# EFFECTS OF CROPPING SYSTEMS, NUTRIENT LEVELS AND CROP RESIDUE APPLICATION ON SOIL ORGANIC CARBON CONTENT UNDER MINIMUM TILLAGE EXPERIMENT IN TESO DISTRICT, KENYA

**BY**

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# DECLARATION

**Declaration by the Candidate**

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

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# DEDICATION

The thesis is dedicated my beloved family, brother, sisters and friends whose support and inspiration made all this work possible.

# ABSTRACT

Minimum tillage practice and the use of cropping systems that maximize crop residue addition to the soil have been efficient agricultural practices in maintaining or increasing soil organic carbon (SOC) which, though central to the sustainability of soil fertility on smallholder farms in the tropics, has significantly declined to very low levels. An on-farm experiment was carried out at Asinge (0º 36' N; 34º 20' E and 1420 m above sea level) in Teso district to test the effects of cropping systems, nitrogen levels and crop residue (maize stover) addition on the changes in soil organic matter and overall maize-soybean production in western Kenya. A 3 x 2 x 2 factorial experiment arranged in a split-split plot design with three cropping systems (maize-soybean rotation, maize-soybean intercropping and continuous maize) as main plots; nutrient N levels (0 and 60 kg N/ha) as subplots and crop residue management (with and without crop residue) as sub-subplots was initiated during the 2005 long rain season. Main plots of 12 m x 12 m were split into subplots of 5.75 m x 12 m each (separated by 0.5 m paths) to accommodate different fertilizer N combinations and hence possible N response. Each subplot was split into sub-subplots of 5.75 m by 5.75 m with inter sub-sub plot spacing of 0.5 m to test with and without crop residue treatments. N fertilizer (Urea) was applied at 0 and 60 kg N/ha with a blanket application of P fertilizer triple superphosphate (TSP) at 60 kg P/ha and also a blanket application of K fertilizer muriate of potash (MOP) at 60 kg $K_20$ /ha to eliminate possible deficiencies for these two nutrients. Crop residue was applied at 0 and 2 t/ha. Maize and soybean were planted as the test crops. Harvesting of crops was done at maturity to determine yields and nutrient uptakes. Soils and plant tissues were sampled after harvesting the crop each season for chemical analysis. Statistical analysis was done using Genstat Discovery Edition 3 for all the data obtained to determine treatment effects. Results for the 2005 LR, 2005 SR and 2006 LR indicated significant differences ($p<0.05$) on soil organic carbon and soil total nitrogen with treatments under crop residue application having higher contents of both soil organic carbon and soil total nitrogen compared to no-residue treatments. In all cropping systems yields were significantly different ($p<0.05$) as a result of fertilizer addition; higher yields were obtained in treatments receiving 60 kg N/ha compared to treatments receiving 0 kg N/ha. Rotation cropping system outperformed other cropping systems by having higher mean yields of 5.23 t/ha of maize in 2006 LR season with continuous and intercropping systems having maize yields of 3.96 and 2.54 t/ha respectively. Economic analysis showed that treatments receiving fertilizer and crop residue in all cropping systems were profitable. However, all treatments under intercropping (maize + soybean) gave gross margins of above Ksh16, 000 hence an attractive alternative and farmers would get better yields when soybean is integrated into the cropping system. There is need for more minimum tillage research especially on the effects of cropping systems and nutrient inputs on different soil types and climate, crop residue management (especially in crop/ livestock systems) and equipment development to determine which of the practices is suitable in sustaining SOC and crop productivity in the nutrient depleted soils of western Kenya region.

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## ACRONYMS AND ABBREVIATIONS

| | |
|---|---|
| AAS | Atomic absorption spectrophotometer |
| AEZ’s | Agro-ecological zones |
| Al | Aluminium |
| ANOVA | Analysis of Variance |
| ANUE | Agronomic nitrogen use efficiency |
| APUE | Agronomic phosphorus use efficiency |
| CAN | Calcium Ammonium Nitrate |
| CIMMYT | International Maize and Wheat Improvement Centre |
| C/N ratio | Carbon and nitrogen ratio |
| CEC | Cation exchange capacity |
| $CO (NH)_2$ | Urea |
| CR | Crop Residue |
| CS | Cropping System |
| CTIC | Conservation Tillage Information Centre |
| DAP | Diammonium Phosphate |
| DMY | Dry Matter Yield |
| FAO | Food and Agriculture Organization of the United Nations |
| FAOSTAT | Food and Agricultural Organization Statistics |
| FURP | Fertilizer Use Recommendation Project |
| GM | Gross Margin |
| GOK | Government of Kenya |
| H.I.V | Human Immuno-Deficiency Virus |

| | |
|---|---|
| IITA | International Institute of Tropical Agriculture |
| I.R | CIMMYT Striga Resistant Maize Variety |
| K | Potassium |
| LR | Long Rains |
| MBILI | Managing Beneficial Interactions in Legume Intercrops |
| MDG | Millennium Development Goal |
| Mg | Magnesium |
| MOP | Muriate of potash |
| MRR | Marginal rate of return |
| M.T | Minimum Tillage |
| N | Nitrogen |
| NGO | Non-governmental organisation |
| NUE | Nutrient Use Efficiency |
| P | Phosphorus |
| SOC | Soil organic carbon |
| SOM | Soil Organic Matter |
| SR | Short Rains |
| SRN | Slow release N fertilizers |
| SSA | Sub-Saharan Africa |
| TSBF-CIAT | Tropical Soil Biology and Fertility-International Centre for Tropical Agriculture |
| TSP | Triple superphosphate |
| UN | United Nations |

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# CHAPTER ONE

# INTRODUCTION

## 1.1 Overview

The first Millennium Development Goal (MDG) aims to eradicate extreme hunger and poverty and reduce, by one half, the proportion of people who suffer from hunger (UN Millennium Project, 2005a). The MDG target of reducing by one half the proportion of people who suffer from hunger is extremely important in Sub-Saharan Africa (SSA), where food security has become increasingly problematic (FAO, 2004). While *per capita* food availability in the rest of the world has increased significantly over the past 45 years, the situation in SSA has improved only slightly. For example, the average cereals yield is still below 1 tonne per hectare in SSA, and the continent-wide average yield has increased by a meager 5.2 kg/ ha/ year over the past 33 years (FAOSTAT, 2006). In contrast, crop yields on well-managed farms in the region are several times larger and yields obtained in research stations are commonly ten times higher than farm average yields (FAO, 2004).

Regarding the soils, smallholder farmers generally cultivate poor quality sandy or sandy loam soils (Twomlow and Bruneau, 2000). Continuous cropping on such soils has resulted in infertility and deficiency in nitrogen, phosphates and sulphur mainly with inappropriate measures being laid out to counter the problem (Burt *et al*., 2001). Also sub-optimal application of fertilizers on such soils and the removal of nutrients in farm produce, erosion losses and the reduction in soil organic matter (SOM) due to tillage without nutrient inputs (Nyamangara, 2001) has led to land degradation and reduction in crop yields. The largest nutrient input into African farming systems is through manure, although some mineral fertilizers and crop residues are used (Nyamangara *et al*., 2003; Sheldrick and Lingard, 2004). Manure and crop residues do not provide sufficient nutrients to meet the needs of crop production, and it is estimated that a minimum increase of 6% p.a in N fertilizer use is required to maintain the level of this soil nutrient until 2020. However, the projected growth of mineral fertilizer use is not sufficient to meet this requirement (Sheldrick and Lingard, 2004).

The low fertilizer usage in Africa is partly due to both high costs of fertilizers (at least twice the international price), and lack of cash or credit facilities for small scale farmers (Micheni, 1996). However, fertilizer in itself is insufficient to produce a major change in the food security situation. Major increases in yield can only be obtained when soil fertility management is combined with soil and water conservation practices such as timely planting and weeding, minimum tillage with crop residue applications under different cropping systems, among others, thereby reducing periods of potential moisture stress/competition (Twomlow *et al*., 1999).

Minimum tillage (MT) is defined as ‘any tillage and planting system that maintains at least 30% of the soil surface covered by residue after planting to reduce soil erosion by water, or where soil erosion by wind is a primary concern, maintains at least 1000 kg/ha of flat, small grain residue equivalent on the surface during the critical wind erosion period (CTIC, 1990; 1995; 1996; 1997). In fact MT is a generic term encompassing all tillage systems that reduce loss of soil and water from crop land, relative to conventional tillage (Lal, 1989; Lal and Kimbler, 1997; Blevins and Frye, 1993). Conventional tillage includes plough-based methods, such as successive operations of ploughing (soil turnover with a mouldboard plough) mixing (with a disc plough) and pulverization (with a rotovator). Minimum tillage eliminates one or several of the operations. Crop residue is an integral part of any MT system and also includes selecting crops that produce sufficient quantities of residue (e.g. maize, wheat, small grains, and sorghum) and sowing cover crops to provide an effective ground cover. Rather than turning under plant materials or crop residues following harvest, the residues are left on the soil surface to protect the soil against the erosive forces of rainfall, run-off and wind.

**1.2 Statement of the problem**

Food insecurity in SSA is of global concern as food aid in this region seems endless (FAO, 1996; World Bank, 1996). In Kenya, over 90% of the population depends on maize while production is low and varies from farm to farm with smallholder farm yields commonly below 0.5 t/ha (Nekesa *et al*., 1999). Soil fertility depletion is a well documented constraint that accounts for the declining crop yields and unsustained productivity across smallholder farms in most African countries (Sanchez *et al*., 1997; Woomer *et al*., 1997a). The sub-optimal fertilizer additions due to high costs, removal of nutrients in farm produce, erosion losses, reduction in SOM due to varying farming practices result in mining of nutrients from the soil (Nyamangara, 2001) which has led to land degradation and decline in crop yields. In Kenya, for instance, nitrogen and phosphorus nutrients are widely depleted in cropland soils (FURP, 1994; Woomer and Muchena, 1996). There have been concerns about the continued decline in soil productivity under smallholder farming systems hence increased call for soil fertility management strategies that enhance soil biological function and protect available resources (Swift, 1998; Gichuru *et al*., 2003). Apart from N and P, which are widely depleted in soils of western Kenya, most soils have very low organic matter levels (Woomer *et al*., 1994). Nutrient release from SOM is dependent upon mineralization of biologically active fractions (Vanlauwe *et al*., 1994; Borrios *et al*., 1996), which may vary qualitatively and quantitatively in relation to the quality and quantity of organic resources used.

Conventional tillage without proper soil management is to blame for soil degradation leading to large losses of productive soils through erosion and depletion in SOC. Tillage methods affect soil processes through physical disturbance and exposure of soil to disruptive forces and through the distribution of plant residues in the plough layer. This affects the soil physical, chemical and biological properties including the retention and loss of SOC thereby creating changes in soil structure, moisture relations and erosion (Quinton and Catt, 2004; Stubbs *et al.,* 2004; Bationo and Vlek, 1997). Use of organic resources and their combinations with inorganic fertilizers (Palm *et al*., 1997; Okalebo *et al*., 1999) are some of the possible technologies to overcome nutrient deficiencies in western Kenya. Current organic material inputs (from leguminous trees in fallows, tree leaf litter, cereal and legume crop residues, animal manures and compost) in high to medium rainfall areas are insufficient to maintain SOC levels in soils of most smallholder farms while in the low rainfall marginal areas it is not possible to grow enough biomass to maintain SOC. Offtake of nutrients in crops is often high with intensive continuous cropping, and losses through other means such as leaching can be large. Stoorvogel *et al.,* (1993) estimated that the annual net nutrient depletion exceeds 30 kg N and 20 kg K/ha of arable land in Malawi and Zimbabwe, as well as several countries in eastern Africa. Agricultural development efforts, therefore, must be directed towards the improvement of productivity and sustainability of smallholder production systems.

Taking into consideration the general need for improving the productivity and sustainability of smallholder production systems, a long-term minimum tillage trial was initiated in 2005 by TSBF-CIAT with the aim of better understanding the changes in SOC in residue and no-residue treatments under various cropping systems generally practiced in Teso, western Kenya. The study addresses one main question:

Is minimum tillage practice able to ensure improvement in SOC, hence crop yield increase in the highly depleted soils of Teso district, western Kenya?

### 1.3 Justification of the study

Maize is the most important agricultural commodity and main staple food in Kenya. It provides about 40% of the population caloric requirements (Pearson *et al*., 1995). In western Kenya smallholder farm maize yields are frequently below 500 kg/ ha/ season (Nekesa *et al*., 1999; Waigwa, 2002; Kifuko, 2002). Reasons for food deficits are multiple, but include frequent droughts, political unrests when land is not cultivated and poor or declining economies of most African countries. But as the countries affected strive to increase agricultural production, they are constrained by the widespread soil fertility depletion and the overall food insecurity. In Kenya for instance, nitrogen and phosphorus nutrients are widely depleted in cropland soils (FURP, 1994; Woomer and Muchena, 1996). Apart from N and P depletion, most soils have very low organic matter levels, the largest source of nutrients for growing crops (Woomer *et al*., 1994). Farmers in western Kenya practice mainly conventional tillage which is based on soil tillage as the main operation. Soil tillage in the past has been associated with increased fertility, which originates from the mineralization of soil nutrients; however, in the long-term it results in a reduction in SOC. The negative impacts of continuous land tillage on the soil have led to a search for minimum soil disturbance in agricultural production. Published MT research has been carried out primarily in temperate regions for large scale producers with adequate financial and other resources mainly to control weeds, diseases and pests. In Africa minimum tillage is mainly at the experimental stage at the on-farm level.

Minimum tillage (MT) is characterized by the following principles:-

- Minimum mechanical soil disturbance. This involves direct planting/ seeding where crops are grown without ploughing or cultivation to prepare a seedbed.
- Permanent soil cover. The residue/stubble from the previous crop is not ploughed under, instead it is left undisturbed (in place) to protect the soil surface and conserve soil moisture (Erenstein, 1999)
- Diversified crop rotations in the case of annual crops or plant associations in case of perennial crops. Crop rotation is not only necessary to offer adverse ‘diet’ to the soil microorganisms, but as plants or crops root at different depths, they are capable of exploring different soil layers for nutrients

Conservation agriculture has associated benefits at the farm, regional/ national and global scales most of which are captured by society. Thus Stonehouse (1997) assessed the benefits and costs of MT relative to conventional tillage in Southern Ontario, Canada and found that its off-site benefits (improved downstream fishing, reduced dredging costs) accounted for the majority of the net social benefits. The wider or societal benefits, which in the case of MT include more regular surface hydrology, reduced sediment loads, and increased carbon sequestration. Fortunately, the net financial impact of conservation agriculture at farm scale appears as positive as well. Financial analyses of MT adoption, whether in a developed world (Stonehouse, 1997) or developing world (Sorrenson, 1997; Sorrenson *et al*., 1998) have shown that MT generally produces higher net returns relative to conventional tillage. This is largely true because of the reduced costs of machinery, fuel and labour, combined with unchanged or improved yields over time.

The positive impacts of conservation agriculture on the distribution of labour during production cycle and reduction in labour requirements are the main reasons why farmers in Teso should practice MT. These farmers rely on family labour which is in short supply because productive population has been wiped away by the HIV aids epidemic. These farmers also, at one stage, used to rely on cattle for cultivation but the cattle were eradicated by Trypanosomiasis (J.R.  Okalebo *pers. comm*). Resource poor farmers in Teso have sandy infertile soils with very low organic matter and N levels (Chapter 3, Table 3). Hence, crop residue should be constantly added to these farms to ensure increase in SOC levels.

Minimum tillage trials are on-going in Nyabeda western Kenya investigating effect of tillage and crop residue on productivity in a predominantly clay soil that compacts naturally (TSBF-CIAT experiment). MT trials for water conservation have also been studied in Machakos and Laikipia districts among smallholder farmers resulting in improved water productivity and crop yields (Kihara, 2002; Muni, 2002). The impacts of MT in terms of increased moisture availability and hence increased crop yields are encouraging its adoption by smallholder farms, especially in semi-arid Laikipia and Machakos districts of Kenya (Kihara, 2002; Muni, 2002). Minimum tillage research in Ethiopia has shown that even if crop yields are similar to those of traditional systems, the gross margins of minimum tillage are almost double due to smaller inputs. The long term benefits from MT may exceed the apparent short term gains from practices which ignore soil conservation (Astatke *et al*., 2002)

There is need for more MT research in Africa especially on the effects of soil type and climate (especially rainfall impact and distribution), crop residue management (especially in crop/ livestock systems) and equipment development (Benites, 1998). Thus it was crucial to study the effects of MT on changes in organic matter under various cropping systems in Teso district.

## 1.4 Objectives

### Overall objective

To determine the effects of cropping systems, nutrient levels and crop residue management practices on changes in soil organic carbon and overall maize and soybean production.

### Specific objectives

1. To determine the effects of crop residue on changes in SOC under different cropping systems.
2. To determine the effects of crop residue combined with inorganic fertilizer on N and P uptake and use efficiencies.
3. To determine the effects of crop residue and cropping systems on overall maize-soybean yield.

4. To determine the profitability of maize and soya bean under different cropping systems.

## 1.5 Hypotheses

### General hypothesis

Effectiveness of minimum tillage in terms of improving SOC is influenced by crop residue addition combined with small quantities of inorganic fertilizer.

### Working hypotheses

1. The changes in SOC are affected by crop residue addition under different cropping systems.
2. Maize-soybean yields under minimum tillage are influenced by crop residue and inorganic fertilizer addition

# CHAPTER TWO

# LITERATURE REVIEW

## 2.1 Influence of tillage system on changes in soil organic carbon (SOC)

Type and length of tillage practice influences the amount of SOC present in the soil (Cambardella, 1994). Accumulation of SOC has been observed to be lower in conventional tillage than no-till system. Thus, Hassink, (1995) and Jastrow, (1996) reported that conventional tillage mixes upper and lower horizon soils and disrupts aggregate protected organic matter. This results in faster decomposition and loss of organic matter and more or less uniform distribution of organic matter in the plough layer (Stockfisch *et al*., 1999). In the Australian cereal belt, cultivation and cropping has led to a substantial loss of SOM; the long term SOC loss often exceeded 60% from the top 0-0.1 m depth in 50 years of cereal cropping. In an experiment conducted in southwestern Saskatchewan, over a 12-year period, a no-till continuous wheat system gained approximately 1.5 Mg $ha^{-1}$ more carbon in the 0-15 cm soil depth than did a continuous wheat system under conventional tillage. Additionally, at the end of 6 years of direct drilling in Denmark, Rasmussen, (1988) found that after direct drilling organic carbon increased significantly (by 7.9 g $kg^{-1}$) in the upper 0-2 cm soil layer, but in the 2-10 and 10-20 cm depths the increases were not significant. However, in minimum tillage, crops are grown with minimal cultivation of the soil (Karlen *et al*., 1994). When the amount of tillage is reduced, the stubble or plant residues are not completely incorporated and most of the residues remain on top of the soil rather than being ploughed or disked into the soil. This reduces at least temporarily the rate and amount of plant nutrients released through residue decomposition (Bayer *et al*., 2000).

A study simulating soil organic carbon dynamics based on data from 10-year field experiments with residue, manure and fertilizer applications in dryland maize production systems in northern China, suggested that with minimum tillage practices at least 50%, on average, of the crop residue should be returned to the soils to maintain acceptable organic carbon levels (Wang *et al.,* 2005). Thus, the potential gain in soil organic matter varied among sites depending on soil and environmental variables, tillage and residue management practices, initial organic carbon, rate of carbon input, source of organic material, time of carbon application, fertilizer use, and cropping systems.

Depending on planting frequency, increases in soil carbon may take 5-10 years to come into effect. In a study at Swift Current, Saskatchewan, Campbell *et al.,* (1995) reported that between 1986 and 1994 organic carbon concentration under direct seeded continuous wheat changed from 1.75% to 1.83%. Over the same time period for a direct seeded/chemical fallow wheat-fallow rotation, the change was from 1.63% to 1.60%. In another study, after 11 years of direct seeding of continuous wheat on a fine sandy loam soil in southwestern Saskatchewan, organic carbon in the 0-7.5 cm depth increased by 21%, but there was no change in organic carbon in the 7.5-15 cm depth.

Reduction in tillage intensity and the use of cropping systems that maximize residue addition to the soil have been efficient agricultural practices to maintain or increase SOM. Accumulation rates of SOM as high as 1 Mg C /ha/yr have been reported in the warm, wet subtropical regions of Brazil under no-tillage and with cropping systems using cover crops (Bayer *et al.*, 2000).

## 2.2 Minimum tillage effects on soil moisture

Minimum tillage has a moderating effect on soil temperatures and soil moisture regimes. It prevents extreme temperatures, and regulates the rate of evaporation (Oldreive, 1995). The tillage method also affects soil moisture through altering root distribution (Fitter, 1991). Consequently, other factors being the same, plant available water reserves in a soil managed by MT are likely to be greater than in plough-till soil. This is especially so during the first and second stages of evaporation. Tessier *et al*., (1990) found out that MT significantly improved water availability to crops compared to tilled plots. The higher soil moisture reserve is due to improved soil structure and decreased evaporation due to the crop residue mulch. Improvement in soil structure takes a long time and is relatively insignificant in coarse textured soils. In such soils, improved soil structure variables are mostly due to the use of crop residue mulch (Angers and Carter, 1996). Blevins *et al*., (1971) also indicated that no-till treatments had higher volumetric moisture content to a depth of 60 cm during most of the growing season. The largest difference occurred in the upper 0- 8 cm depth.

## 2.3 Cropping systems

One of the approaches that have been sought by researchers to increase food production within the tropics is the testing of the different cropping systems (Lathwell, 1990). The most common cropping systems in most of the regions involve growing several crops in association as mixtures or as intercrops (Vandermeer, 1992). This practice provides the farmer with several options for returns from the land and labour, often increases efficiency with which scarce resources are used, and reduces dependence upon a single crop that is susceptible to environmental and economic fluctuations. Cropping systems include the following:

### 2.3.1 Relationship between cereals and legumes

Rotation of cereals with legumes has been extensively used by farmers and studied in recent years (Schoonhoven and Voysest, 1993). Use of rotational systems involving legumes for nitrogen fixation benefits is gaining importance throughout the tropics because of economic and sustainability considerations. The beneficial effects of legumes on succeeding crops is normally exclusively attributed to the increased soil N as a result of $N_2$ –fixation, though some workers have demonstrated that legumes can also deplete soil nitrogen (Schoonhoven and Voysest, 1993)

The use of rotations is almost a rule, if minimum tillage is to be successful due to its beneficial effects such as: offering diverse 'diet' to the soil microorganisms, also as the crops root at different depths, they are capable of exploring different soil layers for nutrients and moisture. A study done in Ontario, Canada, showed that decreases in corn yield due to minimum tillage could be eliminated if rotations were used (Weil, 1989). For short term rotations, higher corn yields were obtained when the previous crop was not corn provided the soil was ploughed either with a mouldboard plough or a chisel. With the zero- till system, good yields were obtained when corn followed soybeans. Also Kihara *et al*., (2005) observed higher maize grain yields under rotation cropping compared to other cropping systems in a reduced tillage practice at Nyabeda, Siaya district, in western Kenya. The beneficial effect was attributed to legumes in rotation which may have contributed to improvement of soil structural stability and moisture retention through soil congregation.

### 2.3.2 Intercropping

Intercropping is a popular cropping system among small-scale farmers in the tropics (Vandermeer, 1992) because of its advantages. Some measures of disease control can also be effected through intercropping (Messiaen, 1994). There is also the possibility that competition between crops could offer some solutions to weed control (Schoonhoven and Voysest, 1993).

Traditional intercropping systems cover over 75% of the cultivated area in the semi arid tropics (Stein *et al*, 1986).  As Norman (1974) observed, the principal reasons for farmers to intercrop are: flexibility, profit, resource maximization, risk minimization, soil conservation and maintenance, weed control and nutritional advantages. In the Sudano-Sahelian zone, cereals such as millet and sorghum are traditionally intercropped with cowpea on small farms. A study by Norman (1974) in Southern Nigeria showed that only 8% of the area was planted to sole sorghum, while about 50% of the area was planted with sorghum intercrop. The author has clearly underscored the importance of intercropping with emphasis on its maximum utilization of resources and stabilization of yields.

The most common associations are cereal/cowpea, cereal/groundnut, and cereal/cereal such as millet /sorghum/maize and millet/sorghum/cowpea. In these systems, pearl millet is normally sown first and acts as a dominant crop. In the cowpea/cereal intercropping, the cowpea and cereal are usually planted in alternating rows, but recent research at IITA- Nigeria, has shown that planting four rows of cowpea to two rows of cereal is more productive. In western Kenya, two maize and two legume stepped rows, popularly known as ‘MBILI’ (or Managing Beneficial Interactions in Legume Intercrops) was researched on by SACRED Africa NGO and some good yield results have been obtained (Langat *et al*., 2003; Thuita *et al*., 2007). For efficiency and sustainability of an intercropping system, the management must allow each species to have sufficient nutrient acquisition and thus increasing nutrient use efficiency (NUE). The system must allow each species to have sufficient energy resources to be able to attain its specific uptake capacity. Hence spatial distribution of the different species in relation to light interception is of great importance.

Fisher (1976) reported that mixed cropping of annual crops in tropical regions is a more efficient means of using available land than the pure stands. One of the important factors to consider in any intercrop is efficient use of nutrients like P, N and water. NUE is often viewed from agronomic, economic or environmental perspectives (Bock, 1984). NUE is based on yield (yield efficiency), the particular nutrients recovered and the nutrient application method and time or yield and nutrient recovered (physiological efficiency). For nutrients such as N, use efficiency has important implications for the environment. Allison (1996) reported that recovery of applied N under average field conditions is greater than 50-60% even if immobilization is taken into consideration under intercropping.

### 2.3.3 Cereal legume intercropping

Most studies on intercropping have focused on the legume–cereal intercropping, a productive and sustainable system. The effects of intercropping can either be negative or positive depending on the intercrops grown especially the legume component.

Ghraffarzadeh *et al*., (1994) found that strip intercropping led to 20-24% greater maize yields and 10-15% lower soybean yields in adjacent border rows in a maize/soybean intercropping system in Iowa, USA. Also in maize/soybean strip intercropping, West and Griffith, (1992) observed a 26% increase in maize yield and a 27% reduction in soybean yield of border rows located at the outside of 8-row alternating strips in Indiana, USA. However, interspecific competition may occur when the two crops are grown together (Van der Meer, 1989). Such competition usually decreases survival, growth or reproduction of at least one species (Crawley, 1997).

### 2.3.4 Green manure crops and intercropping

Timely application of organic materials with a low C/N ratio, such as green manure and compost, could synchronize nutrient release with plant demand and minimize the amount of inorganic fertilizer needed to sustain high crop yields for short-cycle crops such as maize, rice, and soybean, all of which have a high nutrient demand (Sanchez *et al*., 1989; Lathwell, 1990). Fast growing leguminous species such as mucuna (*Mucuna utilis*) and kadzu (*Pueroria phseoloides*) can be especially useful as cover crops for erosion control, weed suppression, for soil moisture conservation and fertility restoration (Burle, 1992). Leguminous green manures and cover crops are able to: enrich the soil with biologically fixed N; conserve and recycle soil mineral nutrients; provide ground cover to minimize soil erosion, and require little or no cash input. However, additional labour is required for timely establishment, maintenance and incorporation of the green manure crop (Lathwell, 1990)

Most leguminous crops are better suited for high base status soils (e.g. Alfisols) containing adequate available phosphorus and calcium and other cations. In the humid lowland forest zones with bimodal rainfall distribution, it is possible to intercrop a slow growing legume (e.g. *Sesbania*) with a food crop (e.g. maize) in the first season, and allow full growth of the legume in the second season to be incorporated as green manure in the first season of the following year (Balasubramanian and Blaise, 1993). Although some research workers have reported evidence of direct transfer of N in a maize/cowpea intercrop, it is believed that the N benefits are mainly for the subsequent crop after roots, nodules and fallen leaves have decomposed (Ledgard and Giller, 1995)

**2.4 Surface residues**

Erenstein (1999) advocated crop residue mulching for improved resource conservation and productivity. Plant residues on the soil surface affect soil temperature and moisture, and consequently crop and weed germination, speed of emergence and root growth. They affect soil water and gas flow, soil structure, residue decomposition, nutrient cycling and availability, weed spectrum and competition and plant disease dynamics (Lafond *et al*., 1992). In semi-arid tropical regions mulch may be crucial in reducing the deleterious effects of intense summer rainfall and may reduce high temperature injury to emerging seedlings by slowing evaporation (McCown, 1996). In cooler areas early in the season, however, Berry *et al*., (1987) found increased soil temperatures at 50 mm depth, and more rapid seedling emergence and development with less residue cover.

The benefits derived from mulch depend on the agro-ecological zone. Where marginal or erratic rainfall or drought is a problem, the major benefits are increased moisture capture and retention, with weed suppression in these and more humid areas. The minimum quantity of mulch needed for short term moisture conservation benefits is 5 t/ha, which is often difficult to achieve due to alternative uses for the generally low quantities of residue, especially in semi-arid regions. Smaller quantities (2-3 t/ha) may improve soil physical properties in the long term if applied each year. Cost of mulching is critical to adoption and large scale mulching of field crops is only likely to be achieved where in situ production is sufficient for both mulch and household needs (Carsky *et al*., 1998) .

Tillage practices which preserve higher levels of surface residues retain more water (Berry *et al*., 1985). Ideally, soils should at all times have a minimum of 30% residue cover, but Oldreive, (1993) maintains that even 10% of residue cover is better than using a mouldboard plough because of the damage this does to soil structure.

### 2.4.1 Management of crop residues

Organic nutrient sources include plant residues, leguminous cover crops, mulches, green manure, animal manure, and household wastes. Under continuous cropping, recycling and reusing nutrients from organic sources may not be sufficient to sustain crop yields. Nutrients exported from the soil through harvested biomass or lost from soil by gaseous loss, leaching, or erosion, must be replaced with nutrients from external sources. In this respect the judicious use of chemical fertilizer is essential to maintain soil fertility (Tandon, 1993)

The beneficial effects of SOC are well known. Physically, it improves soil structure and increases water-holding capacity. Chemically it increases the capacity of the soil to buffer changes in pH, increases the cation exchange capacity (CEC), reduces phosphate fixation, and serves as a reservoir of secondary nutrients and micronutrients. Biologically, organic matter is the energy source of soil fauna and microorganisms, which are the primary agents that manipulate the decomposition and release of mineral nutrients in soil ecosystems (Hossner and Dibb, 1995).

Organic matter in soil exists as partially decomposed plant and animal residues, living and dead microorganisms, and humified organic matter or humus. Stable humus constitutes 50-75% of total soil carbon and is little affected by management. The labile soil organic matter pool, which is important for nutrient release during the growing season, can be manipulated through various soil management practices (Fernandes and Sanchez, 1990). In general, more than 95% of total N and S and up to 75% of the P in surface soils are in organic forms (Fernandes and Sanchez, 1990). Rate of decomposition of both fresh plant residues and humified SOM are three to five times greater in the humid tropical environment than under temperate conditions (Juo and Kang, 1989). Therefore, in cultivated fields in the humid tropics, frequent application and larger quantities of organic materials are required to maintain adequate SOM levels than in temperate regions (Bationo *et al*, 1993).

Strategies and practices for SOC management include: returning organic materials to the soil to replenish soil organic carbon lost through decomposition (recycling of plant and animal residues, green manuring, cover crop rotations); ensuring minimum disturbance of the soil surface (residue mulch, minimum tillage) to reduce the rate of decomposition; reducing soil temperature and water evaporation by mulching the soil surface with plant residues; and integration of multipurpose trees and perennials in cropping systems to increase the production of organic materials.

### 2.4.2 Residue-nutrient availability under minimum tillage

When residues are surface applied or incorporated into the soil, the impacts of crop residues on nutrient availability differ. Rennie and Heimo (1984) reported that incorporation of straw into soil led to significantly lower barley yields than when the straw was left on the soil surface. Furthermore, surface placement of the straw reduced N immobilization as compared to straw incorporated into the soil. Because of greater fluctuations in surface temperature and moisture as well as reduced availability of nutrients to microbes (Douglas *et al.*, 1980; Schomberg *et al*., 1994), soil-incorporated residues tend to decompose faster than surface residues and have a higher potential for N immobilization (Brown and Dickey, 1970).

In addition, Schnurer *et al.*, (1985) demonstrated that residue added to soil with manure or nitrogen fertilizer led to residue decomposition rates that were two times greater than when no amendments were added. Rasmussen *et al.* (1997) found that standing straw residue had a strong adverse effect on wheat yield as well, decreasing yield of winter wheat by 13% compared with chopped straw. Additionally, where the surface temperature during the spring corn seedling period was reduced 2-6 $^{0}$C, lower yield was reported with stubble surface application as compared with treatments where stubble was removed or incorporated (Cai and Wang, 2002). However finding sufficient quantities of crop residue for use as mulch is often a problem in smallholder farms in Africa, due to the competing uses such as for fodder and fuelwood (Fowler and Rockstrom 2001)

## 2.5 Nitrogen availability and nutrition in higher plants

Nitrogen is an essential plant nutrient; it is ironic that where N has the greatest total abundance of 78% in the atmosphere it is the most deficient nutrient contributing to reduced agricultural yields throughout the world (Mackenzie, 1998). However, more than 99% of this N is not available to >99% of the living organisms. The reason for this seeming contradiction is that while there is an abundance of N in nature, it is almost entirely in a chemical form ($N_2$) that is not usable by most organisms. Breaking the triple bond holding the two N atoms together requires a large amount of energy that can be mustered only in high temperature processes or by a small number of specialized N fixing microbes converting into ammonium ($NH_4^+$) and nitrate ($NO_3^-$), the two nitrogen forms utilized by plants (Agboola and Fayemi, 1972).

N is an integral part of compounds like chlorophyll enzymes. It is an essential part of amino acids, cell nucleus and protoplasm as well. It stimulates root growth and development as well as uptake of other elements (Brady, 1990). Most plant species when grown under appropriate conditions utilize either form of N; however, growth responses over a wide array of environments are usually superior for nitrate ($NO^-_3$) than for ammonium ($NH_4^+$). Because $NH_4^+$ is rapidly converted to $NO^-_3$ by microbes in most soils when moisture, aeration and temperature are optimal for plant growth, $NO^-_3$ is considered the primary form of N available to rain-fed crop plants (Hageman, 1984). Under such conditions, the direct role of $NH_4^+$ in crop production becomes insignificant.

The inherent characteristics and properties of the two ions are different; $NH_4^+$ is a cation and $NO^-_3$ is an anion, and in a negatively charged environment (medium) $NH_4^+$ is bound, while $NO^{-}_{3}$ remains mobile. Hence $NO^{-}_{3}$ can move with the soil solution to the root or, it is more readily leached from the soil (Hageman, 1984). For $NO^{-}_{3}$ uptake, a nutrient medium of pH 4.5 to 6.0 is best while for $NH_4^+$ a pH of 6.0 to 7.0 is best (Hewitt, 1970) .

The high mobility of $NO^{-}_{3}$ means it is highly susceptible to losses mainly due to leaching and this has led to the development of slow release N fertilizers (SRN) e.g. urea formaldehyde (38%), Formolene (30%) as reported by Allen, (1984).

However, the concentration of nitrogen is directly dependent on P applied to the crop because the N fixing plant will only grow well and fix N actively when adequate P is present, about 10 kg of N may be fixed per kg of P applied (Tisdale et al., 1990). Nitrogen requirements vary considerably with the plant and at different stages of growth and development. It is minimal in the early stages but the requirements increase as the rate of growth increases to reach a peak in most annual crops, between onset of flowering and early grain or fruit formation (Marschner, 1986). It is because of these temporal N needs that N management for crops usually involves the application of only a small fraction of the total N rate at planting time to stimulate early growth while the bulk is applied later at the period of rapid growth (Tisdale *et al*., 1990). In a review of literature on N use efficiency, Sigunga, (1997) identifies some of the factors affecting fertilizer N uptake by crops to be as follows: plant and its genotype, N source and rate, climatic conditions and N application method and time. These factors may in turn, be influenced by such processes as N leaching, denitrification, $NH_3$ volatilization and soil N mineralization.

### 2.5.1 Urea

Urea ($CO(NH)_2$) is the most concentrated solid N fertilizer available in the market, containing about 46% N. In many countries, it is the cheapest form of N fertilizer (Wild, 1988). Substantial savings on handling, storage, and transportation costs are possible because of urea's high N content (Tisdale *et al*., 1985). Urea is highly soluble in water and is thus susceptible to leaching losses in periods of continuous wet weather. It is also hydrolyzed to release ammonia which can be lost to the atmosphere especially when applied to the surface at high soil and environmental temperatures (Wild, 1988; Tisdale *et al*., 1985). Incorporation into the soil promptly is, therefore, the recommended management practice for urea (Troeh and Thompson, 1993)

### 2.5.2 Fertilizer N availability under minimum tillage

Due to changes in the soil physical, chemical, and biological environments, the rates of N transformation in MT system differ from those in conventional tillage systems. Large amounts of cereal residues with a high C:N ratio that are left on the soil surface under MT temporarily result in a net immobilization of mineral N in the soil, although it is expected that N immobilization will be less than when residues are incorporated (Abiven and Recous, 2007). Farmers without access to mineral fertilizer cannot compensate for such N deficiencies and will suffer yield reductions as a direct result. If soil N availability decreases under MT with a mulch of crop residues – and some studies indicate that this does not always occur (Lal, 1979; Mbagwu, 1990) – a larger amount of N fertilizer will be needed to achieve equivalent yields as compared without crop residues. The amount of fertilizer required will depend on the rates of crop residue added and their quality. If repeated additions of large amounts of crop residues lead to a greater soil C  time this may lead to a greater net N mineralization once a new equilibrium is achieved (Erenstein, 2002). If residues are ploughed into the soil this happens more quickly. The length of time required to achieve net N mineralization depends on rates of residue addition, rates of N fertilizer added and the environmental conditions – particularly on the length and 'dryness' of the dry season. Since usually more nitrogen would be applied to compensate for any sub-optimal physical or biological conditions resulting from no-till systems (Riley *et al.,* 1994), optimum fertilization is more critical with no-till than with conventional tillage systems. In drier regions, the additional stored water with MT increases the yield potential, requiring a greater supply of available N. This may, in part, explain the increased need for N in the early years of some minimum tillage systems (Schoenau and Campbell, 1996). Additionally, fertilizer requirements may even be expected to decline over time as a result of organic matter accumulation (Riley *et al.*, 1994) and reduced erosion losses (Schoenau and Campbell, 1996). Precise placement of N-fertilizer in a no-till system with side-banding can reduce the immobilization effects as the no-till drill separates the fertilizer and residue (Malhi and Nyborg, 1992).

## 2.6 Maize

Maize is a tall, determinate annual plant producing large, narrow, opposite leaves (about a tenth as wide as they are long), borne alternately along the length of a solid stem. It is the most important cereal after wheat and rice and is very widely distributed. Cultivation of maize and the elaboration of its food products are inextricably bound with the rise of the pre-Columbian Mesoamerican civilizations (Salvador, 1997). Due to its adaptability and productivity, the culture of maize spread rapidly around the globe after Spaniards and other Europeans exported the plant from the Americans in the 15$^{th}$ and 16$^{th}$ century. Maize is currently produced in most countries of the world (Salvador, 1997).

In Kenya, maize is grown by 90% of the farm households and provides about 40% of the population's caloric requirements (Pearson *et al*., 1995). About 85% of the country maize is produced by smallholders from many diverse agro-ecological zones (AEZs), the average maize yield in western Kenya is about 1.25 t/ha varying greatly from less than 1 t/ha from smallholders to about 6 t/ha in commercial farms (GOK, 1997)

Ecologically, maize is adapted to a wide range of environments, but it is essentially a crop of warm regions and where soil moisture is adequate. The crop requires an optimum temperature of 21-30 $^{0}$C and soil pH of 5.5-7. Rainfall requirements vary with the variety, and range from 200 to 900 mm in the growing season. Maize is relatively sensitive to periods of low rainfall and water stress and especially during flowering. It is susceptible to flooding for 48 hours to a depth of 5-15 cm reducing yield by 31-63%. Maize grows well on a range of soils but best on intermediate textures (sandy-loams to clay-loams) with good structure and aeration. Poor soil structure, inadequate aeration and soil compaction restrict root development and lower yields (Holland *et al.,* 1999). Maize cultivation under conservation tillage acts as the source of mulch for the previous season. Legumes in association with cereals would make a significant contribution to the quantity and quality of residue mulch in CT systems.

### 2.7 Soybeans (*Glycine max*)

Soybean plant varies in height from about 30 cm to 150 cm and its root system can extend to 2 m under favorable conditions. Most of the roots of soybean are in the topsoil layer (15-20 cm). Most soybean varieties can only be infected by *Bradyrhizobium japonicum* bacteria (Wild, 1993). It is a self-pollinated crop. Shattering or dehiscence of pods before harvest reduces harvestable yield and is most serious when relative humidity is low. Soybean grows from the subtropical to the warm temperate zones. Its growth cycle is 90-120 days (Martin *et al*., 1990). For maximum yields 500-750 mm of water is required during the growing season. Water logging is discouraged since it results in an insufficient oxygen supply, which reduces root respiration, production of toxics by microbes in the rhizosphere and/or increase in ethylene production. Soybean grows in both sandy and heavy textured soils. Major constituents of soybean seed are protein (40-45%) and oil (20-22%). The protein is fairly well balanced in essential amino acids, but somehow low in methioneine and cysteine. Its protein is higher in lysine and trytophan than common cereals. Soybean protein equals that of milk, meat or eggs (Scott and Aldrich, 1983). It can thus be used as a health food since it is high in fiber, low in fat and low in cholesterol. Production of soybean is currently being promoted by TSBF-CIAT in western Kenya and in the neighboring Uganda and also by AMPATH- Indiana, Purdue (USA) and Moi University. Introducing legumes in cropping systems under CT has been shown to have both short term benefits (increased water and nutrient use efficiency, yields and economic returns) and long term effects (increased N-supply power of the soil, microbial diversity and carbon sequestration.

## 2.8 Nutrient Use Efficiency (NUE)

The utilization efficiency with which plants capture nutrients applied in different forms, rates, placements and times is a fundamental aspect in improving nutrient management, (Ruto *et al*., 2004). NUE is a function of the crop genotype, environmental differences, types, methods and time of application of the nutrient and soil factors. In addition, the recovery fraction of added fertilizer/ nutrient depends on its losses, movement of the nutrients to plant roots, including the rooting patterns from genotypes (Obura *et al*., 2003). NUE of a given fertilizer or organic resource is useful in predicting crop response due to application of inputs (J.R. Okalebo, pers comm). NUE can be partitioned into external/ agronomic NUE and internal/ physiological NUE.

External/ agronomic NUE gives the values of grain yield increases above the control per unit of fertilizer N or P added. It is most useful for understanding the factors governing nutrient uptake and fertilizer efficiency and to compare different nutrient management options. Internal/physiological NUE represents the ability of a plant to transform the nutrient taken up into yield, hence provides the magnitudes of grain yield above the control per unit uptake of P or N in the grain (Bowen and Zapata, 1991)

## 2.9 Economic analysis in minimum tillage

Economic evaluation of a new technology is important in its development and transfer; moreover, it enhances adoption by farmers (Kipsat, 2002). Some of the documented factors influencing technology adoption are profitability, risks, and complexity of technology, divisibility of the technology and systems compatibility. The acceptability of improved agricultural technologies is measured by input availability, costs, agronomic performance, labour demands, availability and market of inputs and outputs among other factors (CIMMYT, 1988). The most commonly used methods for economic analysis of treatment combinations include the costs and returns analysis method which is used to determine the impact of a new technology (Barlow *et al*., 1983). Some of the parameters used in economic analysis include gross margins (GM), returns to land, labour and capital and value to cost ratios. Gross margin is used to make annual evaluation of on-going or existing projects and is defined as gross output less variable costs. GM is used to determine profitability of enterprises produced under alternative technologies or treatments. Returns to land, labour and capital are measures of land, labour and capital productivities respectively, and are used as measures of performance of technologies. The average gross returns and variable costs per unit of land are usually determined on the basis of the average market prices, while overhead inputs such as land and sunken capital are ignored (Barlow *et al*., 1983). Several economic indicators were used in this study and they include:

**1. Gross margin analysis**

The method used was Gross Margin Analysis which involves considering total cost of all the inputs, total revenue from the grain yield, and the profits. Gross margin analysis was used to analyze the gross profitability of producing maize under continuous cropping, rotation cropping (maize and soybean) and intercropping (maize + soybean) systems at farm level. It is used to rank technologies under evaluation thus can be used to analyze different treatments in experimental trials. However, it should be noted that the gross margin is not necessarily a profit indicator although it assumes a linear model because increasing the scale of operation could increase the gross margin proportionally and that will not mean that the activity undertaken is profitable. Therefore gross margins would be calculated per unit (land, labour and capital). Generally it is important to ensure that the total gross margin be higher than the total overhead costs to be economically viable.

Mathematically gross margin equation can be expressed as:

$\prod' = Py_j.\ f(X_i) - \sum Px_i X_i$ ............................................................................................................ Equation 1

where $i$ = input, 1,2,…$m$ and $j$ = output, 1,2…$n$

While;

$\prod'$ represents gross margin or profit of a treatment or technology

$Py_j$ represents selling price of output $j$

$f(X_i)$ represents quantity of output $j$ achieved

$Px_i$ represents buying price of input $i$

$X_i$ represents quantity of input $i$ used (CIMMYT, 1988)

**2. Marginal analysis**

Marginal analysis is the process of calculating marginal return between treatments and comparing those rates of return with the minimum rate of return acceptable to farmers. Marginal rate of return (MRR) is calculated by dividing marginal net benefits by marginal cost, expressed as a percentage. Marginal rate of return indicates what farmers expect to gain, on the average, in return for their investment when they decide to change from one treatment to another. Researchers' experience and empirical evidence have shown that for the majority of situations the minimum rate of return acceptable to farmers is between 50-100%. If the technology is new to the farmers, and requires that they learn some new skills, a 100% minimum rate of return is a reasonable estimate. If a change in technologies offers a rate of return above 100%, it would seem safe to recommend it in most cases (CIMMYT, 1988).

# CHAPTER THREE

# MATERIALS AND METHODS

## 3.1 Site description

The field trial was established in 2005 long rain season (LR) on a smallholder farm at Asinge (0º 36' N; 34º 20' E and 1420 m above sea level) in Teso district, western Kenya. The mean annual rainfall is 1800 mm with a bimodal distribution pattern. The long rain season begins from March to July whereas the short rain season occurs from September to January. The soils are loamy sand characterized with low organic carbon content of 0.83% and total nitrogen content of 0.08% with a pH of 5.50 and Olsen extractable P of 6.04 mg/ kg soil (Table 3).

## 3.2 Experimental design and treatments

The experiment was a 3 x 2 x 2 factorial experiment arranged in a split-split plot design with three cropping systems (maize-soybean intercropping, maize-soybean rotation, continuous maize) as main plots; nutrient N levels (0 and 60 kg N/ha) as subplots and crop residue management (with and without crop residue) as sub-subplots replicated three times. The experiment was laid on a 37m by 37m field. Main plots of 12 m x 12 m were split into subplots of 5.75 m x 12 m each (separated by 0.5 m path) to accommodate different fertilizer N combinations and hence N response. Each subplot was split into sub-subplots of 5.75 m by 5.75 m with inter sub-subplot spacing of 0.5 m, to test with and without crop residue treatments. N fertilizer (Urea) was applied at 0 and 60 kg N/ha with a blanket application of P fertilizer triple superphosphate (TSP) at 60 kg P/ha and also a blanket application of K fertilizer muriate of potash (MOP) at 60 kg

$K_2$0/ha. Crop residue (maize stover) was applied at 0 and 2 t/ha. Maize and soybean were planted as the test crops. Treatments are given in Table 1.

**Table 1: Experimental treatments as applied at Asinge in Teso district, western Kenya for three seasons (2005-2006)**

| Treat. No. | Cropping systems | N-levels | Crop residue |
|---|---|---|---|
| **1** | 1. Maize –soybean ROTATION ($CS_1$) | 0 | + Crop residue |
| **2** | **2**. Maize –soybean INTERCROP ($CS_2$) | 0 | + Crop residue |
| **3** | **3.** CONTINUOUS maize ($CS_3$) | 0 | + Crop residue |
| 4 | 1. Maize –soybean ROTATION ($CS_1$) | 0 | - Crop residue |
| **5** | **2**. Maize –soybean INTERCROP ($CS_2$) | 0 | - Crop residue |
| **6** | **3.** CONTINUOUS maize ($CS_3$) | 0 | - Crop residue |
| **7.** | **1.** Maize –soybean ROTATION ($CS_1$) | 60 | + Crop residue |
| **8** | **2**. Maize –soybean INTERCROP ($CS_2$) | 60 | + Crop residue |
| **9.** | **3.** CONTINUOUS maize ($CS_3$) | 60 | + Crop residue |
| **10.** | **1.** Maize –soybean ROTATION ($CS_1$) | 60 | - Crop residue |
| **11.** | **2**. Maize –soybean INTERCROP ($CS_2$) | 60 | - Crop residue |
| **12.** | **3.** CONTINUOUS maize ($CS_3$) | 60 | - Crop residue |

**KEY**

Three cropping systems: Rotation (**$CS_1$**), Intercropping (**$CS_2$**) and Continuous (**$CS_3$**)

Two nutrient levels: 0 kg N/ha and 60 kg N/ha

Two residue management systems: Residue (**+ CR**) and no residue (**- CR**)

NB: Crop residue source is maize stover; N source is Urea

For each cropping systems (main plot), the plots were divided into sub-plots where one sub-plot received 0 kg N/ha while the other 60 kg N/ha. Each sub-plot was split into sub-sub plots where two of the sub-sub plots were applied with crop residue while the remaining two sub-sub plots received none. Under rotation cropping system two of the sub-sub plots were planted with soybean while the other two were planted with maize and rotated every season. All four sub- sub plots under intercropping were planted with both maize and soybean each season. Under continuous cropping system all four sub-sub plots were planted with maize each season.

| | | | | | |
|---|---|---|---|---|---|
| $CS_3N_0$+CR | $CS_3N_0$-CR | $CS_2N_0$+CR | $CS_2N_0$-CR | $CS_3N_1$-CR | $CS_3N_1$+CR |
| $CS_3N_1$-CR | $CS_3N_1$+CR | $CS_2N_1$+CR | $CS_2N_1$-CR | $CS_3N_0$+CR | $CS_3N_0$-CR |
| $CS_1N_0$-CR | $CS_1N_0$+CR | $CS_1N_1$+CR | $CS_1N_1$-CR | $CS_2N_1$+CR | $CS_2N_1$-CR |
| $CS_1N_1$+CR | $CS_1N_1$-CR | $CS_1N_0$-CR | $CS_1N_0$+CR | $CS_2N_0$-CR | $CS_2N_0$+CR |
| $CS_2N_1$-CR | $CS_2N_1$+CR | $CS_3N_1$+CR | $CS_3N_1$-CR | $CS_1N_0$+CR | $CS_1N_0$-CR |
| $CS_2N_0$-CR | $CS_2N_0$+CR | $CS_3N_0$+CR | $CS_3N_0$-CR | $CS_1N_1$-CR | $CS_1N_1$+CR |
| Replication I | | Replication II | | Replication III | |

**Figure 1:** Randomized layout of a 3 x 2 x 2 factorial experiment with twelve treatments arranged in a split-split plot design with three cropping systems ($CS_1$, $CS_2$ and $CS_3$) as main-plot treatments, two nitrogen levels ($N_0$ and $N_1$) as subplot treatments and two

crop residue management practices (+CR and - CR) as sub-subplots treatments, in three replications.

### 3.2.1 Initial land preparation and planting

Initial land preparation was by hand digging with a hoe at about 15 cm depth in all plots; later, the practice changed to minimum tillage where minimum tillage operations were done and at least 30% of residue was left on the surface after planting. Maize variety that is striga tolerant, (IR-CIMMYT hybrid, with seed coated with imazapyr chemical) was used as a test crop because striga weed is common in western Kenya. It was planted at a spacing of 75 cm between rows and 30 cm within rows while soybean (TGX-1448-2E, locally known as SB20) in rotation was planted at an inter-row and intra-row spacing of 75 cm and 10 cm respectively.

### 3.2.2 Treatment application

Crop residue (maize stover) obtained from maize harvested each season in the experimental field, was applied at 0 and 2 t/ha before planting the plots. Fertilizers were placed at the time of sowing. Urea as source of N was applied at 2 rates of (0 and 133.3 kg /ha) supplying 0 and 60 kg N/ha respectively. Blanket applications of 60 kg P/ha triple superphosphate (TSP) and 60 kg $K_20$/ha muriate of potash (MOP) were made (60 kg P is contained in 300 kg of TSP) while (60 kg $K_20$/ha is contained in 120 kg of MOP). The fertilizers were banded close to the seed row to enhance contact between the fertilizer and the roots early in the growing season hence increased nutrient uptake by plants. This was split applied at 1/3 at planting and 2/3 at maize knee height. Bullock and gladiator were applied also at maize knee height to control stem borers and termites respectively.

### 3.2.3 Crop management

All plots were kept weed free by hand pulling particularly of large/ big weeds. Maize stover and soybean residues harvested each season were left on the surface of the field after harvesting the crop. Maize stover was applied the following season at 2 t/ha as crop residue. This rate was considered adequate to minimize N immobilization when incorporated into the soil.

### 3.2.4 Crop harvesting procedures

Maize was harvested from the net plots at maturity leaving 2 border plants (25 cm spacing) on either side and one row (75 cm spacing) from outer ends to eliminate edge effects. Thus, the harvested effective area per plot was 14.0 $m^2$. In the harvested area, total weights of maize ears and cobs (unshelled maize grain) were taken and sub-samples of 8-10 cobs taken from an arrangement of cobs into different classes (big, medium, small). Maize was hand shelled and the grain weights recorded for each plot. Also total weights of soybean pods were taken and sub-samples of 20 pods selected as plot sample. Soybean trash and stalks were left undisturbed in the field. Soybean was hand shelled and the grain weights recorded for each plot. Stover was cut at ground level and its fresh weights taken. Sub–samples of 8 stalks/ plot from the stover were taken and cut into small pieces and mixed thoroughly. Fresh sub- samples of about 500 g of chopped stover / plot were taken. These were sun dried. All plant tissue samples were ground (20 mesh) for plant tissue analysis to determine N and P contents, uptakes and sub-sequent returns of these nutrients into soils through crop residue incorporation. Yield calculations were done using the following expressions:

$$\text{Dry matter factor} = \frac{\text{Sample dry weight}}{\text{Sample fresh weight}} \times 100 \quad \text{.......... Equation 2}$$

$$\text{Yield (kg/ha)} = \frac{\text{Total fresh weight x 10,000}}{\text{Effective area (14.0 m}^2\text{)}} \times \text{dry matter factor} \quad \text{.......... Equation 3}$$

### 3.3 Soil sampling

Soil samples were collected before the start of the experiment for initial characterization of the site at (0-15 cm) and (15-30 cm) depths using an auger. A composite sample was made from 10 samples collected randomly from different parts of each plot, mixed, sub-sampled, air dried and passed through a 2 mm sieve for pH, particle size, extractable phosphorus and through 60 mesh soils for organic carbon and total nitrogen analysis (Okalebo *et al*., 2002). Soil sampling was done each season immediately after harvesting the crop for 3 consecutive seasons to determine changes in SOC and soil total nitrogen mainly.

### 3.4 Nutrient uptake and use efficiencies

N and P uptake and their use efficiencies were calculated using the formulae below.

$$\text{Nutrient uptake} = (N_s \times S_y) + (N_g \times G_y) \quad \text{.......... Equation 4}$$

Where,

$N_s$ and $N_g$ are the nutrient concentrations in the stover and grain.

$S_y$ and $G_y$ is the stover and maize grain yields/ ha respectively on dry matter basis.

The N and P use efficiency was calculated using the following relationship

$$\text{N or P use efficiency (agronomic)} = \frac{\text{Grain yield increase above control}}{\text{Rate of fertilizer N or P applied}} \quad \text{Equation 5}$$

$$\text{N or P use efficiency (physiological)} = \frac{\text{Grain yield increase above control}}{\text{P or N uptake in fertilized crops}} \quad \text{Equation 6}$$

### 3.5 Laboratory analysis of soil and plant tissue

The soil pH, organic carbon, particle size analysis, soil moisture content, Olsen extractable P, total nitrogen and phosphorus in soils and plants, mineral nitrogen in soils were analyzed following the procedures outlined in Okalebo *et al*., (2002).

### 3.6 Statistical analysis of data

All yields, organic carbon, total soil nitrogen, nitrates, moisture content and nutrient uptake data were subjected to analysis of variance (ANOVA) using Genstat Dicovery Edition 3 (Roger *et al.*, 2001). ANOVA table for the analysis is as shown below.

**Table 2: The general layout of the ANOVA table.**

| Source of variation | Df | SS | MS | Computed F | Tabular F (5%) |
|---|---|---|---|---|---|
| **Main plot analysis** | | | | | |
| Replication | 2 | | | | |
| Cropping system (CS) | 2 | | | | |
| Residual (1) | 4 | | | | |
| **Sub-plot analysis** | | | | | |
| Nitrogen levels (N) | 1 | | | | |
| CS*N | 2 | | | | |
| Residual (2) | 6 | | | | |
| **Sub-sub plot analysis** | | | | | |
| Crop residue (CR) | 1 | | | | |
| CS*CR | 2 | | | | |
| N*CR | 1 | | | | |
| CS*N*CR | 2 | | | | |
| Residual (3) | 12 | | | | |
| **Total** | 35 | | | | |

Where: df= degrees of freedom; SS= sums of squares; MS= mean squares

**3.7 Statistical Model for a Split-split plot design**

$X_{jklmn} = \mu + \alpha_j + \beta_k + \Sigma_{jk} + \lambda_l + \delta_{jl} + \Sigma_{jklm} + Q_m + \delta_{jm} + \delta_{lm} + \delta_{jlm} + \Sigma_{jklmn}$

Where:

$\mu$ = mean of plot observation

$\alpha_j$ = main treatment effect

$\beta_k$ = block effect

$\Sigma_{jk}$ = experimental error 1

$\lambda_l$ = sub treatment effect

$\delta_{jl}$ = interaction (A*B)

$\Sigma_{jklm}$ = experimental error 2

$Q_m$ = sub-sub treatment effect

$\delta_{jm}$ = interaction (A*C)

$\delta_{lm}$ = interaction (B*C)

$\delta_{jlm}$ = interaction (A*B*C)

$\Sigma_{jklmn}$ = experimental error 3

**3.7 Economic analysis**

Production and input data were collected throughout the season. Input data consisted of: labour requirements for land preparation, planting, application of fertilizers and crop residue, application of pesticides and fungicides, harvesting and shelling of maize and soybean. Prices of inputs such as maize and soybean seed, gladiator, bulldock, TSP, MOP, and Urea were determined through market survey in the study area. Opportunity cost of capital was estimated as 10% per season, which is the commonly used rate for studies involving resource poor smallholder farmers (Jama *et al*., 1998)

The following economic indicators were used in this study and they include: Gross margin analysis and marginal analysis.

# CHAPTER FOUR

# RESULTS AND DISCUSSION

## 4.1 Initial site characterization

Some of the initial properties of the top soil (0-15 cm) soils obtained before treatment additions are presented in (Table 3).

**Table 3: Characterization of the top soil (0-15 cm) before treatment application at the Teso experimental site**

| | |
|---|---|
| Soil pH ($H_2O$) | 5.50 |
| % Organic carbon | 0.83 |
| Olsen P mg/kg of soil | 6.04 |
| % Total N | 0.08 |
| % Silt | 7.45 |
| % Clay | 7.85 |
| % Sand | 84.7 |
| Textural class | Loamy sand |

The soil pH was within the recommended range of 5.5-6.5 for most food crops Okalebo *et al.,* (2002). Available P (bicarbonate extractable P) was very low below the critical level of 10 mg P/kg of soil below which fertilizer P responses are expected according to ratings given in Okalebo *et al.,* (2002). This justified the blanket application of P each season and the measuring of P levels in soils at harvest to monitor P build up. The organic carbon and N contents in surface soils were low. This was due to the sandy nature of the soil hence less carbon is protected within the soil particles. Soil aggregate dynamics strongly influence carbon sequestration and cycling (Six *et al*., 1998)

### 4.2 Rainfall

Rainfall amounts of 636, 374 and 516 mm were recorded at the site during the three cropping seasons, i.e. 2005 long rain (LR), 2005 short rain (SR) and 2006 LR seasons respectively (Appendix 3). During 2005 SR season, rainfall received was very low and unevenly distributed to sustain crop growth to maturity hence there was crop failure and only above ground biomass was harvested.

### 4.3 Effects of crop residue (maize stover) application on soil organic carbon (SOC) under the three cropping systems.

Residue application significantly increased ($p<0.05$) SOC in surface soils (0-15 cm), (Table 4 and 5). Mean SOC contents of 1.05 and 0.77 % C were obtained during 2005 LR season and 1.51 and 0.72 % C obtained during 2006 LR seasons under residue and no-residue treatments respectively. The higher SOC contents under residue treatments could be attributed to the beneficial effects of residue such as erosion control, nutrient cycling, soil quality enhancement and additional carbon supplied by residue itself also contributed to increased carbon levels in soil. Kushwaha *et al*., (2001) found out that the combined effect of tillage reduction and residue retention on SOC and total N was greater than the effect of either tillage reduction or residue retention alone on a sandy loam soil under tropical dry land agriculture. During 2005 LR season there was a positive interaction effect between fertilizer and residue application on SOC; however the interaction was not observed in second and third cropping seasons (Appendix 1). The reasons for this interaction could possibly be as a result of the higher SOC found under fertilized plots compared to unfertilized plots. During 2006 LR season an interaction effect between cropping system and residue was observed (Appendix 1). Higher SOC of (1.68 % C) was observed in residue treatments under rotation cropping system than in other two systems. This signifies the importance of crop rotations and residue application in any minimum tillage practice. Fertilizer N application at 60 kg N/ha had no significant effect on SOC content, however a slight increase in SOC was observed in fertilized treatments in all seasons.

**Table 4: Effects of cropping systems at two levels of N, with and without crop residue on SOC (%) content in surface (0-15 cm) soils in LR 2005**

| | **Cropping systems** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **Continuous** | | | **Intercropping** | | | **Rotation** | | | |
| **Levels of N (kg N/ ha)** | Minus residue | Plus residue | N-Mean | Minus residue | Plus residue | N-Mean | Minus residue | Plus residue | N-Mean | Overall N mean |
| **0** | 0.74 | 0.89 | 0.81 | 0.88 | 0.94 | 0.91 | 0.81 | 0.91 | 0.86 | 0.86 |
| **60** | 0.77 | 1.17 | 0.97 | 0.65 | 1.24 | 0.94 | 0.79 | 1.15 | 0.97 | 0.96 |
| **Mean residue** | 0.75 | 1.03 | | 0.76 | 1.09 | | 0.8 | 1.03 | | |
| **Overall mean cropping system** | | | 0.89 | | | 0.92 | | | 0.92 | |
| **Residue overall mean** | Minus residue =0.77 | | | | Plus residue =1.05 | | | | | |
| **SED $_{0.05}$ Residue** | | | | | | | | | | 0.036 |
| **SED $_{0.05}$ Fertilizer *Residue** | | | | | | | | | | 0.066 |

**Table 5: Effects of cropping systems at two levels of N, with and without crop residue on SOC (%) content in surface (0-15 cm) soils in LR 2006**

| | **Cropping systems** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **Continuous** | | | **Intercropping** | | | **Rotation** | | | |
| **Levels of N (kg N/ ha)** | Minus residue | Plus residue | N-Mean | Minus residue | Plus residue | N-Mean | Minus residue | Plus residue | N-Mean | Overall N mean |
| **0** | 0.6 | 1.44 | 1.02 | 1.01 | 1.35 | 1.18 | 0.58 | 1.6 | 1.09 | 1.09 |
| **60** | 0.57 | 1.46 | 1.01 | 0.99 | 1.44 | 1.21 | 0.6 | 1.77 | 1.18 | 1.13 |
| **Mean residue** | 0.59 | 1.45 | | 1 | 1.39 | | 0.59 | 1.68 | | |
| **Overall mean cropping system** | | | 1.01 | | | 1.19 | | | 1.13 | |
| **Residue overall mean** | Minus residue = 0.72 | | | Plus residue = 1.50 | | | | | | |
| **SED $_{0.05}$ Residue** | | | | | | | | | | 0.036 |
| **SED $_{0.05}$ Cropping system* Residue** | | | | | | | | | | 0.08 |

**4.3.1 Effects of sampling depth on SOC.**

Sampling was done at 0-15 cm depth during 1st and 2nd seasons. In the third season two soil samples (composites) were taken from 0-15 and 15-30 cm depths. Soils at 15-30 cm depth gave a drop in SOC content as seen in (Figure 2). The high SOC obtained under 0-15 cm depth compared to 15-30 cm depth could be as a result of reduced soil disturbance under minimum tillage; hence the residue added was maintained at the soil surface where it decomposed thereby adding organic matter on surface soils. It is also common experience that SOM in general drops with depth of soils under arable farming.

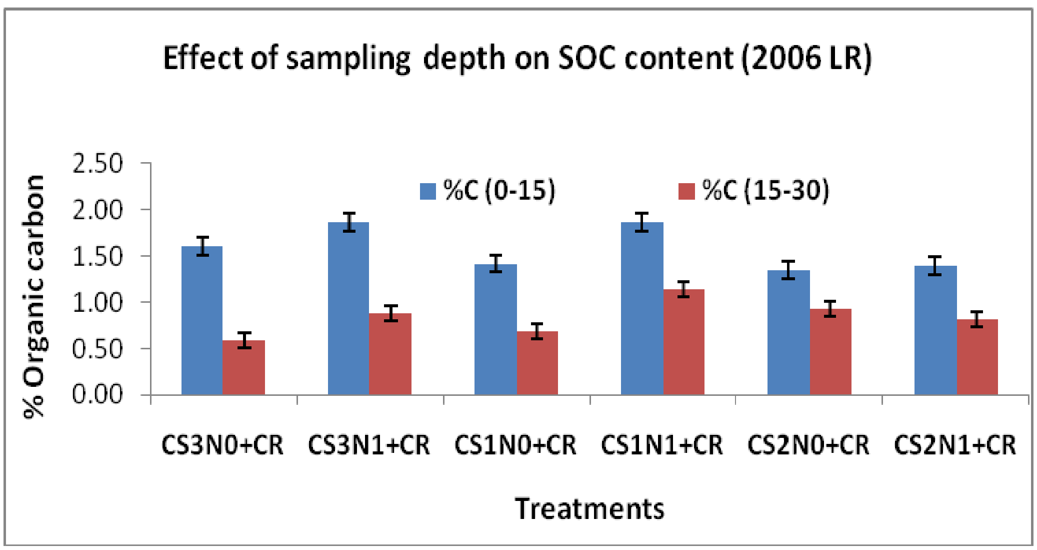


**Figure 2:** Effects of sampling depths (0-15 and 15-30 cm) on SOC content under treatments with residue application.

**KEY:**

**CS1-** Rotation, **CS2-** Intercropping and **CS3-**Continuous cereal

+ **CR**-with residue, **-CR** no residue

0 kg N/ha (**$N_0$**), 60 kg N/ha (**$N_1$**)

### 4.3.2 Effects of crop residue application and fertilizer N addition on soil total N content under various cropping systems

Residue application significantly increased ($p<0.05$) soil total N contents in the surface soils (0-15 cm). Total N contents of 0.083 and 0.073; 0.096 and 0.080% N were obtained during the first season (2005 LR) and third season (2006 LR) under residue and no-residue treatments respectively (Table 6). The high total N content under residue treatments could be attributed to the decomposition of the residues thus releasing nutrients to the soil particularly nitrogen. Application of organic amendments under minimum tillage systems is expected to provide a long term source of N and reduce the need for N fertilization. In western Kenya, incorporation of crop residues (maize stover, wheat straw, bean trash and improved fallows) into soils have been associated with improved N levels in soils and subsequent high maize and bean yields (Palm *et al*., 1997; Okalebo *et al*., 1999; Kifuko, 2002; Ndung´u *et al*., 2006; Waigwa, 2002). Qureshi (1990) also reported that incorporating maize crop residue increased the contents of available P, organic carbon, total N and exchangeable K, Ca and Mg in the soils. Fertilizer N addition also significantly increased ($p<0.05$) total N contents in soils (Table 6). Total N contents of 0.072 and 0.083; 0.080 and 0.096 % N were obtained during the first and third cropping seasons under treatments receiving 0 and 60 kg N/ha respectively. The high total N content under fertilized treatments could be as a result of N application at planting time since Urea contains 45 % N. The minimal N contents obtained under control treatments could be due to continuous crop uptake of N not added to the no-N treatments.

**Table 6: Effects of cropping systems at two levels of N, with and without crop residue on Soil Total N content in surface (0-15 cm) soils in LR 2006**

| | **Cropping systems** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **Continuous** | | | **Intercropping** | | | **Rotation** | | | |
| | Minus residue | Plus residue | N-Mean | Minus residue | Plus residue | N-Mean | Minus residue | Plus residue | N-Mean | Overall N mean |
| **Levels of N (kg N/ ha)** | | | | | | | | | | |
| **0** | 0.067 | 0.090 | 0.078 | 0.075 | 0.089 | 0.082 | 0.070 | 0.086 | 0.078 | 0.079 |
| **60** | 0.086 | 0.100 | 0.093 | 0.091 | 0.106 | 0.098 | 0.089 | 0.101 | 0.095 | 0.095 |
| **Mean residue** | 0.076 | 0.095 | | 0.083 | 0.097 | | 0.079 | 0.093 | | |
| **Overall mean cropping system** | | | 0.085 | | | 0.09 | | | 0.086 | |
| **Residue overall mean** | Minus residue = 0.079 | | | Plus residue = 0.095 | | | | | | |
| **SED $_{0.05}$ Residue** | | | | | | | | | | 0.0012 |
| **SED $_{0.05}$ Cropping system* Residue** | | | | | | | | | | 0.0013 |

**4.4 Soil nitrate –N during the 2006 LR season under crop residue treatments**

Amounts of nitrate-N in soils sampled at 0-15 and 15-30 cm depths varied with high levels obtained within 15-30 cm depth due to leaching of soil nitrogen from top soils to subsoil layers. (Figure 3). Generally, the levels of nitrate-N obtained were minimal, this agrees with Ndung´u *et al.*,(2006), who attributed the low soil $NO_3^-N$ to rapid leaching from the high sand content soils. Low levels of $NO_3^-N$ have also been reported in soils of western Kenya in the sub-soils in a study conducted by Thuita, (2007), but with rather heavier N application rate of 75 kg N /ha as CAN (Calcium ammonium nitrate). The treatments with fertilizer N applied had slightly higher $NO_3^-N$ compared to control treatments with no fertilizer N input. This was probably as a result of N application at planting. Soil sampling for nitrates was done only once during the third cropping season hence differences in $NO_3^-N$ levels under different cropping systems were minimal.

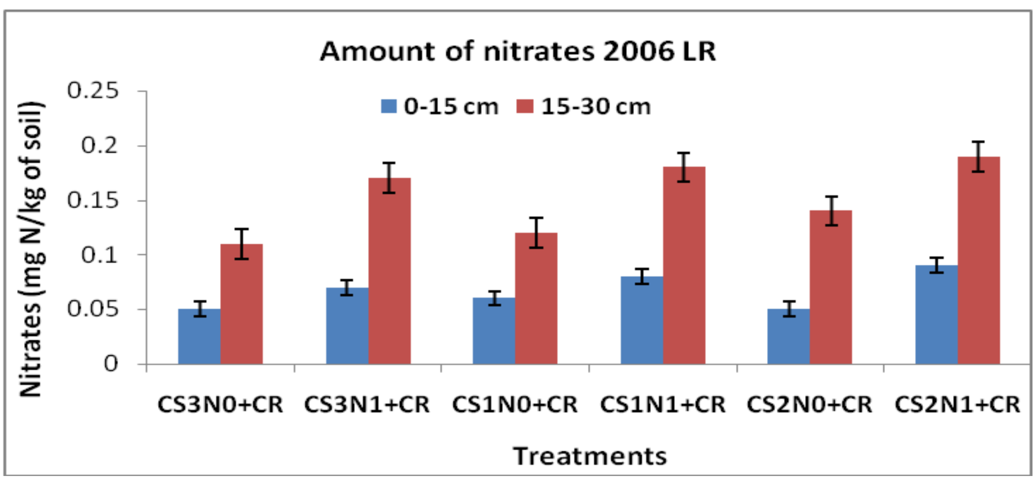


**Figure 3:** Amounts of $NO_3^-N$ during 2006 LR as sampled at 0-15 and 15-30 cm depths.

<u>**KEY**</u>**:** **CS1**-Rotation, **CS2-** Intercropping, **CS3**-Continuous cereal, **+ CR**-with residue, **-CR**-no residue, $\mathbf{N_0}$ -0 kg N/ha and $\mathbf{N_1}$-60 kg N/ha

**4.4.1 Effects of crop residue and cropping systems on soil moisture content of surface soil (0-15 cm) during 2006 LR.**

Moisture content of surface soils (0-15 cm) was measured during 2006 LR cropping season only under residue and no-residue treatments. Treatments under residue had slightly higher soil moisture content of 45% compared to no residue treatments whose soil moisture content was 42% (Figure. 4). Also soil moisture content varied between different cropping systems with values of 44, 45 and 47 % obtained under residue treatments and 41, 42 and 44 % obtained under no-residue treatments in continuous, rotation and intercropping systems respectively. In both cases intercropping had slightly higher moisture contents compared to other cropping systems (however the moisture contents were not statistically higher) possibly as a result of addition of crop residue which acted as a mulch and the canopy provided by underneath soybean crop. The higher soil moisture content under residue treatments could be due to the benefits of minimum tillage in increasing infiltration, water retention and reducing evaporation. Crop residue retains soil moisture (FAO, 2005).

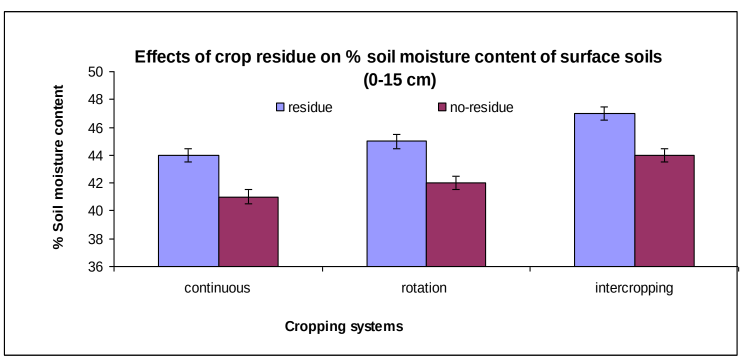


**Figure 4**: Percentage soil moisture content of surface soils (0-15 cm) under residue and no-residue treatments.

### 4.5 Maize yields

#### 4.5.1 Effects of crop residue application on maize grain yields

Crop residue application significantly increased ($p<0.05$) maize grain yields in each cropping season (Table 7 and 8). The high yields obtained under residue treatments in each season could be as a result of moisture conserved in these plots. High yields have been observed with use of crop residues under minimum tillage experiments in Brazil (FAO, 2005). However, the yields will only rise above conventional tillage figures when the system has stabilized. Experiments conducted in western Kenya have demonstrated that higher yields can be obtained when organic residues have been incorporated (Gachengo *et al*., 1999; Palm 1996). Combining minimum tillage with surface residue has also been shown to improve crop performance (Dam *et al.,* 2005; Wayesa and Bennie, 2004).

#### 4.5.2 Effects of fertilizer N addition on maize grain yields

Fertilizer N addition at 60 kg N/ ha significantly increased ($p<0.05$) maize grain yields in each cropping season, (Table 7 and 8). The higher yields obtained under fertilized treatments in each season indicate that the crop responded well to N fertilization due to the low organic matter content of the soil as reported in (Chapter 3, Table 3). In rotation cropping system, for example, the high yields obtained under treatments receiving N indicate that even where soybean had been planted as a previous crop, some mineral N may still need to be applied to the succeeding cereal. The positive yield increase following application of N fertilizer is not unique in our study, as this has been reported in several other studies (Kamara *et al.,* 2008; Kihara *et al.*, 2008; Muleba, 1999).

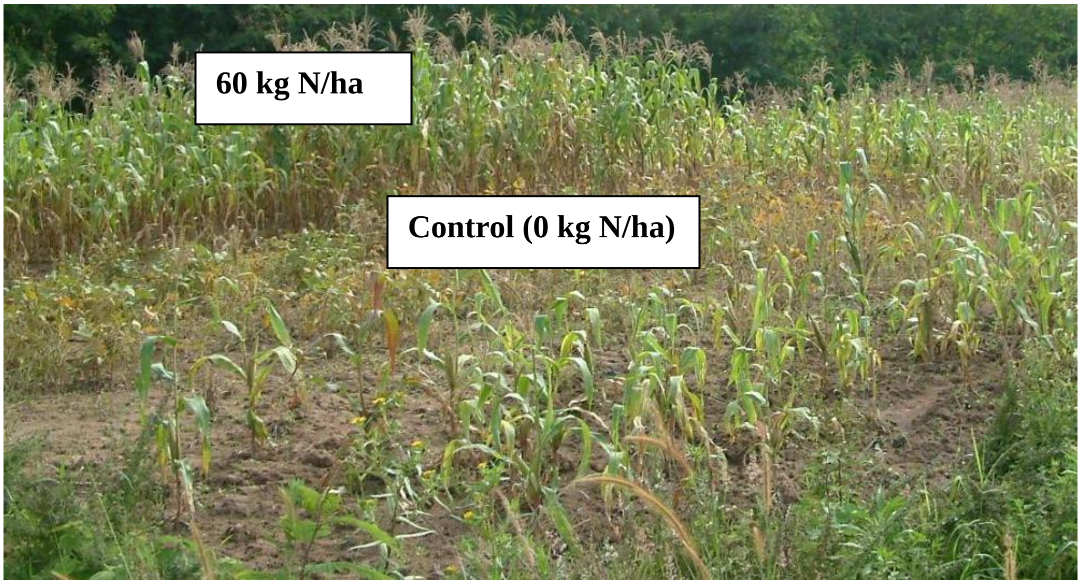


**Plate 1:** Effects of fertilizer N addition on maize growth (Source: Asinge site)

#### 4.5.3 Effects of cropping systems on maize yields

Cropping systems had a significant effect ($p<0.05$) on maize grain yields in each cropping season, (Table 7 and 8). During the first cropping season rotation system gave higher yields of 2.53 t/ha followed by continuous cropping 1.99 t/ha with intercropping giving lowest yields of 1.54 t/ha, while during the third season also higher yields of 3.73 t/ha were obtained under rotation plots 3.1 t/ha under continuous cropping and 2.15 t/ha in intercrop plots respectively. The highest yields under rotation plots could be attributed to the beneficial effects of the previous legume crop (soybean). Giller, (1999) found that maize planted following soybeans benefited more compared to continuous maize, largely due to effects of improved soil fertility. Kasasa *et al.*, (1999) also found increased maize yields following the planting of promiscuous soybean varieties. However, yields under intercropping were lower compared to continuous and rotation plots. The low yields could possibly be as a result of interspecific competition which might have occurred when the two crops were grown together (Van der Meer., 1989). Such competition usually decreases survival, growth or reproduction of at least one of the species (Crawley, 1997). There were interactions between cropping systems and fertilizer N; cropping systems and residue during 2005 LR season while during 2006 LR season interactions were observed between cropping systems and fertilizer N; cropping systems and fertilizer N and residue.

**Plate 2:** Intercropping system (Source: Asinge site)

**Plate 3:** Rotation cropping system (Source: Atsinge site)

**Table 7: Effects of cropping systems at two levels of N, with and without crop residue on maize grain yield (t/ha) during LR 2005**

| | **Cropping systems** | | | | | | | | | Overall N mean |
|---|---|---|---|---|---|---|---|---|---|---|
| | **Continuous** | | | **Intercropping** | | | **Rotation** | | | |
| | Minus residue | Plus residue | N-Mean | Minus residue | Plus residue | N-Mean | Minus residue | Plus residue | N-Mean | |
| **Levels of N (kg N/ ha)** | | | | | | | | | | |
| **0** | 0.92 | 1.18 | 1.05 | 1.3 | 1.09 | 1.19 | 1.36 | 3.14 | 2.25 | 1.49 |
| **60** | 2.55 | 3.32 | 2.93 | 1.88 | 1.90 | 1.89 | 1.99 | 3.63 | 2.81 | 2.54 |
| **Mean residue** | 1.73 | 2.25 | | 1.59 | 1.49 | | 1.67 | 3.38 | | |
| **Overall mean cropping system** | | | 1.99 | | | 1.54 | | | 2.53 | |
| **Residue overall mean** | Minus residue = 1.66 | | | Plus residue = 2.37 | | | | | | |
| **SED $_{0.05}$ Cropping system** | | | | | | | | | | 0.04 |
| **SED $_{0.05}$ Fertilizer** | | | | | | | | | | 0.06 |
| **SED $_{0.05}$ Cropping system *Fertilizer** | | | | | | | | | | 0.08 |
| **SED $_{0.05}$ Residue** | | | | | | | | | | 0.05 |
| **SED $_{0.05}$ Cropping system* Residue** | | | | | | | | | | 0.08 |

**Table 8: Effects of cropping systems at two levels of N, with and without crop residue on maize grain yields (t/ha) during LR 2006**

| | Cropping systems | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Continuous | | | Intercropping | | | Rotation | | | |
| | Minus residue | Plus residue | N-Mean | Minus residue | Plus residue | N-Mean | Minus residue | Plus residue | N-Mean | Overall N mean |
| **Levels of N (kg N/ ha)** | | | | | | | | | | |
| **0** | 2.53 | 1.93 | 2.23 | 1.51 | 2.04 | 1.77 | 1.69 | 2.78 | 2.23 | 2.07 |
| **60** | 3.4 | 4.53 | 3.96 | 2.57 | 2.5 | 2.53 | 5.03 | 5.44 | 5.23 | 3.9 |
| **Mean residue** | 2.96 | 3.23 | | 2.04 | 2.27 | | 3.36 | 4.11 | | |
| **Overall mean cropping system** | | | 3.09 | | | 2.15 | | | 3.73 | |
| **Residue overall mean** | Minus residue = 2.78 | | | Plus residue = 3.20 | | | | | | |
| **SED $_{0.05}$ Cropping system** | | | | | | | | | | 0.11 |
| **SED $_{0.05}$ Fertilizer** | | | | | | | | | | 0.11 |
| **SED $_{0.05}$ Cropping system *Fertilizer** | | | | | | | | | | 0.18 |
| **SED $_{0.05}$ Residue** | | | | | | | | | | 0.09 |
| **SED $_{0.05}$ Cropping system*Fertilizer* Residue** | | | | | | | | | | 0.24 |

## 4.6 Soybean yields

### 4.6.1 Effects of cropping system and fertilizer N application on soybean yields under various cropping systems

In general soybean yields at Asinge were low (< 0.5 t/ha). Cropping systems had a significant effect ($p < 0.05$) on soybean yields in each season. The highest yields in both 2005 and 2006 LR seasons were obtained under rotation cropping system while intercropping had lower yields, (Table 9 and 10). The lower yields obtained under intercropping could be as a result of light and nutrient competition between maize and soybean, soybeans are susceptible to intercropping (Dugje et al., 2009) while under rotation system the crop benefited from sufficient moisture advantage since the crop could form a canopy which completely covered the soil and protected soil water from surface evaporation. Fertilizer application at 60 kg N/ha had a significant effect ($p<0.05$) on soybean yields in each cropping season. Higher yields in 2005 and 2006 LR cropping seasons were obtained in fertilized plots. The higher yields obtained under fertilized treatments could be an indication that the crop needed some starter N at planting to ensure the young seedlings would have an adequate N supply until the rhizobia could become established on their roots for N fixation (Agboola and Fayemi., 1972)

**Table 9: Effects of cropping systems at two levels of N, with and without crop residue on soybean grain yields (t/ha) during LR 2005**

| | Cropping systems | | | | | | |
|---|---|---|---|---|---|---|---|
| | Intercropping | | | Rotation | | | |
| **Levels of N (kg N/ha)** | Minus residue | Plus residue | N mean | Minus residue | Plus residue | N mean | Overall N mean |
| **0** | 131 | 146 | 138 | 257 | 257 | 257 | 197 |
| **60** | 182 | 209 | 195 | 311 | 298 | 304 | 249 |
| **Mean residue** | 156 | 177 | | 284 | 277 | | |
| **Overall mean cropping system** | | | 166 | | | 280 | |
| **Overall mean residue** | | Minus residue = 220 | | | Plus residue = 227 | | |
| **SED $_{0.05}$ Cropping system** | | | | | | | 7.24 |
| **SED $_{0.05}$ Fertilizer** | | | | | | | 9.92 |

**Table 10: Effects of cropping systems at two levels of N, with and without crop residue on soybean grain yields (t/ha) during LR 2006**

| | Cropping systems | | | | | | |
|---|---|---|---|---|---|---|---|
| | Intercropping | | | Rotation | | | |
| **Levels of N (kg N/ha)** | Minus residue | Plus residue | N mean | Minus residue | Plus residue | N mean | Overall N mean |
| **0** | 143 | 140 | 142 | 370 | 379 | 374 | 258 |
| **60** | 293 | 277 | 285 | 397 | 442 | 419 | 352 |
| **Mean residue** | 218 | 208 | | 383 | 410 | | |
| **Overall mean cropping system** | | | 213 | | | 397 | |
| **Overall mean residue** | | Minus residue = 300 | | | Plus residue = 309 | | |
| **SED $_{0.05}$ Cropping system** | | | | | | | 22.01 |
| **SED $_{0.05}$ Fertilizer** | | | | | | | 4.88 |
| **SED $_{0.05}$ Cropping system* Fertilizer** | | | | | | | 24.66 |

### 4.7 Nutrient uptake and use efficiencies

#### 4.7.1 Effects of cropping systems on N and P uptake

N and P uptakes in maize grain trends were similar with those of crop yields (Table 11 and 12). N uptake in the first season ranged from 20 to 89 kg/ha and 32 to 138 kg/ha in the third season respectively, while P uptake ranged from 2.2 to 9.5 kg/ha in the first season and 3.1 to 14.7 kg/ha in the third season. Cropping systems had a significant effect ($p<0.05$) on P uptake and on N uptake. During the third season, treatments under rotation had highest N uptake of 88 kg/ha. This could be due to the residual effect of legumes incorporated into soils in increasing grain yield, stalk yields and N uptakes of maize. Increased N uptake in maize grown after soybean is said to be due to the biological N fixation by the soybean; N transfer from legumes to succeeding maize crop has been reported by several workers (Nair *et al*., 1979; Nnadi and Haque, 1986).

#### 4.7.2 Effects of fertilizer N application on N and P uptake

Fertilizer addition at 60 kg N/ha significantly increased ($p<0.05$) N uptake by maize (Table 11) possibly due to split application of the fertilizer such as in this experiment, which has also been shown to increase N uptake and N recovery rates considerably in communal areas in Zimbabwe (Piha, 1993). An increased uptake in fully fertilized plots compared to unfertilized control has also been reported in Zimbabwe but with rather heavier N (ammonium nitrate) application rates of 90 kg N/ha, Chikowo *et al*., (2004). Fertilizer N addition at 60 kg N/ha also increased P uptake (Table 12).

**Table 11: Effects of cropping systems at two levels of N, with and without crop residue on maize grain N uptake (kg/ha) during LR 2006**

| **Levels of N (kg N/ ha)** | **Cropping systems** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **Continuous** | | | **Intercropping** | | | **Rotation** | | | |
| | Minus residue | Plus residue | N-Mean | Minus residue | Plus residue | N-Mean | Minus residue | Plus residue | N-Mean | Overall N mean |
| **0** | 59.7 | 45 | 52.3 | 45.2 | 61.1 | 53.1 | 41.4 | 64.8 | 53.1 | 52.8 |
| **60** | 80 | 106.6 | 93.3 | 77.1 | 75 | 76 | 118.5 | 127.9 | 123.2 | 97.5 |
| **Mean residue** | 69.8 | 75.8 | | 61.1 | 68.1 | | 79.9 | 96.3 | | |
| **Overall mean cropping system** | | | 72.8 | | | 64.6 | | | 88.1 | |
| **Residue overall mean** | Minus residue = 70.2 | | | Plus residue = 80.1 | | | | | | |
| **SED $_{0.05}$ Cropping system** | | | | | | | | | | 2.82 |
| **SED $_{0.05}$ Fertilizer** | | | | | | | | | | 2.81 |
| **SED $_{0.05}$ Cropping system *Fertilizer** | | | | | | | | | | 4.43 |
| **SED $_{0.05}$ Residue** | | | | | | | | | | 2.16 |
| **SED $_{0.05}$ Cropping system*Fertilizer* Residue** | | | | | | | | | | 5.73 |

**Table 12: Effects of cropping systems at two levels of N, with and without crop residue on maize grain P uptake (kg/ha) during LR 2006**

| | **Cropping systems** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Continuous | | | Intercropping | | | Rotation | | | |
| | Minus residue | Plus residue | N-Mean | Minus residue | Plus residue | N-Mean | Minus residue | Plus residue | N-Mean | Overall N mean |
| **Levels of N (kg N/ ha))** | | | | | | | | | | |
| **0** | 6.32 | 4.82 | 5.57 | 3.77 | 5.09 | 4.43 | 4.22 | 6.94 | 5.58 | 5.19 |
| **60** | 8.49 | 11.32 | 9.9 | 6.42 | 6.25 | 6.34 | 12.57 | 13.59 | 13.08 | 9.77 |
| **Mean residue** | 7.4 | 8.07 | | 5.09 | 5.67 | | 8.39 | 10.26 | | |
| **Overall mean cropping system** | | | 7.73 | | | 5.38 | | | 9.33 | |
| **Residue overall mean** | Minus residue = 6.96 | | | Plus residue = 8 | | | | | | |
| **SED $_{0.05}$ Cropping system** | | | | | | | | | | 0.28 |
| **SED $_{0.05}$ Fertilizer** | | | | | | | | | | 0.29 |
| **SED $_{0.05}$ Cropping system *Fertilizer** | | | | | | | | | | 0.45 |
| **SED $_{0.05}$ Residue** | | | | | | | | | | 0.23 |
| **SED $_{0.05}$ Cropping system*Fertilizer* Residue** | | | | | | | | | | 0.60 |

### 4.7.3 External/Agronomic nitrogen and phosphorus use efficiency

There were significant differences (p= 0.05) in agronomic nitrogen use efficiency (ANUE) in maize as a result of crop residue application (Table 13). During 2005 LR season mean (ANUE) of 25.44 and 22.15 kg of maize/kg of N applied were obtained under residue and no-residue treatments respectively. The high nitrogen use efficiency under crop residue treatments could possibly be as a result of improved moisture supply to the surface soil horizon where most nutrients under minimum tillage are concentrated hence increased uptake of these nutrients from decomposing residue. Means (ANUE) of 31.44, 11.47 and 28.47 kg of maize/kg of N applied were obtained under continuous, intercropping and rotation cropping systems respectively. The higher (ANUE) in continuous and rotation cropping are further reflected by the high maize grain yields produced in these treatments compared to the intercrop treatment. There were also significant differences in agronomic phosphorus use efficiency (APUE) in maize as a result of crop residue application with similar values as obtained in ANUE being obtained, since the unit nutrient applied in all cases was similar, being 60 kg N/ha and 60 kg P/ha. ANUE and APUE for intercropping system were lower compared to other cropping systems. The reasons for this observation were not clear from the data obtained but it is likely that this may be due to the competition for P between the two intercrops. Under continuous and rotation cropping systems more of the applied P was utilized, possibly due to higher P requirements from these systems.

**Table 13: Effects of cropping system, with and without crop residue on Agronomic Nitrogen Use Efficiency by maize grain LR 2005**

| | **Cropping systems** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **Continuous** | | | **Intercropping** | | | **Rotation** | | | |
| | Minus residue | Plus residue | N-Mean | Minus residue | Plus residue | N-Mean | Minus residue | Plus residue | N-Mean | Overall N mean |
| **Levels of N (kg N/ ha))** | | | | | | | | | | |
| **60** | 27.22 | 35.67 | 31.4 | 9.61 | 13.33 | 11.47 | 29.61 | 27.33 | 28.47 | 23.8 |
| **Overall mean cropping system** | | | 31.4 | | | 11.47 | | | 28.47 | |
| **Residue overall mean** | Minus residue = 22.14 | | | Plus residue = 25.44 | | | | | | |
| **SED $_{0.05}$ Cropping system** | | | | | | | | | | 1.03 |
| **SED $_{0.05}$ Residue** | | | | | | | | | | 1.33 |
| **SED $_{0.05}$ Cropping system *Residue** | | | | | | | | | | 1.88 |

### 4.7.4 Agronomic nutrient use efficiency by soybean, 2005 LR

Agronomic nutrient use efficiency for soybean was lower than that of maize crop as a result of low soybean yields obtained, (Table 14). This was also due to the N fixing nature of soybean hence the legume was able to use P efficiently and this could have led to the low response observed, since all treatments selected received a blanket application of 60 kg P/ha and 60 kg N/ha. Njeri and Okalebo, (1999) observed low nutrient use efficiency under soybean especially when high rates of P fertilizer had been applied. However, there were significant differences ($p<0.05$) in Agronomic N and P use efficiencies due to cropping systems. Similar ANUE and APUE of 0.72 and 2.45 kg of soybeans / kg of N and P applied were obtained under intercropping and rotation cropping systems respectively since the unit nutrients used were similar being 60 kg N/ha and 60 kg P/ha. On the basis of these results, it was observed that rotation cropping system had higher agronomic nutrient use efficiencies over the intercropping system. This is further reflected by the higher yields obtained under rotation treatments compared to intercropping treatments, as described above.

**Table 14: Effects of cropping system, with and without crop residue on Agronomic Phosphorus Use Efficiency by soybean grain LR 2005**

| | **Cropping systems** | | | | | | |
|---|---|---|---|---|---|---|---|
| **Levels of N (kg N/ha)** | Minus residue | Plus residue | N mean | Minus residue | Plus residue | N mean | Overall N mean |
| **60** | 0.5 | 0.94 | 0.72 | 2.5 | 2.39 | 2.44 | 1.58 |
| **Mean residue** | | | 0.72 | | | 2.44 | |
| **Overall mean cropping system** | | | 0.72 | | | 2.44 | |
| **Overall mean residue** | Minus residue = 1.5 | | | Plus residue = 1.66 | | | |
| **SED $_{0.05}$ Cropping systems** | | | | | | | 0.38 |

**4.8 Correlation between soil total N and soil organic carbon**

Correlation analyses were conducted between soil total N, organic carbon and yields. Soil total N and organic carbon showed a significant ($r > 0.5$) positive linear correlation for first and third seasons with correlation coefficients of 0.75 and 0.82 respectively, (Figure. 5). There was a poor correlation between maize grain yields and % organic carbon with correlation coefficients of 0.48 and 0.33 in first and third seasons respectively. The poor correlation between maize yields and soil organic carbon could possibly be as a result of the slow nutrient release of the organic resource (maize stover) hence the crop did not get immediate benefits from the nutrients released mainly N. Although most of the organic resources show limited increases in crop growth, they do increase soil organic carbon status (Vanlauwe *et al*., 2001a) and have a potentially positive impact on the environmental services and functions of the soil resource.

### 4.9 Economic analysis of grain yields between different cropping systems

#### 4.9.1 Gross margin analysis

Gross margin analysis was used to analyze the gross profitability of producing maize under continuous, rotation and intercropping systems with and without crop residue. The gross margin (GM) for each treatment was computed as the difference between total revenue and total variable costs.  Gross margin is used to rank technologies under evaluation thus can be used to analyze different treatments in experimental trials. All treatments had positive GM (Figure 6) except rotation treatment plus 0 kg N/ha minus crop residue ($CS_1N_0$-CR) which had a negative GM of -2,124 Ksh/ha. Rotation treatment plus 60 kg N/ha plus crop residue ($CS_1N_1$+CR) and intercropping plus 60 kg N/ha plus residue ($CS_2N_1$+CR) had higher GM of 38,796 and 37,090 Ksh/ha respectively. This is due to the higher yields obtained under rotation treatments hence high revenue, under intercropping high revenue was obtained from both maize and soybean. In general treatments under intercropping had GM of 16,000 Ksh/ha and above hence the most recommended practice. Continuous cropping plus 0 kg N/ha plus residue ($CS_3N_0$+CR) and rotation cropping plus 0 kg N/ha minus residue ($CS_1N_0$-CR) had the least GM of 1,427 Ksh/ha and -2,124 Ksh/ha respectively. This indicates that combined application of residue and fertilizer N are an important component in any minimum tillage practice. This agrees with work done by Zingore and Giller, 2012 who carried out maize–soybean research on sandy and clay soils of Zimbabwe and found out that the gross margins from maize and soybean without fertilizer inputs were small on the granitic sandy soil, while greatest economic benefits for both maize and soybean were obtained with manure addition.

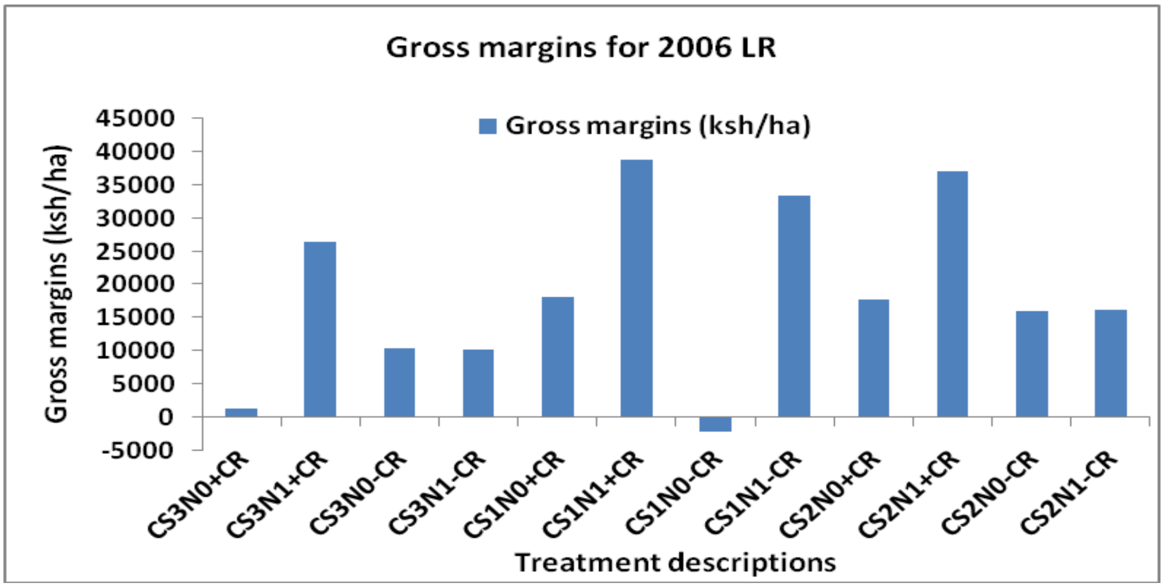


**Figure 5:** Gross margins for 2006 LR

**KEY: CS1-** Rotation, **CS2-** Intercropping and **CS3-**Continuous cereal

**+ CR**-With residue, **-CR** no residue

**$N_0$**- 0 kg N/ha, N1-60 kg N/ha

### 4.9.2 Marginal analysis

Marginal analysis is the process of calculating marginal rate of return between treatments and comparing those rates of return with the minimum rate of return acceptable to farmers. Marginal rate of return (MRR) was calculated by dividing the difference in marginal net benefits of each treatment and its control and the difference in marginal cost of each treatment with its control, expressed as a percentage. Since these technologies have not been widely used, the minimum rate of return for this study was 100% (CIMMYT, 1988). Four treatments had MRR above 100% hence can be recommended for adoption (Table 15). Rotation treatment plus 60 kg N/ha minus crop residue ($CS_1N_1$-CR) had the highest MRR of 322% followed by continuous cropping plus 60 kg N/ha plus crop residue ($CS_3N_1$+CR), then rotation cropping plus 60 kg N/ha plus residue ($CS_1N_1$+CR) and finally intercropping plus 60 kg N/ha plus residue ($CS_2N_1$+CR) which had MRR of 228, 187 and 175% respectively. All these 4 treatments with MRR of 100% and above are therefore profitable and can be recommended to farmers for adoption. These results are consistent with the conclusions arrived at using gross margin analysis.

**Table 15: Marginal rate of return (MRR %) for different treatment options during 2006 LR**

| Treatment description | Treat variable costs (Ksh/ha) | Gross margins/net benefits (Ksh/ha) | MRR % |
|---|---|---|---|
| $CS_3N_0$+CR | 28431 | 1427 | |
| $CS_3N_1$+CR | 39453 | 26529 | 228 |
| $CS_3N_0$-CR | 25987 | 10538 | |
| $CS_3N_1$-CR | 37009 | 10178 | -3 |
| $CS_1N_0$+CR | 28431 | 18222 | |
| $CS_1N_1$+CR | 39453 | 38796 | 187 |
| $CS_1N_0$-CR | 25987 | -2124 | |
| $CS_1N_1$-CR | 37009 | 33373 | 322 |
| $CS_2N_0$+CR | 32920 | 17840 | |
| $CS_2N_1$+CR | 43942 | 37090 | 175 |
| $CS_2N_0$-CR | 30476 | 16018 | |
| $CS_2N_1$-CR | 41498 | 16293 | 2 |

**Source: Computations derived from field trials in this study in 2006 LR**

**KEY: CS1-** Rotation, **CS2-** Intercropping and **CS3-**Continuous cereal

**+ CR**-With residue, **-CR** no residue

0 kg N/ha (**$N_0$**), 60 kg N/ha (**$N_1$**)

# CHAPTER FIVE

# CONCLUSIONS AND RECOMMENDATIONS

## 5.1 Conclusions

- Chemical analysis and physical analysis of soil samples from the Asinge site before nutrient application confirmed that the soils in the area are sandy characterized with low soil organic matter, soil nitrogen and available phosphorus. This means that, no increased crop yields can be obtained without application of crop residue with modest quantities of N and P fertilizer to ensure build up in organic matter hence improved soil fertility.
- Minimum tillage combined with addition of crop residue (maize stover), which release nutrients slowly into the soil, can be considered to be a practice for long-term build up in organic matter hence soil fertility improvement. Maize stover was applied at a rate of 2 t/ha safe rate to minimize N immobilization when incorporated into the soil.
- Fertilizer N addition at 60 kg N/ha has an additive effect on organic matter build up but does not seem to be significant in this preliminary study.
- Surface application of crop residue under minimum tillage is beneficial in trapping soil and water hence improved nutrient use efficiency.
- Residue application in combination with modest quantities of fertilizer N (60 kg N/ha) has a potential in increasing soil total N and organic carbon.
- Residue application in combination with fertilizer N addition at 60 kg N/ha led to an increase in yields of both maize and soybean in all cropping systems and

seasons. This was due mainly to the beneficial effect of surface applied residue in conserving soil and water and the responses due to N addition were evident due to the low organic matter and hence low N content of the soil.

- The gross margins from this study suggest that intercropping combined with crop residue and fertilizer additions at 60 kg N/ha is the most economically attractive alternative since high revenue was obtained from maize and soybean combined in all treatments under intercropping. Also the MRR for this treatment was above 100%, hence the technology is profitable and can be recommended to farmers for adoption.

### 5.2 Recommendations for research

- In this research only maize stover was studied as a crop residue; there is still need to investigate and test more organic residues e.g. soybean to identify the potential alternatives to maize stover for different agro-climatic conditions and on different soil types.
- More research should be carried out to investigate the nutrient use efficiency of different legumes, under different soil types. In our study only soybean which was planted on a loamy sand soil was studied and it was found to have low nutrient use efficiency especially due to low yields obtained.
- Also further research is needed especially on the effects of cropping systems, nutrient inputs and crop residue application within different soil types and rainfall regimes in order to determine which of the farmers practice is important in sustaining SOC and improving crop productivity.

- Long term experiment required for more conclusive results, especially with SOC and moisture storage.
- Future studies to be carried out on additional physical properties of soil like bulk density and hydraulic conductivity which would be beneficial for water intake/flow and storage under minimum tillage practices.

**5. 3 Recommendations for farmers**

- Farmers should always incorporate crop residue as surface mulch in the minimum tillage system to avoid substantial losses of soil nutrients such as P and reduced maize yields.

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# APPENDICES

## APPENDIX I: ANOVA for soil organic carbon and soil total nitrogen

**a) Mean squares of SOC for 1st (2005 LR) season as affected by cropping system, fertilizer and crop residue incorporation and their interactions**

| Source of variation | df | S.S | M.S | V.R | F pr. |
|---|---|---|---|---|---|
| Rep stratum | 2 | 0.04191 | 0.02095 | 1.56 | |
| **Rep. cropping system stratum** | | | | | |
| Cropping system | 2 | 0.00811 | 0.00405 | 0.3 | 0.755 |
| Residual | 4 | 0.05371 | 0.01343 | 0.57 | |
| **Rep. cropping system .fertilizer stratum** | | | | | |
| Fertilizer | 1 | 0.09425 | 0.09425 | 3.98 | 0.093 |
| Cropping system * fertilizer | 2 | 0.02282 | 0.01141 | 0.48 | 0.639 |
| Residual | 6 | 0.14198 | 0.02366 | 1.71 | |
| **Rep. cropping system. fertilizer .residue stratum** | | | | | |
| Residue | 1 | 0.69723 | 0.069723 | 50.34 | <.001 |
| Cropping system *residue | 2 | 0.01562 | 0.00781 | 0.56 | 0.583 |
| Fertilizer * residue | 1 | 0.27214 | 0.27214 | 19.65 | <.001 |
| Cropping system*fertilizer * residue | 2 | 0.03737 | 0.01869 | 1.35 | 0.296 |
| Residual | 12 | 0.1662 | 0.01385 | | |
| **Total** | 35 | 1.55132 | | | |
| CV (%). Rep | | | | | 4.6 |
| CV (%). Rep*cropping system | | | | | 6.4 |
| CV (%). Rep*cropping system* fertilizer | | | | | 11.9 |
| CV (%). Rep*cropping system*fertilizer* residue | | | | | 12.9 |

**b) Mean squares of SOC for 2nd (2005 SR) season as affected by cropping system, fertilizer and crop residue incorporation and their interactions**

| Source of variation | df | S.S | M.S | V.R | F pr. |
|---|---|---|---|---|---|
| Rep stratum | 2 | 0.0378 | 0.0189 | 11.57 | |
| **Rep. cropping system stratum** | | | | | |
| Cropping system | 2 | 0.022317 | 0.011158 | 6.83 | 0.051 |
| Residual | 4 | 0.007 | 0.001633 | 0.6 | |
| **Rep. cropping system .fertilizer stratum** | | 0.006533 | | | |
| Fertilizer | 1 | 0.010747 | 0.010747 | 3.98 | 0.093 |
| Cropping system * fertilizer | 2 | 0.008072 | 0.004036 | 1.49 | 0.297 |
| Residual | 6 | 0.0162 | 0.0027 | 0.71 | |
| **Rep. cropping system. fertilizer .residue stratum** | | | | | |
| Residue | 1 | 2.907025 | 2.907025 | 766.1 | <.001 |
| Cropping system *residue | 2 | 0.012517 | 0.006258 | 1.65 | 0.233 |
| Fertilizer * residue | 1 | 0.000336 | 0.000336 | 0.09 | 0.771 |
| Cropping system*fertilizer * residue | 2 | 0.010139 | 0.005069 | 1.34 | 0.299 |
| Residual | 12 | 0.045553 | 0.003794 | | |
| **Total** | 35 | 3.077219 | | | |
| CV (%). Rep | | | | | 3.9 |
| CV (%). Rep*cropping system | | | | | 2 |
| CV (%). Rep*cropping system* fertilizer | | | | | 3.6 |
| CV (%). Rep*cropping system*fertilizer* residue | | | | | 6.1 |

**c) Mean squares of SOC for 3rd (2006 LR) season as affected by cropping system, fertilizer and crop residue incorporation and their interactions**

| **Source of variation** | **df** | **S.S** | **M.S** | **V.R** | **F pr.** |
|---|---|---|---|---|---|
| Rep stratum | 2 | 0.01095 | 0.00548 | 0.24 | |
| **Rep. cropping system stratum** | | | | | |
| Cropping system | 2 | 0.19802 | 0.009901 | 4.31 | 0.1 |
| Residual | 4 | 0.09183 | 0.02296 | 1.81 | |
| **Rep. cropping system .fertilizer stratum** | | | | | |
| Fertilizer | 1 | 0.0163 | 0.0163 | 1.28 | 0.3 |
| Cropping system * fertilizer | 2 | 0.01377 | 0.00689 | 0.54 | 0.607 |
| Residual | 6 | 0.07615 | 0.01269 | 1.05 | |
| **Rep. cropping system. fertilizer .residue stratum** | | | | | |
| Residue | 1 | 5.51467 | 5.51467 | 456 | 0.001 |
| Cropping system *residue | 2 | 0.76071 | 0.38035 | 31.45 | 0.001 |
| Fertilizer * residue | 1 | 0.023 | 0.023 | 1.9 | 0.193 |
| Cropping system*fertilizer * residue | 2 | 0.00404 | 0.00202 | 0.17 | 0.848 |
| Residual | 12 | 0.14513 | 0.01209 | | |
| **Total** | 35 | 6.85457 | | | |
| CV (%). Rep | | | | | 1.9 |
| CV (%). Rep*cropping system | | | | | 6.8 |
| CV (%). Rep*cropping system* fertilizer | | | | | 7.1 |
| CV (%). Rep*cropping system*fertilizer* residue | | | | | 9.9 |

**d) Mean squares for soil total nitrogen for 3rd (2006 LR) season as affected by cropping system, fertilizer and crop residue incorporation to the soil and their interactions**

| Source of variation | df | S.S | M.S | V.R | F pr. |
|---|---|---|---|---|---|
| Rep stratum | 2 | 1.106E-05 | 5.53E-06 | 0.2 | |
| **Rep. cropping system stratum** | | | | | |
| Cropping system | 2 | 0.0001151 | 5.75E-05 | 2.05 | 0.244 |
| Residual | 4 | 0.0001124 | 2.81E-05 | 1.91 | |
| **Rep. cropping system .fertilizer stratum** | | | | | |
| Fertilizer | 1 | 0.0025167 | 0.002517 | 170.6 | <.001 |
| Cropping system * fertilizer | 2 | 2.06E-06 | 1.03E-06 | 0.07 | 0.933 |
| Residual | 6 | 0.0000885 | 1.48E-05 | 0.65 | |
| **Rep. cropping system. fertilizer .residue stratum** | | | | | |
| Residue | 1 | 0.002288 | 0.002288 | 100.5 | <.001 |
| Cropping system *residue | 2 | 6.806E-05 | 3.4E-05 | 1.49 | 0.263 |
| Fertilizer * residue | 1 | 2.669E-05 | 2.67E-05 | 1.17 | 0.3 |
| Cropping system*fertilizer * residue | 2 | 2.239E-05 | 1.12E-05 | 0.49 | 0.624 |
| Residual | 12 | 0.0002733 | 2.28E-05 | | |
| **Total** | 35 | 0.0055243 | | | |
| CV (%). Rep | | | | | 0.8 |
| CV (%). Rep*cropping system | | | | | 3 |
| CV (%). Rep*cropping system* fertilizer | | | | | 3.1 |
| CV (%). Rep*cropping system*fertilizer* residue | | | | | 5.4 |

**APPENDIX II: Mean squares for crop yields , nutrient uptake and their use efficiencies**

**a) Mean squares for maize grain yields in 1st (2005 LR) season as affected by cropping systems, fertilizer and crop residue**

| Source of variation | Df | S.S | M.S | V.R | F pr. |
|---|---|---|---|---|---|
| Rep stratum | 2 | 0.10344 | 0.05172 | 4.24 | |
| **Rep. cropping system stratum** | | | | | |
| Cropping system | 2 | 5.85667 | 2.92834 | 240 | <.001 |
| Residual | 4 | 0.04881 | 0.0122 | 0.32 | |
| **Rep. cropping system .fertilizer stratum** | | | | | |
| Fertilizer | 1 | 18.3184 | 18.3184 | 482.1 | <.001 |
| Cropping system * fertilizer | 2 | 2.50262 | 1.25131 | 32.93 | <.001 |
| Residual | 6 | 0.22798 | 0.038 | 1.41 | |
| **Rep. cropping system. fertilizer .residue stratum** | | | | | |
| Residue | 1 | 0.97351 | 0.97351 | 36.15 | <.001 |
| Cropping system *residue | 2 | 0.79894 | 0.39947 | 14.83 | <.001 |
| Fertilizer * residue | 1 | 0.08801 | 0.08801 | 3.27 | 0.096 |
| Cropping system*fertilizer * residue | 2 | 0.15317 | 0.07659 | 2.84 | 0.098 |
| Residual | 12 | 0.32317 | 0.02693 | | |
| **Total** | 35 | 29.39472 | | | |
| CV (%). Rep | | | | | 3.2 |
| CV (%). Rep*cropping system | | | | | 2.7 |
| CV (%). Rep*cropping system* fertilizer | | | | | 6.8 |
| CV (%). Rep*cropping system*fertilizer* residue | | | | | 8.1 |

**b) Mean squares for maize grain yields in 3rd (2006 LR) season as affected by cropping systems, fertilizer additions and crop residue incorporation and their interactions**

| **Source of variation** | **df** | **S.S** | **M.S** | **V.R** | **F pr.** |
|---|---|---|---|---|---|
| Rep stratum | 2 | 0.61476 | 0.30738 | 3.86 | |
| **Rep. cropping system stratum** | | | | | |
| Cropping system | 2 | 15.13491 | 7.56745 | 94.94 | <.001 |
| Residual | 4 | 0.31884 | 0.07971 | 0.65 | |
| **Rep .cropping system .fertilizer stratum** | | | | | |
| Fertilizer | 1 | 30.23167 | 30.23167 | 247.4 | <0.001 |
| Cropping system * fertilizer | 2 | 7.54704 | 3.77352 | 30.88 | <.001 |
| Residual | 6 | 0.73317 | 0.12219 | 1.54 | |
| **Rep. cropping system. fertilizer .residue stratum** | | | | | |
| Residue | 1 | 1.55834 | 1.55834 | 19.59 | <.001 |
| Cropping system *residue | 2 | 0.50387 | 0.25194 | 3.17 | 0.079 |
| Fertilizer * residue | 1 | 0.05063 | 0.05063 | 0.64 | 0.441 |
| Cropping system*fertilizer * residue | 2 | 2.81085 | 1.40542 | 17.66 | <.001 |
| Residual | 12 | 0.95477 | 0.07956 | | |
| **Total** | 35 | 60.45883 | | | |
| CV (%). Rep | | | | | 5.3 |
| CV (%). Rep*cropping system | | | | | 4.7 |
| CV (%). Rep*cropping system* fertilizer | | | | | 8.3 |
| CV (%). Rep*cropping system*fertilizer* residue | | | | | 9.4 |

**c) Mean squares for soybean grain yields in 1st (2005 LR) season as affected by cropping system, fertilizer and residue incorporation and their interactions**

| Source of variation | Df | S.S | M.S | V.R | F pr. |
|---|---|---|---|---|---|
| Rep stratum | 2 | 161.6 | 80.8 | 0.62 | |
| **Rep. cropping system stratum** | | | | | |
| Cropping system | 1 | 77520.7 | 77520.7 | 593.8 | 0.002 |
| Residual | 2 | 261.1 | 130.5 | 0.29 | |
| **Rep. cropping system .fertilizer stratum** | | | | | |
| Fertilizer | 1 | 16432.7 | 16432.7 | 36 | 0.004 |
| Cropping system * fertilizer | 1 | 140.2 | 140.2 | 0.31 | 0.609 |
| Residual | 4 | 1825.7 | 456.4 | 1.36 | |
| **Rep. cropping system. fertilizer .residue stratum** | | | | | |
| Residue | 1 | 294 | 294 | 0.88 | 0.376 |
| Cropping system *residue | 1 | 1148.2 | 1148.2 | 3.43 | 0.101 |
| Fertilizer * residue | 1 | 0.2 | 0.2 | 0 | 0.983 |
| Cropping system*fertilizer * residue | 1 | 216 | 216 | 0.64 | 0.445 |
| Residual | 8 | 2681.7 | 335.2 | | |
| **Total** | 23 | 100681.8 | | | |
| CV (%). Rep | | | | | 1.4 |
| CV (%). Rep*cropping system | | | | | 2.6 |
| CV (%). Rep*cropping system* fertilizer | | | | | 6.7 |
| CV (%). Rep*cropping system*fertilizer* residue | | | | | 8.2 |

**d) Mean squares for soybean grain yields in 3rd (2006 LR) season as affected by cropping system, fertilizer and residue incorporation and their interactions**

| Source of variation | Df | S.S | M.S | V.R | F pr. |
|---|---|---|---|---|---|
| Rep stratum | 2 | 240.1 | 120 | 0.1 | |
| **Rep. cropping system stratum** | | | | | |
| Cropping system | 1 | 201850 | 201850 | 167.5 | 0.006 |
| Residual | 2 | 2410.1 | 1205 | 10.91 | |
| **Rep .cropping system .fertilizer stratum** | | | | | |
| Fertilizer | 1 | 53110 | 53110 | 480.8 | <.001 |
| Cropping system * fertilizer | 1 | 14553.4 | 14553.4 | 131.8 | <.001 |
| Residual | 4 | 441.8 | 110.5 | 0.22 | |
| **Rep. cropping system. fertilizer .residue stratum** | | | | | |
| Residue | 1 | 425 | 425 | 0.84 | 0.386 |
| Cropping system *residue | 1 | 2035 | 2035 | 4.02 | 0.08 |
| Fertilizer * residue | 1 | 198.4 | 198.4 | 0.39 | 0.549 |
| Cropping system*fertilizer * residue | 1 | 925 | 925 | 1.83 | 0.214 |
| Residual | 8 | 4052 | 506.5 | | |
| **Total** | 23 | 280241 | | | |
| CV (%). Rep | | | | | 1.3 |
| CV (%). Rep*cropping system | | | | | 5.7 |
| CV (%). Rep*cropping system* fertilizer | | | | | 2.4 |
| CV (%). Rep*cropping system*fertilizer* residue | | | | | 7.4 |

**e) Mean squares for maize grain P uptake in 1st (2005 LR) season as affected by cropping systems, fertilizer additions and crop residue incorporation and their interactions**

| Source of variation | Df | S.S | M.S | V.R | F pr. |
|---|---|---|---|---|---|
| Rep stratum | 2 | 0.6465 | 0.3232 | 4.24 | |
| **Rep. cropping system stratum** | | | | | |
| Cropping system | 2 | 36.6042 | 18.3021 | 240 | <.001 |
| Residual | 4 | 0.3051 | 0.0763 | 0.32 | |
| **Rep. cropping system .fertilizer stratum** | | | | | |
| Fertilizer | 1 | 114.49 | 114.49 | 482.1 | <.001 |
| Cropping system * fertilizer | 2 | 15.6414 | 7.8207 | 32.93 | <.001 |
| Residual | 6 | 1.4249 | 0.2375 | 1.41 | |
| **Rep. cropping system. fertilizer .residue stratum** | | | | | |
| Residue | 1 | 6.0844 | 6.0844 | 36.15 | <.001 |
| Cropping system *residue | 2 | 4.9934 | 2.4967 | 14.83 | <.001 |
| Fertilizer * residue | 1 | 0.5501 | 0.5501 | 3.27 | 0.096 |
| Cropping system*fertilizer * residue | 2 | 0.9573 | 0.4787 | 2.84 | 0.098 |
| Residual | 12 | 2.0198 | 0.1683 | | |
| **Total** | 35 | 183.717 | | | |
| CV (%). Rep | | | | | 3.2 |
| CV (%). Rep*cropping system | | | | | 2.7 |
| CV (%). Rep*cropping system* fertilizer | | | | | 6.8 |
| CV (%). Rep*cropping system*fertilizer* residue | | | | | 8.1 |

**f) Mean squares for maize grain P uptake in 3rd (2006 LR) season as affected by cropping system, fertilizer additions and crop residue incorporations and their interactions**

| Source of variation | Df | S.S | M.S | V.R | F pr. |
|---|---|---|---|---|---|
| Rep stratum | 2 | 3.8422 | 1.9211 | 3.86 | |
| **Rep. cropping system stratum** | | | | | |
| Cropping system | 2 | 94.5932 | 47.2966 | 94.94 | <.001 |
| Residual | 4 | 1.9928 | 0.4982 | 0.65 | |
| **Rep. cropping system .fertilizer stratum** | | | | | |
| Fertilizer | 1 | 188.9479 | 188.9479 | 247.4 | <.001 |
| Cropping system * fertilizer | 2 | 47.169 | 23.5845 | 30.88 | <.001 |
| Residual | 6 | 4.5823 | 0.7637 | 1.54 | |
| **Rep. cropping system .fertilizer .residue stratum** | | | | | |
| Residue | 1 | 9.7396 | 9.7396 | 19.56 | <.001 |
| Cropping system *residue | 2 | 3.1492 | 1.5746 | 3.17 | 0.079 |
| Fertilizer * residue | 1 | 0.3164 | 0.3164 | 0.64 | 0.441 |
| Cropping system*fertilizer * residue | 2 | 17.5678 | 8.7839 | 17.66 | <.001 |
| Residual | 12 | 5.9673 | 0.4973 | | |
| **Total** | 35 | 377.8677 | | | |
| CV (%). Rep | | | | | 5.3 |
| CV (%). Rep*cropping system | | | | | 4.7 |
| CV (%). Rep*cropping system* fertilizer | | | | | 8.3 |
| CV (%). Rep*cropping system*fertilizer* residue | | | | | 9.4 |

**g) Mean squares for maize grain N uptake in 3rd (2006 LR) season as affected by cropping system, fertilizer additions and crop residue incorporations and their interactions**

| Source of variation | df | S.S | M.S | V.R | F pr. |
|---|---|---|---|---|---|
| Rep stratum | 2 | 382.99 | 191.5 | 4.03 | |
| **Rep. cropping system stratum** | | | | | |
| Cropping system | 2 | 3425.18 | 1712.59 | 36.01 | 0.003 |
| Residual | 4 | 190.25 | 47.56 | 0.67 | |
| **Rep. cropping system .fertilizer stratum** | | | | | |
| Fertilizer | 1 | 17951.58 | 17951.58 | 254.1 | <.001 |
| Cropping system * fertilizer | 2 | 3405.27 | 1702.64 | 24.1 | 0.001 |
| Residual | 6 | 423.96 | 70.66 | 1.68 | |
| **Rep .cropping system. fertilizer .residue stratum** | | | | | |
| Residue | 1 | 858.42 | 858.42 | 20.43 | <.001 |
| Cropping system *residue | 2 | 203.23 | 101.62 | 2.42 | 0.131 |
| Fertilizer * residue | 1 | 21.95 | 21.95 | 0.52 | 0.484 |
| Cropping system*fertilizer * residue | 2 | 1647.02 | 823.51 | 19.6 | <.001 |
| Residual | 12 | 504.27 | 42.02 | | |
| **Total** | 35 | 29014.13 | | | |
| CV (%). Rep | | | | | 5.3 |
| CV (%). Rep*cropping system | | | | | 4.6 |
| CV (%). Rep*cropping system* fertilizer | | | | | 7.9 |
| CV (%). Rep*cropping system*fertilizer* residue | | | | | 8.6 |

**h) Mean squares for maize nitrogen use efficiency during 2005 LR season as affected by cropping system and residue incorporation and their interaction.**

| **Source of variation** | d.f | s.s | m.s | v.r | F pr. |
|---|---|---|---|---|---|
| Rep stratum | 2 | 51.225 | 25.613 | 7.99 | |
| **Rep. cropping system stratum** | | | | | |
| Cropping system | 2 | 1393.448 | 696.724 | 217.21 | <.001 |
| Residual | 4 | 12.83 | 3.208 | 0.5 | |
| **Rep. cropping system. residue strarum** | | | | | |
| Residue | 1 | 48.895 | 48.895 | 7.65 | 0.033 |
| Cropping system. Residue | 2 | 86.633 | 43.316 | 6.78 | 0.029 |
| Residual | 6 | 38.333 | 6.389 | | |
| **Total** | 17 | 1631.364 | | | |
| CV (%). Rep | | | | | 8.7 |
| CV (%). Rep* cropping system | | | | | 5.3 |
| CV (%). Rep* cropping system*residue | | | | | 10.6 |

**i) Mean squares for maize nitrogen use efficiency during 2006 LR season as affected by cropping system and residue incorporation and their interaction.**

| **Source of variation** | d.f | s.s | m.s | v.r | F pr. |
|---|---|---|---|---|---|
| Rep stratum | 2 | 158.11 | 79.06 | 13.41 | |
| **Rep. cropping system stratum** | | | | | |
| Cropping system | 2 | 4192.26 | 2096.13 | 355.67 | <.001 |
| Residual | 4 | 23.57 | 5.89 | 0.3 | |
| **Rep. cropping system. residue strarum** | | | | | |
| Residue | 1 | 28.54 | 28.54 | 1.45 | 0.274 |
| Cropping system. Residue | 2 | 1565.98 | 782.99 | 39.67 | <.001 |
| Residual | 6 | 118.43 | 19.74 | | |
| **Total** | 17 | 6086.89 | | | |
| CV (%). Rep | | | | | 11.9 |
| CV (%). Rep* cropping system | | | | | 5.6 |
| CV (%). Rep* cropping system *residue | | | | | 14.6 |

**j) Mean squares for maize phosphorus use efficiency during 2005 LR season as affected by cropping system and residue incorporation and their interaction.**

| **Source of variation** | d.f | s.s | m.s | v.r | F pr. |
|---|---|---|---|---|---|
| Rep stratum | 2 | 51.225 | 25.613 | 7.99 | |
| **Rep. cropping system stratum** | | | | | |
| Cropping system | 2 | 1393.448 | 696.724 | 217.21 | <.001 |
| Residual | 4 | 12.83 | 3.208 | 0.5 | |
| **Rep. cropping system. residue strarum** | | | | | |
| Residue | 1 | 48.895 | 48.895 | 7.65 | 0.033 |
| Cropping system. Residue | 2 | 86.633 | 43.316 | 6.78 | 0.029 |
| Residual | 6 | 38.333 | 6.389 | | |
| **Total** | 17 | 1631.364 | | | |
| CV (%). Rep | | | | | 8.7 |
| CV (%).Rep. cropping system | | | | | 5.3 |
| CV (%). Cropping system. Residue | | | | | 10.6 |

**k) Mean squares for maize phosphorus use efficiency during 2006 LR season as affected by cropping system and residue incorporation and their interaction.**

| **Source of variation** | d.f | s.s | m.s | v.r | F pr. |
|---|---|---|---|---|---|
| Rep stratum | 2 | 158.11 | 79.06 | 13.41 | |
| **Rep. cropping system stratum** | | | | | |
| Cropping system | 2 | 4192.26 | 2096.13 | 355.67 | <.001 |
| Residual | 4 | 23.57 | 5.89 | 0.3 | |
| **Rep. cropping system. residue strarum** | | | | | |
| Residue | 1 | 28.54 | 28.54 | 1.45 | 0.274 |
| Cropping system. Residue | 2 | 1565.98 | 782.99 | 39.67 | <.001 |
| Residual | 6 | 118.43 | 19.74 | | |
| **Total** | 17 | 6086.89 | | | |
| CV (%). Rep | | | | | 11.9 |
| CV (%).Rep. cropping system | | | | | 5.6 |
| CV (%). Cropping system. Residue | | | | | 14.6 |

**APPENDIX**

**III: Rainfall distribution for ten days in 2005 LR, 2005 SR and 2006 LR season.**

**Ten Day rainfall distribution (mm) for the 2005 LR, 2005 SR and 2006 LR seasons during the cropping period.**

| Days | 2005 LR | 2005 SR | 2006 LR |
|---|---|---|---|
| 10.00 | 159.83 | 34.65 | 160.80 |
| 20.00 | 64.01 | 65.90 | 105.10 |
| 30.00 | 148.14 | 62.04 | 47.10 |
| 40.00 | 40.57 | 109.76 | 60.00 |
| 50.00 | 21.62 | 8.61 | 14.30 |
| 60.00 | 33.54 | 0.00 | 10.50 |
| 70.00 | 11.69 | 15.23 | 42.10 |
| 80.00 | 19.34 | 0.00 | 0.00 |
| 90.00 | 61.56 | 0.00 | 5.00 |
| 100.00 | 40.02 | 0.00 | 67.30 |
| 110.00 | 29.04 | 47.4 | 4.60 |
| 120.00 | 7.26 | 30.8 | 0.00 |
| **Totals/ season** | **636.62** | **374.39** | **516.80** |