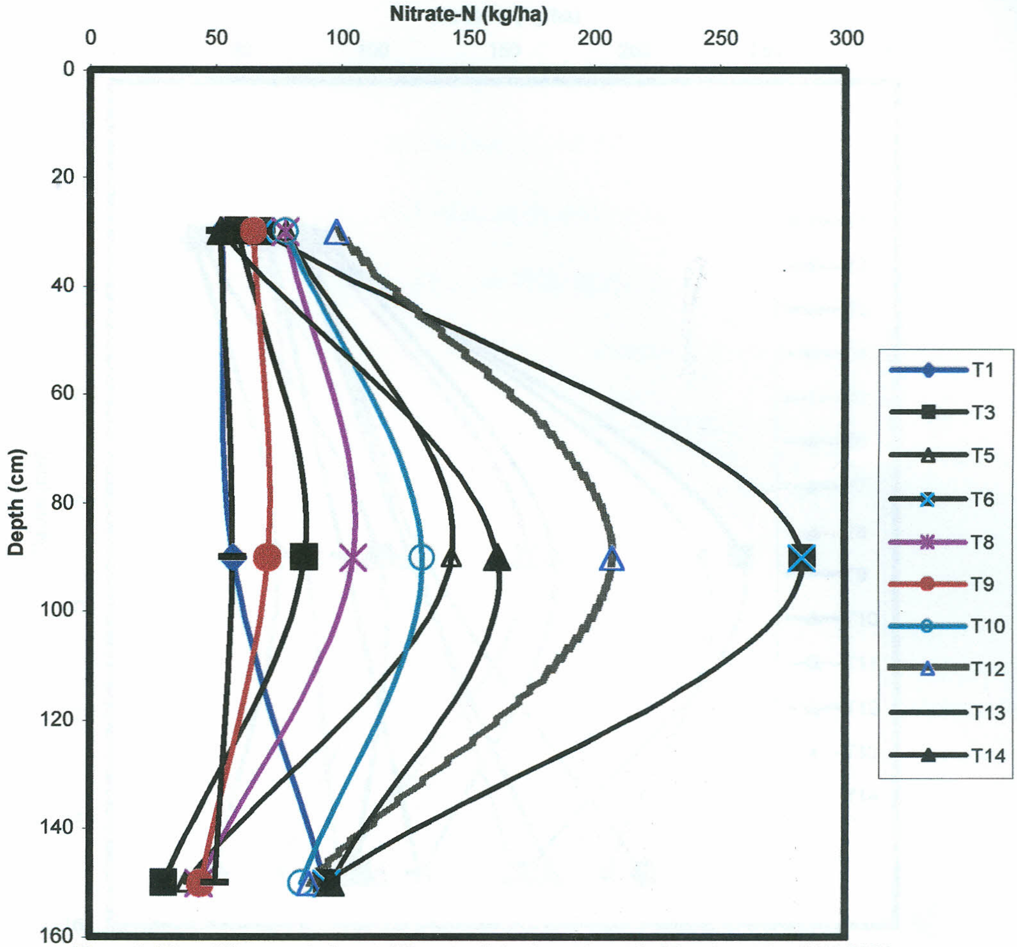


Figure 1: Mineral N concentration at different soil depths at the end of the short rains 2000/2001 season at Chuka
(T1 = mucuna; T3 = mucuna + 1/2 fert; T5 = manure; T6 = tithonia; T8 = leucaena; T9 = manure + 1/2 fert; T10 = tithonia + 1/2 fert; T12 = leucaena + 1/2 fert; T13 = rec fert; T14 = control)

Figure 2: Mineral N concentration at different soil depths at the end of 2000/2001 short rains season at Chuka

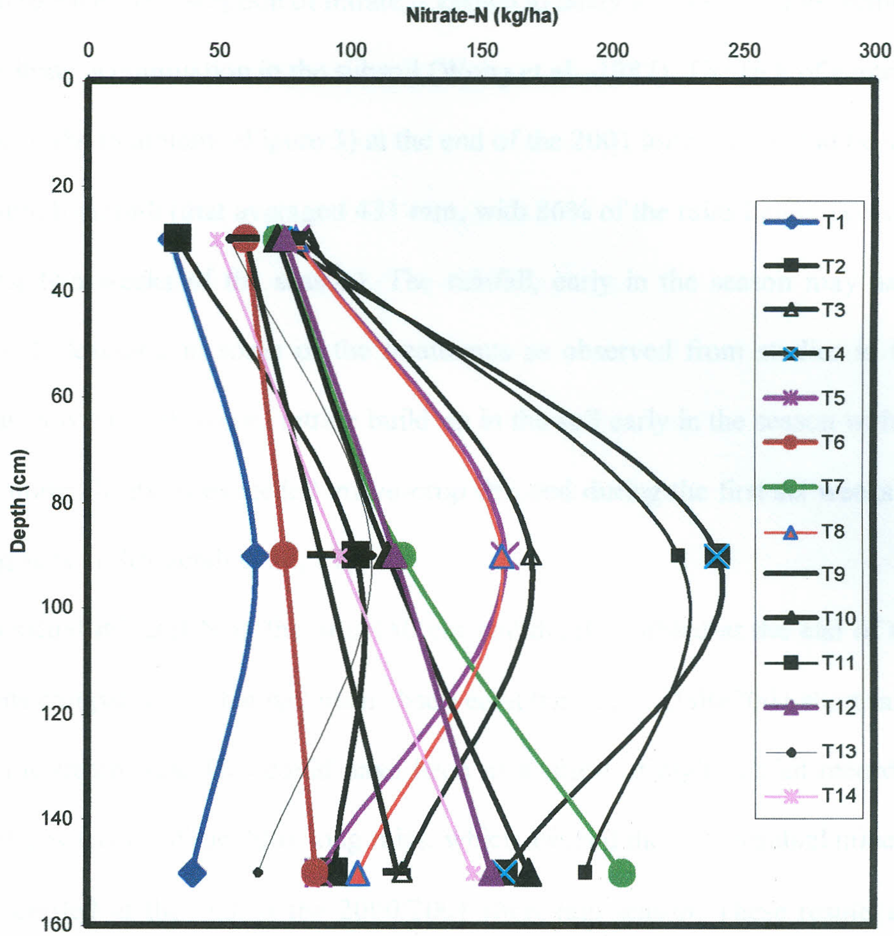


Figure 2: Mineral N concentration at different soil depths at the end of the 2001 long rain season at Chuka (T1 = mucuna; T2 = crotalaria; T3 = mucuna + 1/2 fert; T4 = crotalaria + 1/2 fert; T5 = manure; T6 = tithonia; T7 = calliandra; T8 = leucaena; T9 = manure + 1/2 fert; T10 = tithonia + 1/2 fert; T11 = calliandra + 1/2 fert; T12 = leucaena + 1/2 fert; T13 = rec fert; T14 = control)

Figure 3: Mineral N concentration at different soil depths at the end of the 2001 long rains season at Chuka

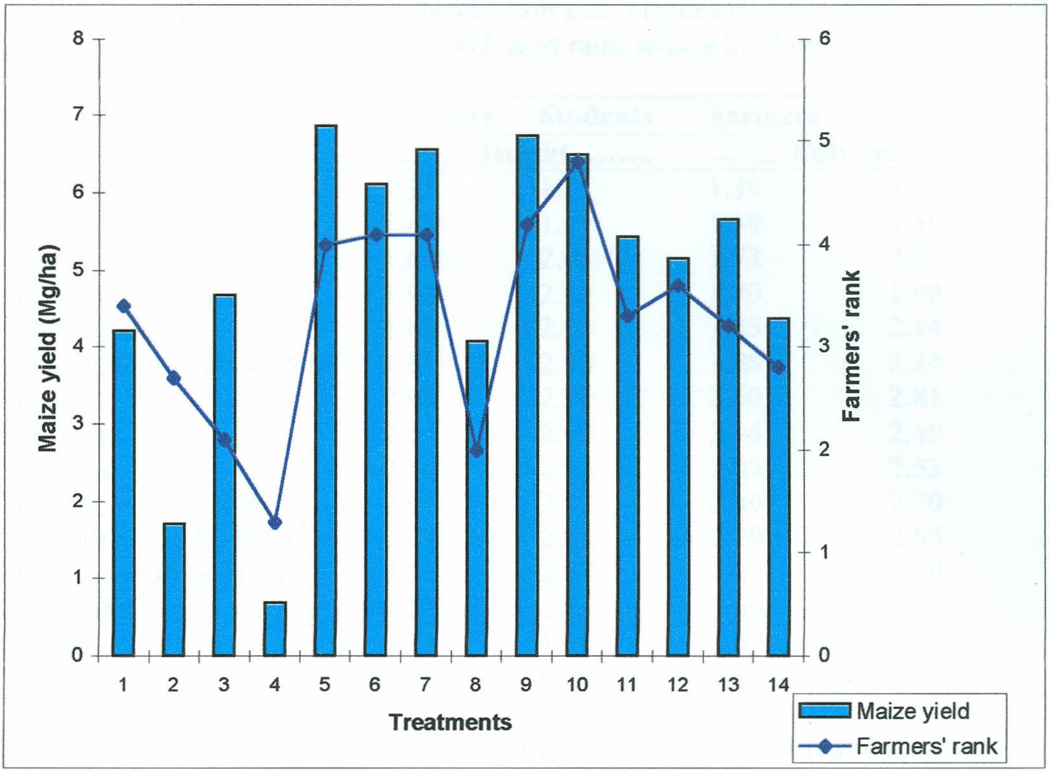
The presence of the bulge agrees with Kindu et al. (1997) who reported a bulge in nitrate at 0.3 to 1.5 m depth in the maize land use system in western Kenya. The bulge (accumulation) in nitrate at this depth could be attributed to greater N mineralization compared to plant uptake of top soil N immediately after the onset of the rainy season, subsequent nitrate leaching and then adsorption of nitrate on positively charged soil surfaces. Hartemink et al. (1996) reported that about 60% of nitrate at 1 to 2 m depth was sorbed on soil surfaces; this sorption of nitrate is known to delay its downward movement and result in nitrate accumulation in the subsoil (Wong et al., 1987). The lack of a nitrate bulge in some of the treatments (Figure 3) at the end of the 2001 long rains could be as a result of too much rainfall (that averaged 431 mm, with 86% of the rains being recorded within the first two weeks of the season). The rainfall, early in the season may have contributed to N leaching in some of the treatments as observed from studies in the central highlands where substantial nitrate build up in the soil early in the season with N supply (from mineralization) exceeded maize-crop demand during the first six weeks of each cropping season (Mugendi et al., 1999).

The residual mineral N in the 100-150 cm soil depth doubled at the end of the 2001 long rains compared to what had been observed at the end of 2000/2001 short rains season in all the treatments. This could have been as a result of high rainfall recorded within the first few weeks of the 2001 long rains, which leached the high residual mineral N that was recorded at the end of the 2000/2001 short rain season. These results are consistent with others (Silvertooth et al., 1992; Hartemink et al., 1996; Mugendi et al., 2000) who observed that leaching potential is high early in the rainy season when evapotranspiration is low and when the plant roots are not well developed to take up the available nitrate. The mineral N observed in the 100-150 cm depth is below the rooting zone of most maize plants and may not be available to the maize crop (Mugendi et al., 2000). It may also not be readily transformed (denitrified or assimilated) because of the limited microbial population and available C at this depth (Paramasivam et al., 1999). The high concentrations of mineral N at this soil depth is of concern as this mineral N is prone to leaching or may percolate to the water table or it could find its way to streams and rivers.

Therefore, measures to curb the downward movement of N, like timely application of inputs and split fertilizer application that have been reported to reduce N leaching should be encouraged (Gunnar and Helena, 2000; Delgado et al., 2001; Randall and Mulla, 2001; Paramasivam et al., 2001). In addition, trees if well planted and integrated in the farming systems may assist in recovering some of this N that is lost to annual crops as observed by Mugendi et al. (2000) who reported that treatments with tree hedges (*Leucaena leucocephala* and *Calliandra calothyrsus*) recorded an average of 22-66 kg N ha^{-1} while those without tree hedges recorded higher amounts of mineral-N averaging 330-660 kg N ha^{-1} in the 100-300 cm soil depth indicating that trees are capable of intercepting and recapturing the crop-inaccessible nutrients, below the roots of the annual crops by the action of their deep roots. Hartemink et al. (1996), Kindu et al. (1997), and Jama et al. (1998b) also reported the same trend in their work in Western Kenya.

4.6 Farmers' Evaluation

The farmers' evaluation carried out at maize grain filling stage during field days was based on qualitative assessment of the plant height, vigour, colour, and cob size. During the 2000/2001 short rains season, farmers ranked tithonia with half recommended rate of inorganic fertilizer treatment as the best with a rank of 4.8 (rank 5 represented best attribute and rank 1 poorest) and sole leucaena followed closely with a rank of 4.2. The poorest treatment was crotalaria with half recommended rate of inorganic fertilizer which was ranked 1.3 followed closely by sole calliandra with rank 2. The farmers' treatment ranking was closely related to the actual maize grain yields that were harvested later at the end of the season as shown in Figure 4.



Treatment (1= mucuna; 2 = crotalaria; 3 = mucuna + ½ fert; 4 = crotalaria + ½ fert; 5 = manure; 6 = manure + ½ fert; 7 = tithonia; 8 = calliandra; 9 = leucaena; 10 = tithonia + ½ fert; 11 = calliandra + ½ fert; 12 = leucaena + ½ fert; 13 = rec fert; 14 = control)

Figure 4: Maize grain yield and farmers' treatments evaluation during the 2000/2001 short rains season in Chuka

In the 2001/2002 short rains season the farmers and students evaluated the treatments once again following the same attributes as in the 2000/2001 short rains season (height, vigor, cob size and colour), however, the rankings were minimized with rank 1 representing the poorest attribute and 3 the best. On average, the farmers ranked sole tithonia with half recommended rate of inorganic fertilizer as the treatment with the tallest maize plants with a mean rank of 2.91 with sole tithonia following closely with a rank of 2.90 (Table 13).

Table 13: Treatment ranking (height, cob size, vigour and colour) by farmers and students in the 2001/2002 short rains season in Chuka

Treatment	**Farmers**	**Students**	**Farmers**	**Students**
	……… Height ……..		**……. Cob size …….**	
Mucuna	1.35	1.73	1.39	1.76
Crotalaria	1.43	1.51	1.39	1.59
Mucuna + 30 kg N ha^{-1}	1.68	2.06	1.73	2.03
Crotalaria + 30 kg N ha^{-1}	1.98	2.35	1.70	1.90
Cattle manure	1.89	2.33	1.85	2.14
Cattle manure + 30 kg N ha^{-1}	1.81	2.40	1.88	2.24
Tithonia	2.90	2.96	2.60	2.81
Calliandra	2.64	2.69	2.14	2.40
Leucaena	2.56	2.66	2.05	2.53
Tithonia + 30 kg N ha^{-1}	2.91	2.92	2.49	2.70
Calliandra + 30 kg N ha^{-1}	2.69	2.88	2.29	2.65
Leucaena + 30 kg N ha^{-1}	2.51	2.67	2.07	2.30
60 kg N ha^{-1}	1.57	1.83	1.66	1.77
Control	1.13	1.19	1.09	1.29
SED	**0.29**	**0.28**	**0.27**	**0.26**
	……. Vigour …..		**……. Colour …….**	
Mucuna	1.39	1.55	1.66	1.71
Crotalaria	1.34	1.30	1.45	1.33
Mucuna + 30 kg N ha^{-1}	1.70	1.78	1.75	1.93
Crotalaria + 30 kg N ha^{-1}	1.86	1.73	1.64	1.71
Cattle manure	1.81	1.99	1.75	1.87
Cattle manure + 30 kg N ha^{-1}	1.93	2.05	2.01	2.04
Tithonia	2.47	2.43	2.31	2.42
Calliandra	2.05	2.16	1.96	2.02
Leucaena	2.04	2.24	1.98	2.16
Tithonia + 30 kg N ha^{-1}	2.27	2.37	2.18	2.23
Calliandra + 30 kg N ha^{-1}	2.23	2.35	2.21	2.35
Leucaena + 30 kg N ha^{-1}	2.14	2.11	2.17	2.05
60 kg N ha^{-1}	1.88	1.81	2.14	2.05
Control	1.12	1.17	1.26	1.49
SED	**0.25**	**0.23**	**0.26**	**0.24**

The students on the other hand ranked sole tithonia as the treatment with the tallest maize plants with a rank of 2.96 while tithonia with half recommended rate of inorganic fertilizer followed closely with a rank of 2.92. Both the farmers and students ranked the control as the poorest treatment in terms of height with ranks 1.13 and 1.19 respectively. Both groups ranked sole tithonia as the treatment with the largest maize cobs with ranks of 2.6 and 2.81 respectively and they also ranked control as the treatment with smallest maize cobs with ranks 1.09 and 1.29 respectively. For maize plant vigor, both the farmers and students ranked sole tithonia as the treatment with the best vigor with ranks of 2.47 and 2.43 respectively. They also ranked the control as the treatment with the poorest maize plant vigor with 1.12 and 1.17 respectively (Table 13).

Lastly, sole tithonia was ranked as the treatment with the greenest maize by both groups with ranks 2.31 and 2.42 respectively. However, the farmers ranked the control as the worst treatment (yellowish colour) and assigned it a rank of 1.26 while the students ranked sole crotalaria as their worst treatment with a colour rank of 1.33.

In general, the ranking of both the farmers and the students was closely related to the actual maize grain yields attained later at the end of the season, concurring with what Mutuo et al. (2000) observed with farmers in Western Kenya.

Plate 1: Farmers visiting the different technologies and discussing the technologies during a farmers' field day in Chuka

4.7 Willingness to adopt the technologies

During every farmers' field day, the farmers were asked to select the technologies (treatments) they wished to take to their farms. During the 2001 long rains season a few farmers were already trying some technologies on their farms mostly with tithonia and calliandra. Calliandra is used as a supplementary animal feed in the area. At the onset of the 2001/2002 short rains season about 90% farmers (153 out of the 171 who attended the field day) were willing to take the technologies to their farms (on-farm). Table 14 shows the technologies selected for adoption by the farmers at the onset of the 2001/2002 short rains season.

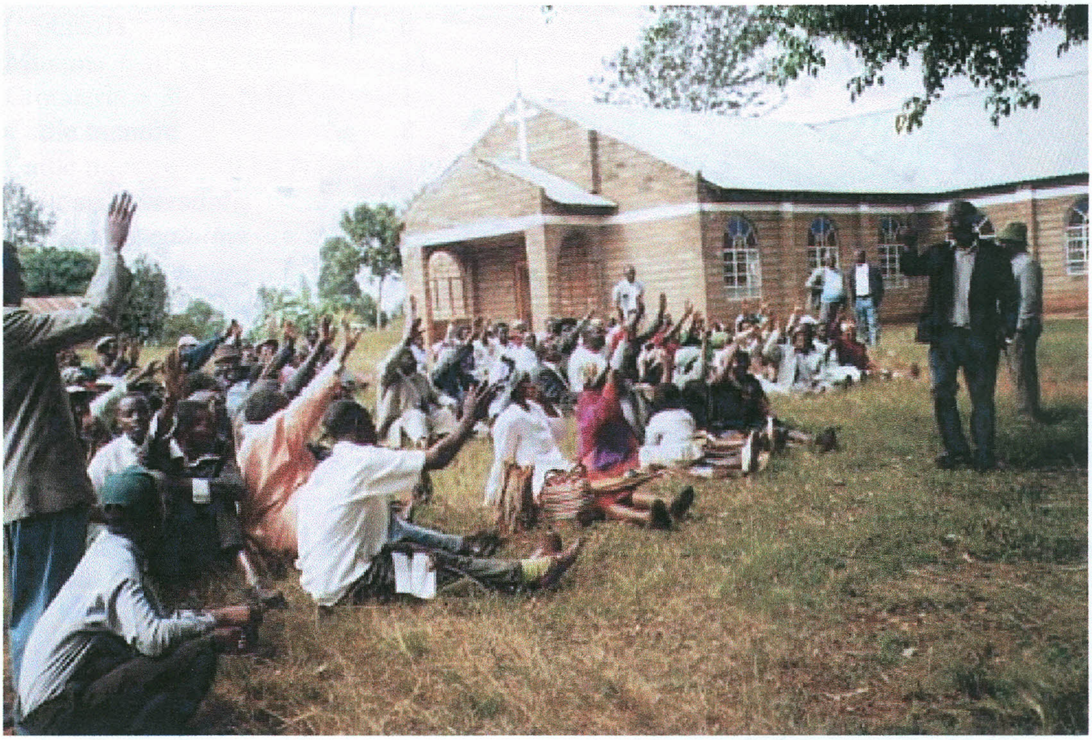


Plate 2: Farmers selecting the technologies they wish to take to their farms during a farmers' field day in Chuka

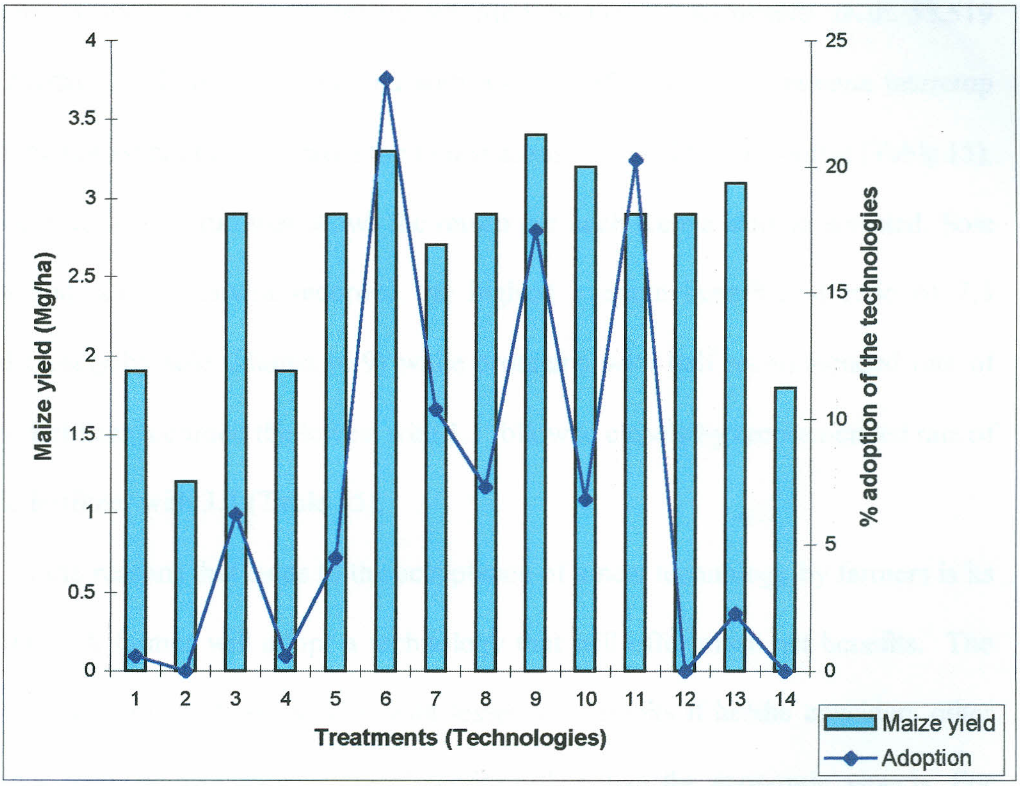
Most farmers (23.5%) were willing to adopt sole tithonia most probably because of its local availability and the fact that it had been giving the best maize grain yield over the seasons. To overcome the problem of limited availability (as it is required in large amounts to meet 60 kg N ha^{-1} – 30 Mg ha^{-1} wet weight) farmers said they would plant tithonia hedges, and most of them knew how to propagate it through cuttings. Calliandra was also highly selected because of its supplementary role as an animal feed. The farmers with animals said that they would use calliandra as an animal feed to improve the quality of their manure, however the ones with no animals wished to use it as a direct source of soil fertility.

Table 14: The number of farmers (%) willing to experiment with different technologies on their farms during the 2001/2002 short rains season at Chuka

Treatment	**Frequency**	**Percentage (%)**	**Rank**
Mucuna	1	0.6	10
Crotalaria	0	0	12
Mucuna + 30 kg N ha^{-1}	11	6.2	7
Crotalaria + 30 kg N ha^{-1}	1	0.6	10
Cattle manure	8	4.5	8
Cattle manure + 30 kg N ha^{-1}	31	17.5	3
Tithonia diversifolia	41	23.5	1
Calliandra calothyrsus	18	10.4	4
Leucaena trichadra	13	7.3	5
Tithonia + 30 kg N ha^{-1}	12	6.8	6
Calliandra + 30 kg N ha^{-1}	36	20.3	2
Leucaena + 30 kg N ha^{-1}	0	0	12
Rec. rate of fertilizer	4	2.3	9
Control	0	0	12
Total	**176**	**100**	

(Note: Some farmers selected more than one technology hence a frequency of 176 farmers as opposed to the actual number of 153)

The above results show that most farmers (51.6%) were interested in adopting technologies that combined both the organics and inorganic inputs while 46.4% were interested in sole organic inputs, and 2.3% in sole inorganic fertilizer. The higher percentage with the integration could have been as a result of better maize performance as shown in Table 8 and also because some of the farmers could afford the half rate of the recommended inorganic fertilizer and were therefore willing to supplement the other half with the organics. However, most of the farmers who were willing to adopt the sole organics were not in a position to purchase the inorganic fertilizer even at half rate. It was interesting to note that there were no farmers interested with adopting leucaena + 30 kg N ha^{-1} and sole crotalaria despite the fact that these were not the poorest performing technologies (Figure 5). This could have been associated to other factors other than the maize grain yield. Sole calliandra and crotalaria with half recommended rate of inorganic fertilizer had the lowest yields in the 2000 and 2001 long rains seasons but despite this, 10.4% and 0.6% farmers were willing to adopt them respectively.



Treatment (1= mucuna; 2 = crotalaria; 3 = mucuna + ½ fert; 4 = crotalaria + ½ fert; 5 = manure; 6 = Tithonia; 7 = calliandra; 8 = leucaena; 9 = manure + ½ fert; 10 = tithonia + ½ fert; 11 = calliandra + ½ fert; 12 = leucaena + ½ fert; 13 = rec fert; 14 = control)

Figure 5: Average maize grain yield across the seasons and the % adoption of the technologies at the beginning of the 2001/2002 short rains season in Chuka

4.8 Cost – Benefit Analysis

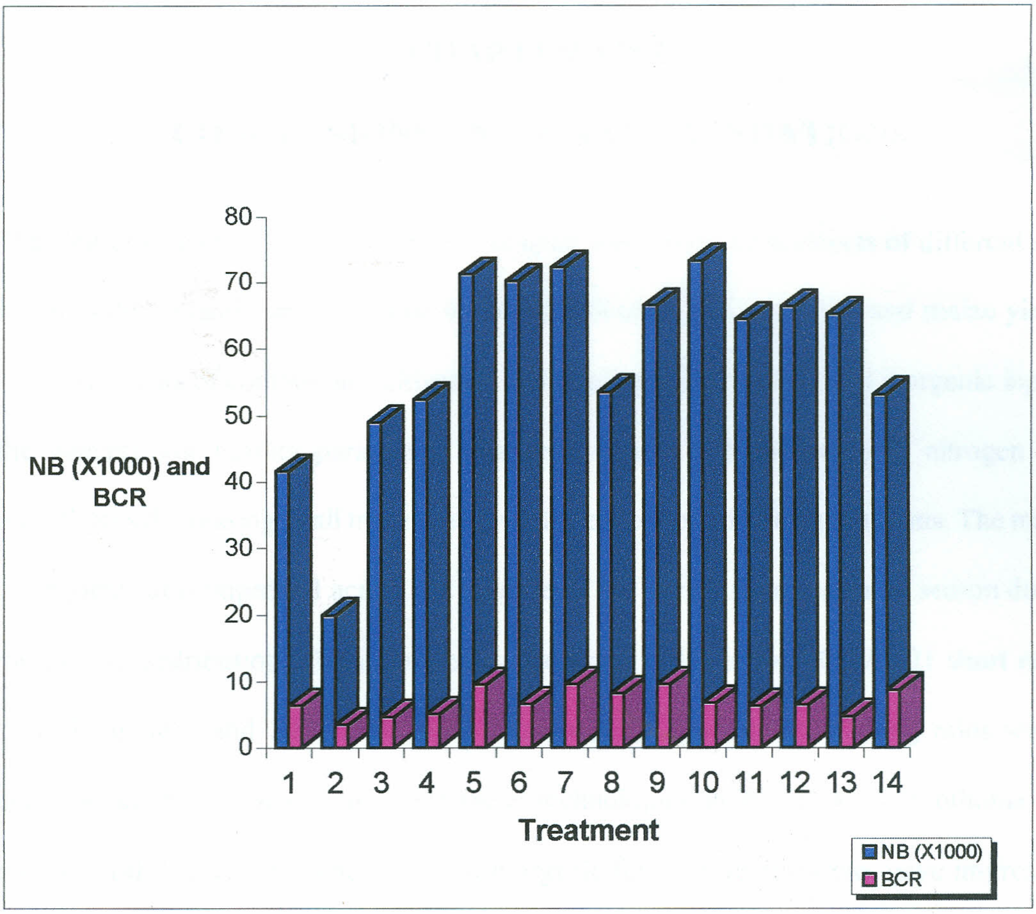
The benefit-cost analysis in this study was done without considering soil nutrients dynamics and the resultant maize yields due to long-term application of inorganic and organic inputs. It was assumed that all the organic materials were locally available in the farm and that labour was from the household (Appendix 6). The results are presented in Table 15.

On average, across the treatments during the four seasons, tithonia with half recommended rate of inorganic fertilizer recorded the highest net benefit (Ksh. 55,519 ha^{-1}) followed closely by sole leucaena with Ksh. 54,953 ha^{-1}. Sole mucuna intercrop reported the lowest net benefit across the four seasons followed by the control (Table 15). Benefit-cost ratio is a ratio that shows the return per each Kenya shilling invested. Sole leucaena and sole calliandra recorded the highest average benefit-cost ratio of 7.3 followed closely by sole tithonia (6.9) while crotalaria with half recommended rate of inorganic fertilizer recorded the lowest with 3.1 followed closely by recommended rate of inorganic fertilizer with 3.3 (Table 15).

One of the reasons that leads to the acceptance of a new technology by farmers is its profitability. A farmer will adopt a technology that will offer more net benefits. The farmer will only go for a technology with lesser net benefits if he/she considers other factors (e.g., climate and social cultural needs) rather than the economic aspects. For instance, though tithonia with half recommended rate of inorganic fertilizer treatment recorded the highest net benefit across the seasons, it was not the technology in which most farmers were interested in adopting as it was ranked 6th (Table 14). Other technologies reported high net benefits like leucaena with half recommended rate of inorganic fertilizer (Ksh. 48,958 ha^{-1}) but apparently there were no farmers interested in

Though most studies (Jama et al., 1997; Mutuo et al., 2000) have indicated that the organics have high labour costs, the farmers in the study area did not consider them costly probably due to the low opportunity cost of their time. Mutuo et al. (2000) observed the same trend with some farmers in their study in Western Kenya. However, some of the organic materials like calliandra and leucaena could be more economically attractive when used as a protein supplement for dairy cattle (ICRAF, 1993; Reynolds and Jabbar, 1994; Jama et al., 1997).

Although some treatments had a higher net benefit (NB), they respectively had a lower benefit cost ratio (BCR) as exemplified by results of the 2000/2001 short rains season (Figure 6). For example, tithonia with half recommended rate of inorganic fertilizer (Treatment 10) had a net benefit of Ksh 73,301 and a benefit-cost ratio of 6.8 compared to sole tithonia (Treatment 7) with a net benefit of Ksh 70,253 and a benefit-cost ratio of 9.6. Thus, considering net benefit alone could be misleading as far as cost effectiveness of the different soil fertility amendment inputs is concerned, therefore, BCR seems to be the most appropriate economic tool for determining the most economical soil fertility amendment technologies. It is most appropriate (convenient) because it is a comparison between net benefit and cost, which shows the return per shilling invested.



Treatment (1= mucuna; 2 = crotalaria; 3 = mucuna + ½ fert; 4 = crotalaria + ½ fert; 5 = manure; 6 = manure + ½ fert; 7 = tithonia; 8 = calliandra; 9 = leucaena; 10 = tithonia + ½ fert; 11 = calliandra + ½ fert; 12 = leucaena + ½ fert; 13 = rec fert; 14 = control)

Figure 6: Comparison of net benefit (NB) and benefit-cost ratio (BCR) for the different soil fertility replenishment inputs during the 2000/2001 short rains season at Chuka

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

The first objective of the study was to compare and contrast the effects of different soil-incorporated organic and inorganic inputs on soil chemical properties and maize yields. After two years of continuous cultivation and application of organic and inorganic inputs, the general soil fertility parameters changed slightly with the soil pH, nitrogen and phosphorus decreasing in all treatments with the exception of a few treatments. The maize grain yields also improved across the treatments but varied from season to season due to the rainfall distribution. The improved maize grain yields in the 2000/2001 short rains, 2001 long rains and 2001/2002 short rains seasons from the 2000 long rains season demonstrate the positive impact of these technologies in the area. Sole tithonia and tithonia with half recommended rate of inorganic fertilizer technologies gave impressive yields over the four seasons and most farmers have taken them to their farms. Indeed, by the 2001/2002 short rains season, 23.5% of the farmers who had attended the field days had started working with sole tithonia and (20.3%) with calliandra and half recommended rate of inorganic fertilizer technologies in their farms. Attempts to expose farmers to these improved locally available technologies through the field days has led to some impact in the study area where farmers are already aware of their farming constraints and are willing to test and adopt these new technologies that may regenerate or improve their farm productivity.

On the second objective, which was to assess the rate of nitrogen leaching in the soils in the study area, the study has indicated that there is a substantial amount of mineral-N that is being leached below the rooting zones of the annual crops (maize). This calls for action and from previous studies it would be recommended that farmers in the study area be encouraged to incorporate non-competitive fast growing trees that will assist in capturing the leached nutrients and recycle them back to the system. The incorporated trees should be able to offer other multiple benefits in their farming systems. For instance they can be planted on terraces together with napier grass since most of the farms in the region are located on steep gradients. The trees would not only help in capturing and recycling the subsoil N, but would also assist in the reduction of soil loss and encourage formation of natural terraces. They can also be pruned periodically and the resulting biomass be incorporated into the soil or used as fodder for livestock with the resulting manure recycled back to the farms to improve soil fertility. Careful management of soil fertility inputs like timely application of organic manures and split fertilizer application of inorganic fertilizers could also be recommended as it has been reported to reduce mineral-N leaching.

The third objective of the study was to evaluate the economic implications of the different nutrient replenishment technologies and encourage the farmers to adopt the most cost effective ones. Treatments with sole calliandra and leucaena biomass application were the most cost effective (highest BCR) followed closely by sole tithonia across the four seasons, thus farmers are encouraged to adopt these technologies, however, tithonia would be most appropriate for it is locally available. Since the organic materials may not be available in large amounts that are required for sole application, farmers are encouraged to adopt the integration of the organic and the inorganic though these may have lower benefit-cost ratios.

To overcome the constraints of organic material availability, farmers should be encouraged to plant them on their farms especially along the contours and on the farm boundaries. The planted materials will not only assist in improving soil fertility but will also help in reducing soil erosion. In addition, availability of organic materials within short distances from the farm will reduce the labour required for transporting them. The farmers should also be encouraged to use the organic materials available effectively so as to achieve higher returns, for instance they could apply the required rates on smaller plots other than applying insufficient quantities on large areas.

The current study should also continue to investigate whether the demonstrated technologies are really being adopted by farmers who have shown interest during the field days and also investigate ways in which farmers are modifying the technologies so as to fit in their social, economic, and cultural backgrounds. The current project should also try to investigate whether the farmers who are taking the technologies to their farms are getting equivalent yields as in the demonstration site. Benefit-cost analysis should be carried out by farmers on the different technologies in their farms, which can then be compared with the results that have emanated from the demonstration site. This will give an indication on the performance of the technologies on-farm.

More research needs to be carried out in the area on the herbaceous legumes, which did not do well, though they have been tested and reported to perform well in other ecologically similar areas. Other legumes with better cash returns to the like soybean should also be researched on. More research also needs to be done on the ways in which tithonia accumulates different nutrients even in soils that are very poor (since it is not a nitrogen fixer) so that as farmers are encouraged to plant it in their farms its long-term impacts on the ecosystem could be better understood. Rainfall data in the four growing seasons has shown a deviation from the long-term expected rainfall distribution in the study area, where the long rains are heavier and more reliable compared to the short rains. The short rains have apparently been better than the long rains, therefore all the stakeholders involved in farmer advisory should look into this seriously and advice the farmers accordingly.

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Appendix 1: Experimental layout

Block 1

	PLOT 1 TRT 11	PLOT 2 TRT 2	PLOT 3 TRT 4	PLOT 4 TRT 13
PLOT 9 TRT 7	PLOT 8 TRT 10	PLOT 7 TRT 3	PLOT 6 TRT 9	PLOT 5 TRT 14
PLOT 10 TRT	PLOT 11 TRT 1	PLOT 12 TRT 8	PLOT 13 TRT 5	PLOT 14 TRT 6

Block 2

PLOT 15 TRT8	PLOT 16 TRT 7	PLOT 17 TRT 11	PLOT 18 TRT 5	PLOT 19 TRT 9	PLOT 20 TRT 12		
PLOT 28 TRT 4	PLOT 27 TRT	PLOT 26 TRT 2	PLOT 25 TRT 3	PLOT 24 TRT 6	PLOT 23 TRT 13	PLOT 22 TRT 1	PLOT 21 TRT 10

Block 3

PLOT 29 TRT 3	PLOT 30 TRT 8	PLOT 31 TRT 2	PLOT 32 TRT 6	PLOT 33 TRT 7	PLOT 34 TRT 13	PLOT 35 TRT 4
PLOT 42 TRT 5	PLOT 41 TRT 11	PLOT 40 TRT 1	PLOT 39 TRT 10	PLOT 38 TRT 12	PLOT 37 TRT 9	PLOT 36 TRT 1

Appendix 2: Calculations

1. SOIL SAMPLES

- **Soil moisture content**

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

- **Exchangeable acidity**

Exchangeable acidity (soil volume basis)

$$\text{EAME100M} = (\text{EATITRAT-EABLANK})\ \frac{(\text{NNAOH})}{0.01}$$

Where: EAME100M=Exchangeable acidity (me/100 mL soil)
EATITRAT = titration volume for sample (mL)
EABLANK = Titration volume for blank (mL)
NNAOH = Normality of NaOH

Exchangeable acidity (soil mass basis)

$$\text{EAME100G-EAME100M}\ \frac{(\text{EASOLVOL})}{\text{EASOILWT}}$$

Where: EAME100G = Exchangeable acidity (me/100 g soil)
EASOLVOL = Volume of extracted soil (mL)
EASOILWT = Weight of dry soil extracted (g)

- **Extractable soil Ammonium**

Ammonium - N concentration (dry soil basis):

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

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)

Ammonium - N content of soil (kg N/ha) (EXANKGHA):

$$\text{EXANKGHA} = \frac{\text{EXANMGKG (BD) SD}}{10}$$

where: BD = Soil bulk density (g/cm^3)
SD = Depth of soil layer (cm)

- **Extractable Nitrate**

1. Dry weight of extracted soil (g) (EXNSDSWT)

$$\frac{(\text{EXNSLWT})\ 100}{(100 + \text{EXNGWC})}$$

Where: EXNSLWT = Field-moist weight of extracted soil (g)
EXNGWC = Gravimetric soil water content (%)

2. Nitrate - N concentration (dry soil basis):

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

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)

3. Nitrate - N content of soil (kg N/ha) (EXNNKGHA):

$$\frac{\mathrm{EXNNMGKG}\ (\mathrm{BD})\ \mathrm{SD}}{10}$$

where: BD = Bulk density (g/cm^3)
SD = Depth of soil layer (cm)

- **Total nitrogen**

  N concentration in soil (SNPER) (%):

$$\frac{((\mathrm{SNCONC} - \mathrm{SNBLNK})\ \mathrm{SNVOL})}{\mathrm{SNSOLWT}}\ 0.0001$$

where: SNCONC = N concentration in soil digest (mg/L)
SNBLNK = N concentrations in blank digest (mg/L)
SNVOL = Total volume of diluted digest (mL)
SNSOLWT = Soil/plant sample weight (g)

- **Total Phosphorus**

  The values read from the instrument are in me/100 mL of soil. The mean blank reading must be subtracted from the sample readings to obtain net concentration values.

  P concentration in soil (%):

$$\frac{((\mathrm{SPCONC} - \mathrm{SPBLNK})\ \mathrm{SNVOL})}{\mathrm{SNSOLWT}}\ 0.0001$$

where: SPCONC = P concentration in soil digest (mg/L)
SPBLNK = P concentration in blank digest (mg/L)

- **Exchangeable Potassium**

The values read from the instrument are in me/100 mL of soil. The mean blank reading must be subtracted from the sample readings to obtain net concentration values.

a) Exchangeable K (soil volume basis):

EXK100M = EXKCONC – EXKBLNK

where: EXK100M = Exchangeable K (me/100 mL soil)
EXKCONC = Concentration of K in sample (instrument reading for sample, in me/100 mL soil)
EXKBLNK = Concentration of K in blank (instrument reading for blank, in me/100 mL soil)

b) Exchangeable K (soil mass basis)

$$\text{EXK100G} = \text{EXK100M}\ \frac{\text{(EXKSOLVL)}}{\text{EXKSOLWT}}$$

Where: EXK100G = Exchangeable K (me/100g soil)
EXKSOLVL = Volume of extracted soil (mL)

- **Exchangeable Calcium and Magnesium**

The values read from the instrument are in me/100 mL of soil. The mean blank reading must be subtracted from the sample readings to obtain net concentration values.

1) Exchangeable Ca and Mg (soil volume basis):
EXCA100M = EXCACONC - EXCABLNK
EXMG100M = EXMGCONC - EXMGBLNK

where: EXCA100M, EXMG100M = Exchangeable Ca and Mg (me/100 mL soil)
EXCACONC, EXMGCONC = Concentration of Ca and Mg in sample (instrument for sample, in me/100 mL soil)
EXCABLNK, EXMGBLNK = Concentration of Ca and Mg in blank (instrument for blank, in me/100 mL soil)

2) Exchangeable Ca and Mg (soil mass basis):

$$\text{EXCA100G} = \text{EXCA100M}\ \frac{\text{(EASOLVOL)}}{\text{EASOILWT}}$$

$$\text{EXMG100G} = \text{EXMG100M}\ \frac{\text{(EASOLVOL)}}{\text{EASOILWT}}$$

where: EXCA100G, EXMG100G = Exchangeable Ca, Mg, respectively (me/100 g soil)
EASOLVOL = Volume of extracted soil (mL)
EASOILWT = Weight of dry soil extracted (g)

- **Total organic Carbon in soils: colorimetric method**

The mean blank value must be subtracted from sample concentration values to give a value for corrected concentration.

Total soil organic carbon (%) (SCPER):

$$\frac{\text{SCCONC - SCBLNK) (0.1)}}{\text{SCSOLWT}}$$

where: SCCONC = Carbon content of sample (mg C)

SCBLNK = Carbon content of blank (mg C)
SCSOLWT = Dry weight of soil sample (g)

2. PLANT SAMPLES

Nitrogen

$$\text{PNPER} = \frac{(\text{PNCONC}-\text{PNBLNK})\ (\text{PNVOL})\ 0.0001}{\text{PNWT}}$$

Where: PNPER = N concentration in plant tissue (%)
PNCONC = N concentration in plant digest
PNBLNK = N concentration in blank digest
PNVOL = Total volume of diluted digest (mL)
PNWT = Plant sample weight (g)

Phosphorus

$$\text{PPPER} = \frac{(\text{PPCONC}-\text{PPBLNK})\ (\text{PNVOL})\ 0.0001}{\text{PNWT}}$$

Where: PPPER = P concentration in plant tissue (%)
PPCONC = P concentration in plant digest
PPBLNK = P concentration in blank digest
PNVOL = Total volume of diluted digest (mL)
PNWT = Plant sample weight (g)

Potassium

$$\text{PKPER} = \frac{(\text{PKCONC}-\text{PKBLNK})\ (\text{PNVOL})\ (\text{KDF})\ 0.0001}{\text{PNWT}}$$

Where: PKPER = K concentration in plant tissue (%)
PKCONC =KN concentration in plant digest
PKBLNK = K concentration in blank digest
PNVOL = Total volume of diluted digest (mL)
PNWT = Plant sample weight (g)
KDF = K dilution factor (usually =5)

Calcium

$$\text{PCA} = \frac{(\text{PCACONC}-\text{PCABLNK})\ (\text{PNVOL})\ 0.001}{\text{PNWT}}$$

Where: PCA = Ca concentration in plant tissue (%)
PCACONC = Ca concentration in plant digest (mg/L)
PCABLNK = Ca concentration in blank digest (mg/L)
PNVOL = Final volume of diluted plant digest (mL)
PNWT = Weight of plant tissue digested (g)

Magnesium

$$\text{PMG} = \frac{(\text{PMGCONC}-\text{PMGBLNK})\ (\text{PNVOL})\ 0.001}{\text{PNWT}}$$

Where:
PMG = Mg concentration in plant tissue (%)
PMGCONC = Mg concentration in plant digest (mg/L)
PMGBLNK = Mg concentration in blank digest (mg/L)
PNVOL = Final volume of diluted plant digest (mL)
PNWT = Weight of plant tissue digested (g)

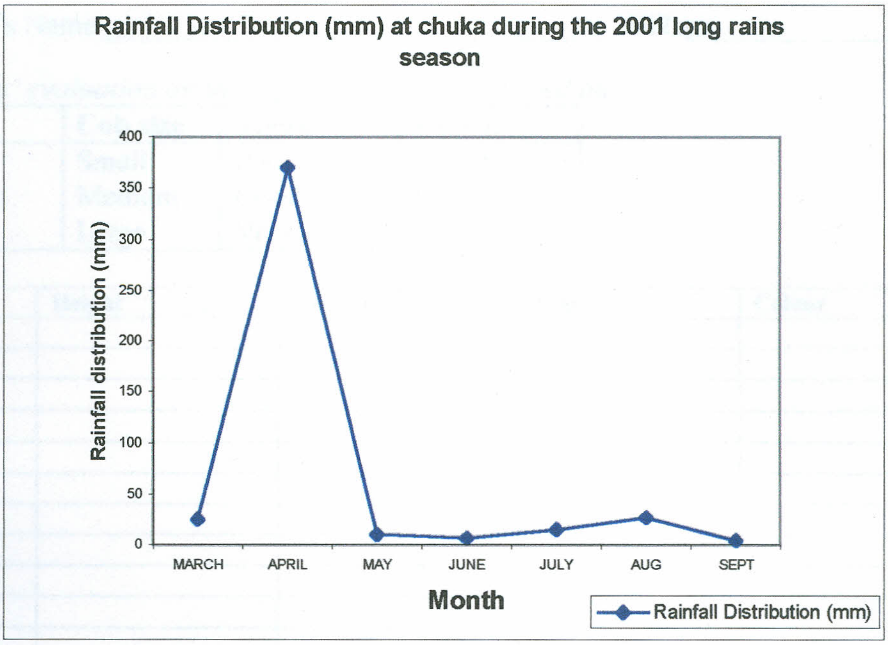
Source: Parkinson and Allen (1975); Dorich and Nelson (1984); Anderson and Ingram (1993)

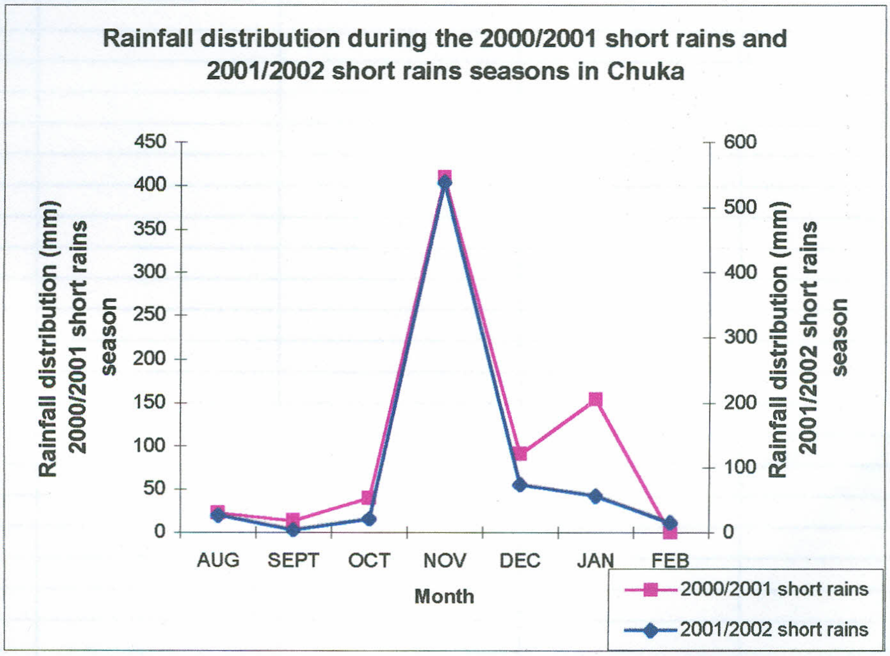
Appendix 3: Maize plant height (cm) during the 2000 long rains, 2001 long rains and 2001/2002 short rains seasons at Chuka

Treat[1]	**2000 long rains**	**2001 long rains**	**... 2001/2002 short rains season .....**			
	.... Weeks after planting (WAP)					
	8	**20**	**4**	**8**	**16**	**20**
1	49	187	40	87	200	220
2	34	185	50	103	190	190
3	41	187	43	107	220	220
4	41	167	50	123	250	260
5	39	197	53	120	240	260
6	55	261	33	87	237	240
7	37	258	83	183	290	300
8	37	223	90	180	280	283
9	42	249	73	153	263	273
10	59	277	77	170	290	290
11	46	245	77	157	267	277
12	46	257	67	147	270	277
13	43	239	30	70	220	243
14	35	136	37	70	180	190
SED	**6**	**43**	**6**	**13**	**19**	**17**

Treat[1] = Treatment (1= mucuna; 2 = crotalaria; 3 = mucuna + ½ fert; 4 = crotalaria + ½ fert; 5 = manure; 6 = manure + ½ fert; 7 = tithonia; 8 = calliandra; 9 = leucaena; 10 = tithonia + ½ fert; 11 = calliandra + ½ fert; 12 = leucaena + ½ fert; 13 = rec fert; 14 = control)

Appendix 4: Rainfall distribution during the 2000/2001 short rains, 2001 long rains and 2001/2002 short rains seasons in Chuka





Appendix 5: Farmers' evaluation of different technologies in Chuka

Farmer's Name________________________________ Village________________

Farmers' evaluation on the different treatments based on:

Height	**Cob size**	**Vigour**	**Colour**
Short Medium Tall	Small Medium Large	Poor Good Very good	Yellow Green Deep green

Plot No.	Height	Cob size	Vigour	Colour
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
13				
14				
15				
16				
17				
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41				
42				

APPENDIX 6: Table showing various variables used in the calculations of net benefit and benefit–cost analysis for the four seasons in Chuka *(Cost-benefit analysis of maize production under different soil fertility amendment technologies during the 2000 long rains season)*

	Soil fertility amendment options 2000 long rains season (Treatments)													
Treat	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Variable	……………… Ksh ………………													
Fixed cost (FC)	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000
Purchase of soil fertility input $^{1\&2}$	360	360	3,882	3,882	750	3,897	750	375	375	3,897	3,710	3,710	7,044	0
Harvesting	208	157	124	174	157	208	157	87	174	226	174	191	243	122
Empty bags (@ 25/=)	333	250	389	278	250	333	250	139	278	361	278	305	388	194
Storage dust @ 10/= bag^{-1}	133	100	156	144	100	133	100	55	111	144	111	122	156	77
Total variable cost (TVC)	1,034	867	4,551	4,478	1,257	4,571	1,257	656	938	4,628	4,273	4,328	7,831	393
Total cost (TC) =TVC + FC	**5,034**	**4,867**	**8,551**	**8,478**	**5,257**	**8,571**	**5,257**	**4,656**	**4,938**	**8,628**	**8,273**	**8,328**	**11,831**	**4,393**
Maize grain (Mg ha^{-1})	1.2	0.9	1.4	1.0	0.9	1.2	0.9	0.5	1.0	1.3	1.0	1.1	1.4	0.7
Stover (Mg ha^{-1})	8.2	8.1	10.2	8.0	6.1	8.0	8.0	5.2	8.0	8.5	8.0	7.5	10.3	5.2
Grain sales (@ Ksh 1000 per 90kg bag)	13,333	10,000	15,556	11,111	10,000	13,333	10,000	5,556	11,111	14,444	11,111	12,222	15,556	7,778
Stover (@ Ksh 1500 Mg^{-1})	12,300	12,150	15,300	12,000	9,150	12,000	12,000	7,800	12,000	12,750	12,000	11,250	15,450	7,800
Total sales	**25,623**	**22,150**	**30,856**	**23,111**	**19,150**	**25,333**	**22,000**	**13,356**	**23,111**	**27,194**	**23,111**	**23,472**	**31,006**	**15,578**
Net Benefit	**20,583**	**17,283**	**22,305**	**14,633**	**13,893**	**16,762**	**16,743**	**8,700**	**18,173**	**18,566**	**14,838**	**15,144**	**19,175**	**11,185**
Benefit/cost ratio (BCR)	**4.1**	**3.6**	**2.6**	**1.7**	**2.6**	**2.0**	**3.2**	**1.9**	**3.7**	**2.2**	**1.8**	**1.8**	**1.6**	**2.5**

Treat = Treatment (1= mucuna; 2 = crotalaria; 3 = mucuna + ½ fert; 4 = crotalaria + ½ fert; 5 = manure; 6 = manure + ½ fert; 7 = tithonia; 8 = calliandra; 9 = leucaena; 10 = tithonia + ½ fert; 11 = calliandra + ½ fert; 12 = leucaena + ½ fert; 13 = rec fert; 14 = control)

Assumptions

1. All the organic materials are locally available in the farmers' fields.
2. Labour is from the household