INFLUENCE OF AGROECOLOGICAL INTENSIFICATION TECHNIQUES ON SOIL MOISTURE, NUTRIENT STATUS AND YIELDS OF SORGHUM (S*orghum bicolor (L.) Moench*) AND CASSAVA (*Manihot esculanta Crantz*) IN YATTA SUB-COUNTY, KENYA

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DECLARATION

This thesis is my original work and has not been shared or presented for the award of a degree in any other academic institution.

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DEDICATION

TO MY DAD ERNEST AND MUM MARY NAMOI
“FOR THE GIFT OF EDUCATION”

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GENERAL ABSTRACT

Despite agriculture being the principle source of livelihood for majority of households in the arid and Semi-Arid Lands (ASALs), agricultural productivity has continued to decline mainly due to, among others, declining soil fertility, poor crop production practices and erratic and unreliable rainfall. Food security is further threatened by adoption of crop varieties not adapted to the ASALs at the expense of more drought tolerant varieties. A study was conducted to contribute towards enhancing soil fertility and food availability in the ASALs through use of selected Agro-ecological intensification techniques. The study examined the effect of different cropping systems and organic inputs on soil moisture, nutrient status and yield of cassava and sorghum. The ecological sustainability of the treatments was also assessed by calculating nutrient balances. On farm field experiments were conducted for two Short Rain seasons (SRS) and two Long Rain seasons (LRS), making a total of four seasons (SRS of 2010, LRS of 2011, SRS of 2011 and LRS of 2012). The experimental design was a randomized complete block design with a split plot arrangement. The main plots were three cropping systems: (i) Intercropping (Dolichos [*Lablab purpureus*]/Cassava, Dolichos/Sorghum, Pigeon pea [*Cajanus cajan (L.*) Millsp.]/Sorghum, Pigeon pea/Cassava); (ii) Rotation (Dolichos-Cassava, Dolichos-Sorghum, Pigeon pea-Cassava, Pigeon pea-Sorghum); (iii) Monocrop (pure cassava and sorghum). The split plots were; Farm Yard Manure (FYM), compost and control. All crops had above ground biomass incorporated after harvest in the same plot they were harvested from. Soil moisture, Organic Carbon (OC), Nitrogen (N), Phosphrous (P) and Pottasium (K) levels were determined at the end of every rainy season. NPK content of sorghum grain and cassava tuber was also dertemined at harvest. Soil NPK, tissue NPK as well as yields of various crops were used to as data input into the NUTMON toolbox for the calculation of nutrient balances as a basis of assessing the sustainability of the of the imposed treatments.

The results showed that the highest moisture levels were observed under sorghum/pigeon pea intercrop (9.81% in Katangi and 12.30% at Ikombe) and cassava/dolichos intercrop (8.10 at Katangi and 10.30% at Ikombe) with FYM application. Sorghum grain and tuber yields were highest under sorghum/dolichos (2.23 tha^{-1} at Katangi and 2.0 t ha^{-1} at Ikombe respectively) and cassava/pigeon pea intercrop (23.53 tha^{-1} at Katangi and 37.80 tha^{-1} at Ikombe) respectively with FYM application. In the sorghum cropping systems, high soil Organic carbon were observed under sorghum/dolichos inetcrop with FYM (1.86% at Katangi and 1.95% at Ikombe during the LRS 2011). High soil N levels were

under sorghum/doliochos intercrop with application of FYM (0.27% during SRS 2011 at Katangi and 0.21% during the LRS of 2011 at Ikombe). High P levels were observed under sorghum/dolichos intercrop with FYM (37.28 ppm during LRS of 2012 at Katangi and 39.78 ppm SRS of 2011) while K levels were similarly high under sorghum/dolichos intercrop with FYM (1.21 cmol/kg at Katangi and 1.10 cmol/kg at Ikombe during the SRS 2010). In the cassava cropping systems, soil OC was highest under cassava/dolichos intercrop with FYM during the LRS of 2012 (2.90% at Katangi and 2.12% at Ikombe). High N levels were observed under cassava/dolichos intecrop with FYM (0.14% at Katangi and 0.11% at Ikombe during the SRS of 2011), while soil P values were high under the same cropping system and organic input combination (38.80 ppm at Katangi during the SRS of 2010 and 39.61 ppm at Ikombe during the LRS 2011). Soil K levels were similarly higher under cassava/dolichos intercrop with FYM (0.73 cmol/kg at both sites during the SRS 2010). Sorghum grain N was highest under sorghum monocrop (1.52% during of SRS 2011 at Katangi and 2.62% LRS of 2011 at Ikombe) except in LR 2012 at Katangi where it was highest under dolichos-sorghum rotation with FYM (1.86%). Tuber N was highest under cassava/pigeon pea intercrop rotation with FYM (1.71% and 1.65% during SRS 2011-LRS 2012 at Katangi and Ikombe respectively) except in SR 2010-LR 2011 at Katangi where higher tuber N was under pigeon pea-cassavarotation monocrop with FYM (1.59%). Sorghum grain P was not influenced by cropping systems in SR 2010, LR 2011 at both sites as well as SR 2011 and LR 2012 in Katangi and Ikombe respectively. FYM application resulted in higher grain P than compost and control respectively. Grain P concentration was highest under sorghum/dolichos intercrop with FYM in LR 2012 (1281.69 ppm) but this was not significantly different to sorghum/pigeon pea intercrop with FYM applied at Katangi. In SR 2011 at Ikombe, grain P was highest under sorghum monocrop with FYM (119.80 ppm) but this was not different to sorghum/pigeon pea and sorghum/dolichos intercrop with FYM. Sorghum grain K was affected by cropping systems only in LR 2012 at both sites and SR 2011 in Katangi only. At Katangi in SR 2011 (0.25 cmol/kg) and LR 2012 (0.24cmol/kg), sorghum/pigeon pea intercrop produced the highest grain K but this was not different to sorghum/dolichos intercrop and pigeon pea-sorghum rotation. At Ikombe in LR 2012, sorghum/dolichos intercrop (0.24 cmol/kg) produced higher grain K though not different to monocrop, sorghum/pigeon pea intercrop and dolichos-sorghum rotation. Organic inputs also did not affect grain K in Ikombe in all the seasons and in SR 2010 at Katangi. Where organic

inputs' effects were significant, FYM application resulted in higher K compared to compost and control.

NPK balances under cassava based cropping systems were significantly lower than sorghum based cropping systems. N balances were significantly higher when cassavaor sorghumwas rotated with dolichos and compost applied. For dolichos-cassava rotation with compost applied, the balances were 21.00 Kg/ha/yr at Katangi and 14.90 Kg/ha/yr at Ikombe during SRS 2010-LRS 2011. Dolichos-sorghum rotation and compost applied had balances of 61.00 Kg/ha/yr and 61.87 Kg/ha/yr during SRS 2010-LRS 2011, and 25.03 Kg/ha/yr and 23.30 Kg/ha/yr during SRS 2011-LRS 2012 at Katangi and Ikombe respectivelyP losses were less negative under pigeon pea-sorghum with FYM applied during SRS 2010-LRS 2011 (0.13 Kg/ha/yr at Katangi and -0.07 Kg/ha/yr at Ikombe) and SRS 2011-LRS 2012 (-2.00 Kg/ha/yr at Ikombe and -0.63Kg/ha/yr at Ikombe). Pigeon pea-cassava rotation with compost applied had less negative P balances (-8.40 Kg/ha/yr at Katangi and _-8.96Kg/ha/yr at Ikombe) during SRS 2010-LRS 2011 . Pigeon pea rotation with sorghum and FYM applied during SRS 2010-LRS 2011 (13.60 Kg/ha/yr at Katangi and -28.20 Kg/ha/yr at Ikombe) and SRS 2011-LRS 2012 (13.5 Kg/ha/yr at Katangi and 14.53 Kg/ha/yr at Ikombe) resulted in reduced K losses while with cassava the same cropping system was superior with application of FYM during SRS 2010-LRS 2011 (27.53 Kg/ha/yr at Katangi and 60.20 Kg/ha/yr at Ikombe).

Cassava/pigeon pea and sorghum/dolichos intercrop produced higher yields and would be appropriate in addressing food insecurity in the short run. However, since long-term sustainability is important for food availability to be enhanced, then farmers should be encouraged to adopt practices that would reduce losses of nutrients especially N and P. Therefore, rotation sorghum or cassava with dolichos would reduce N losses while P losses would reduce under rotation with pigeon pea with FYM and compost applied in sorghum and cassava respectively. Appropriate strategies should be sought in order to improve the productivity of the latter technology. Alternatively, strategies that would reduce nutrient losses under cassava/pigeon pea and sorghum/dolichos with FYM should be investigated in order to make them sustainable.

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LIST OF ABBREVIATIONS

AEI	Agroecological Intensification
ANOVA	Analysis of Variance
ASALs	Arid and Semi-arid lands
BNF	Biological Nitrogen Fixation
CEC	Cation Exchange Capacity
DST	Decision Support Tools
FAO	Food and agriculture Organization
FYM	Farm Yard Manure
LSD	Least Significant Differences
NUTMON	Nutrient Monitoring
RCBD	Randomized Complete Block Design
SSA	Sub-Saharan Africa

CHAPTER ONE: GENERAL INTRODUCTION

1.0 Background information

Per capita agricultural production continues to decline in Sub-Saharan Africa (SSA) despite agriculture being a major source of livelihood (Sanchez and Palm, 1996). Several reasons have been advanced for this situation. These include low and declining soil fertility due to unsustainable production practices (e.g. continued export of nutrient though harvested products without adequate replenishment); low and erratic rainfall and high evapotranspiration (Sanchez *et al.*, 1997; Itabari, 2004; Kinama *et al.,* 2005). Traditionally, shifting cultivation and production of crops with low nutrient demands were the main strategies used to preserve soil fertlity (Okalebo, 1987). However, the increased need to produce more staple food for the increasing population and the need to grow cash crops has forced farmers to abandon these practices in favour of intensive systems with heavy reliance on external inputs (De Jager *et al.*, 1998).Small-scale farmers are however seldom able to apply these inputs in recommended levels due to inaccessibility and high costs resulting in declining soil fertility (Smestad *et al.,* 2002). Nutrient mining and other adverse effects on the environment and ecosystem including contamination of water bodies by agroechemicals have therefore put in doubt the sustainability of these modern agricultural practices. Consequently, there is need for sustainable agricultural production alternatives such as agroecological intensification (Kaiser, 2004; De Jager *et al.,* 2001).

Agro-ecological intensification (AEI) is a sustainable approach to farming that relies on indigenous farming knowledege and incorporation of modern scientific understanding of biological principles and resources for increased crop production and natural resource conservation. The use of AEI techniques offers an environmentally sound and affordable option for small-holder to sustainably intensify agricultutral production (Altieri *et al.*, 1998). Agro-ecological intensification involves use of locally available resources and non-use of synthetic inputs in order to improve sustainability of agriculture (Altieri *et al.,* 1998; Place *et al.,* 2003). The main objective of AEI is to “work with nature not against it” in farming. This would involve use of crop varieties which are adapted to the harsh conditions of the ASALs as well as organic resources to improve soil fertility (Altieri, 1999). Abandoned traditional crops, which are drought tolerant and highly adaptable, can be combined with the appropriate technology to improve the food security situation in the ASALs (GOK, 2010). Cassava and sorghum are some of the crops that offer potential benefits for food security in the ASALs as they have been shown to be adaptable to drought and can grow in low soil fertility and under minimum input requirement. Cassava has the added advantage of being flexible in harvesting (El-Sharkawy, 2003; Gobeze *et al.,* 2005; World Bank, 2005). Drought tolerant legumes can be incorporated into cropping systems to allow spreading of risk, improvement of soil fertility as well as reduction in soil erosion and moisture losses (Zougmore *et al.,* 2000; Gobeze *et al.,* 2005; Rao and Mathuva, 2000).

Attempts at soil fertility management require consideration of diverse and dynamic aspects that affects the choices that farmers make. These include aspects such as weather, crop management factors, weeds, pests and diseases, and various socio-economic factors that determine farmers' choices (Scoones, 2001). In order to take variability into account, the traditional approach would require rapid increase in experimental research units as a soil fertility management option chosen for one site may not work for another site. Decision support tools (DSTs) solve this problem as they allow for the analysis, comprehension of the existing situation and subsequently offer alternatives to solve the problems or explore opportunities without the need for repeated field experiments (Bontkes and Wopereis, 2003; Walker, 2002*)*. Due to the importance attached to the accurate assessment of sustainability of the newly introduced technologies (Tait and Morris, 2000), DSTs could be applied in this endeavour as they allow for the analysing and interpretation of results of experiments with a systems approach (Rizzoli and Young, 1997). Despite the introduction of various DSTs with diverse applications, their use has not gained traction in SSA mainly due to huge data requirements, complexity in their use and their failure to capture the complexity within which the small-scale farmers operate in (Bontkes and Wopereis, 2003). It is with this in mind that NUTrient MONitoring-Toolbox (NUTMON-Toolbox) was developed (Vlaming *et al.,* 2001) to address some of these problems associated with earlier models. NUTMON is simple to use and utilizes data that is easy to obtain in order to estimate flows even when such flows are difficult to quantify (Vlaming *et al.,* 2001). It operates fromthe premise that quantification of nutrient balances can be used as indicators of agricultural sustainability

(Smaling *et al.,* 1996) hence could be applicable in choosing the optimal combination of options for soil fertility management when various options are available.

1.1 Statement of the problem

Despite the rapid population growth, agricultural productivity has either remained constant or declined thus posing a major threat to food security in the ASALs whose population is heavily reliant on agriculture (Sanchez and Palm, 1996). Inherently infertile soils especially N and P deficiency and low soil moisture due to low, erratic and unreliable rainfall are some of the underlying reasons for the low agricultural productivity. (Sanchez *et al.,* 1997). Decline in soil fertility is worsened by practices that cause soil nutrient mining (Ikombo, 1984). Furthermore, the ability of soils to cope with droughts, which is very important especially given effects of climate change, has been reduced due to loss of organic matter (Riley *et al.*, 2008). Complete packages which inlcude soil fertility management options and ways of determining their sustsainability have rarely been provided. In most cases, where strategies aimed at soil fertlity management are embraced, the quantitave assessment of their effects has rarely been satisfactory. This is because most farmers have mainly used visible indicators such as color, tilth, and crop yield (Murage *et al.,* 2006). As the farmers can not adequately monitor soil fertlity trends, this has resulted in practices that mine soil off nutrients hence leading to production decline and consequently food insecurity. Food insecurity is further negatively impacted by abandonment of traditional crops which are more drought tolerant (Macharia, 2004) in favour of maize which is now the staple food despite its high vulnerability to drought (Heisey and Edmeades, 1999). In addition, research has mostly concentrated on hybrids and high-value exportable crops favouring commercial farmers at the expense of high value traditional crops, which are important to the livelihoods of the most small-scale farmers (Tripp, 2000). Consequently, insufficient food situation and lack of economic opportunity and poverty that arise have led to increasing dependence on expensive food aid programmes and rural-urban migration especially in periods of drought (Mbogoh, 1991; Kaluli *et al*., 2005; Muriuki, 2004).

1.2 Justification

With the increasingly erratic and low rainfall and decreasing soil fertility, an alternative production system that makes use of the locally available resources and builds on tradition is imperative. Use of Agroecological intensification techniques has been suggested as apotential solution to the food insecurity problems in marginal environments. This is because it makes use of locally available resources to increase soil fertility and utilizes crop varieties more suited for a specific environment. Techniques such as Crop rotations, intercropping and application of organic inputs enhance soil fertility and increase stability and resilience of the soil to droughts due to their effect on soil organic carbon content, which has major implications on soil structure. Besides minimizing risks, rotation and intercropping with legumes also stabilizes yield, promotes dietary diversity and maximize returns even when low levels of technology and resources are used. Numerous studies have been done on the effects of cropping system and organic inputs on yield of crops. However, few have focused on the effect of various combinations of cropping systems and inputs on soil fertility and yields. Furthermore, no studies have attempted to apply NUTMON in the assessment of the impact of these technologies on nutrient balances under experimental conditions. The current study was therefore tailored towards assessing how various combinations of agroecological intensification techniques (cropping systems and organic inputs) affect moisture and nutrient status of the soil. The study also evaluated the effect of these techniques on yield of cassava and sorghum and status of NPK in the grain and tuber. In order to provide a complete package, sustainability of the various techniques was assessed by calculating balances of macronutrients using NUTMON toolbox. It is envisaged that the study would therefore contribute towards enhancing the long-term sustainability of agricultural production and hence improve food security.

1.3 Research objectives

1.3.1 Broad objective

To contribute towards enhanced soil fertility and food availability in the ASALs through application of Agro-ecological intensification techniques.

1.3.2 Specific objectives

i. To assess the effects of intercopping, rotation and application organic inputs on soil moisture and yields of cassava and sorghum
ii. To determine the effects of intercopping, rotation and application organic inputs on soil and plant nutrient status
iii. To evaluate the effect of intercopping, rotation and application of organic inputs on soil nutrient balances using NUTMON.

1.4 Hypothesis

i. Intercropping and crop rotation coupled with application of FYM and compost will increase soil moisture and yields of cassava and sorghum compared to monocropping.
ii. Intercropping and crop rotation coupled with application of FYM and compost willincrease soil Organic Carbon, and NPK of soil and plant tissues compared to monocropping.
iii. Intercropping and crop rotation coupled with application of FYM and compost will result in higher balances of NP and K compared to monocropping.

CHAPTER TWO: LITERATURE REVIEW

2.1 Agro-ecological intensification and its practices

Though green revolution substancially contributed to increase in food production (Koohafkan *et al.*, 2011; Altieri *et al.*, 2012), it created a myriad of problems such as increasing ineaquality between farmers (those who could afford these technologies and those who could not), econonomic debt (as a result of increased dependance on external input) and rural-urban migration. This led to the increase in poverty, hunger and malnutrion levels which are the very things the green revolution was intended to address (Utviklingsfondet, 2011; McKay, 2012). Futhermore, the green revolution has also resulted in environmental costs including loss of genetic diversity, soil degradation, increased vulnerabilty to pests and diseases and increased contribution to climate change amidst other social costs. This led to calls for a shift to a more sustainable form of agriculture hence the emergence of Agroecological intensification (AEI) as a viable alternative (De Schutter and Vanloqueren, 2011; McKay, 2012; Koohafkan *et al.*, 2011).

AEI can be seen as a way of bringing together the often confilicting concepts of of sustainable agriculture and intensive farming. This approach aims at creating an ecologically friendly agriculture that also enhances productivity of the farm (Diamond Collins and Chandrasekaran, 2012). AEI implies intergration of ecolgical principles into management of the farming system in order to improve its perfomance. AEI is characterised by strategies that seek to increase biodiversity of the farm in space and time (through practices such as crop rotation, intercropping) strenghtening of ecological processes hence replacing chemical inputs and enhance use of local resources (e.g recycling of biomass and other organic fertlizers), reducing risk and increasing productivity of the farm through enhancing its resilince and adaptation (e.g through use of crop varities suited to the harsh conditions in the ASALs (Altieri *et al.*, 1998; Altieri, 1999; Place *et al.*, 2003; Rosset *et al.*, 2011).

2.1.1 Use of drought tolerant crops to enhnance adaptation and increase productivity

In most areas of the ASALs low and erratic rainfall, high temperatures and evaporation rates as well as effects of climate change such as frequent droughts create difficult conditions for crop growth (Itabari *et al.,* 2004; Kinama *et al.,* 2005; Funk *et al.,* 2008; Lobell *et al.,* 2008) which impacts on food security. Embracing crops which are more tolerant to environenmental stresses including drought and climate change (crop adaptation) is among the widely advocated adaptation measures (Lobell *et al.,* 2008; Howden *et al.*, 2007). Cassava and sorghum legumes such as Dolichos and pigeon pea are some of the crops suitable to the ASALs as they are drought tolerant, more resilient and adaptable to the changing conditions in the ASALS in addition to requiring minimal inputs (Shava, 2000 and 2005; Asafo-Adjei, 2004)

2.1.1.1 Cassava (Manihot esculanta Crantz)

Cassava is an important food crop in the tropics, being consumed by more than 500 million people and providing more than half of the dietary calories for over 200 million people in SSA (Khizzah *et al.,* 2003). Its production is closely linked to small-scale farmers in poor households residing in marginalized areas and is considered a crop of last resort due to its ability to grow on poor soils, under difficult climatic conditions and with minimum inputs. It has the advantage of flexible root harvesting whenever there is a need as it can remain in the soil for long periods without major deterioration in quality (El-Sharkawy, 2003). In Kenya, cassava is grown in both low and high potential areas mainly as a food crop but also as a cash crop whenever there is a surplus (Philips *et al.,* 2004), and is mainly grown as an intercrop with beans. Sole cropping is done on 24.7% of the cassava fields. The main varieties grown are Kibandameno, Sudhe, Obarodak, B. Adhumani and Mucericeri (Kariuki *et al.,* 2002).

Despite cassava's importance as a food crop, its production and per capita consumption in most of Africa, including Kenya, has decreased without substitution by other food crops (FAO, 2005; Sarma and Kunchai, 1991). This is attributed to among other factors policies which have led to abandonment of cassava in favor of cash crops (Kenyon *et al.,* 2006.). Other constraints of cassava production include lack of quality planting material, inadequate fertlizers use, poor agronomic practices (such as early harvesting and poor weed management), poor soil fertlity and early water stress sue to inadequate rainfall (Mwango'mbe *et al.*, 2013; Fermont *et al.*, 2009).

2.1.1.2 Sorghum (Sorghum bicolor (L.) Moench)

Sorghum is the fifth most important grain crop in the world and second only to maize in Eastern Africa (FAOSTAT, 2011). It is important especially in the semi-arid areas due to its relative tolerance to drought (Borrell *et al.*, 2000) and the ability to perform better than other local cereals under low soil fertility, as well as the ability to resist disease and weed such as *striga* (Riches, 1999). Sorghum is capable of improving livelihoods of the vulnerable communities residing in the ASALs according to World Bank (2005). In Kenya, sorghum is produced mostly in the drought-prone marginal areas of Nyanza, Eastern and coast. It could be used as an alternative to enhance food security especially in eastern Kenya where maize failure is a common phenomenon (Jaetzold *et al.,* 2006; MOA, 2003)

Sorghum production in Kenya is constrained by lack of income to purchase inputs, poor quality seed, and pests and disease (e.g stem borer, midge, shoot fly, grain mold and striga) (Muui *et al.*, 2013; ICRISAT, 2004)

2.1.1.3 Pigeon pea (Cajanus Cajan (L.) Millspaugh)

Pigeon pea is an important pulse crop in the ASALs that receive insufficient rainfall (Reddy *et al.,* 1993). Kenya is the second largest producer of pigeon pea in the world with the semi-arid areas of eastern Kenya giving 90% of the total production (District Annual Agricultural Reports, 2005). Pigeon pea can survive and performs well under low moisture conditions. It is a multiple purpose drought tolerant crop because of its numerous benefits to resource poor households. These include providing plant protein, fuel, fencing and building material and acting as a soil erosion control measure (Siambi *et al.,* 1992). Pigeon pea also contributes to improved soil fertility through residue from leaves and nutrient cycling (Mapfumes, 1993).

In Kenya, long duration varieties of pigeon pea are grown usually as an intercrop with cereals (maize and sorghum) and short duration legumes (beans and cowpea) with minimal inputs resulting into low yields. Low productivity is also due to use of low yielding cultivars or cultivars not agro-ecologically adapted; lack of quality seeds; pests infestation and diseases. Other factors include poor production practices such as late planting, low plant population, poor land preparation and poor weeding; and environmental and socioeconomic factors including low soil fertility, drought stress, poor pricing, marketing and infrastructure (Kimani *et al.,* 1994; Silim *et al.,* 2001).

2.1.1.4 Dolichos lablab (*Lablab purpureus*)

Dolichos lablab is a grain legume that is tolerant to high temperatures and drought (Muchow, 1985). It has the capacity to replace common legumes that are more vulnerable to low rainfall and higher temperature grown in the ASALS. Dolichos is as a multi-purpose crop utilized as a pulse, green vegetable and animal feed (Maass, 2005) and is grown by small-scale farmers mainly in Eastern, Central and Coast provinces as an intercrop with maize or pure stand. Dolichos can also be utilized as short fallow in order to maintain soil fertility and organic matter (English *et al.,* 1999). The yield potential of lablabhas not been achieved due to use of unimproved varieties, pests and diseases and low use of inputs (Kinyua *et al.,* 2008).

2.1.2 Legumes use in intercropping and rotation systems to increase productivity

Inclusion of legumes into the cropping system has been rescognised as a way to eliminate the need for inorganic N due to their nitrogen fixing ability. They are important components in sustainable production systems in semi-arid tropics when grown as intercrops or in rotation with cereals (Willey *et al.,* 1989). Under optimal conditions, legumes can fix up to 200 kg N ha^{-1} year^{-1} (Giller, 2001). For example pigeon pea can fix upto 235 kg N ha^{-1} and produces more N per unit area from plant biomass than many other legumes (Peoples *et al*., 1995). Apart from its ability to fix nitrogen, pigeon pea also has the ability to bring minerals from the deeper soil horizons to the surface as well as improving soil air circulation (Kumar Rao *et al*, 1983). Dolichos has also been found to have roots that are capable of capturing nitrates from the subsoil (Lelei *et al.,* 2009).

2.1.2.1 Effect of rotation on soil fertility and yields of crops

Crop rotation is a system where different plants are grown in a defined recurring sequence (Altieri, 1995). This temporal diversity within cropping systems has the principal objective of providing crop nutrients and breaking the life cycles of several insect pests, diseases, and weeds. Crop rotations are the main avenues for supply of nitrogen in organic cropping systems especially when they include a mixture of leguminous and cash crops. Rotations are divided into nutrient building and nutrient depleting phases which must be in balance or show a slight surplus to ensure long-term fertility (Altieri, 1995). By influencing soil structure and crop growth conditions, rotations play a critical role in sustainable crop production (Ball *et al.,* 2005).

Nene (1987) showed that residual effects of N fixed by pigeon pea under rotation can be as much as 40Kg N ha^{-1}. Rao and Mathuva (1999) found that maize-pigeon pea rotation produced slightly better maize yields compared to Maize–cowpea sequential and pigeonpea/maize intercropping systems which produced 17% and 24% respectively higher maize yields than continuous sole maize. Adjei-Nsiah (2012) showed that pigeon/pea-maize rotations could increase maize yield by 75%-200% in the semi-deciduous forest and the forest/savanna transitional agroe-cological zones of Ghana.

Cheruiyot *et al.,* (2001) while studying the contribution of chickpea, field bean, soybean, garden pea and dolichos on soil nitrogen status and yield of the succeeding maize crop found that dolichos gave the highest improvement in the soil N status. The yield of maize when rotated with dolichos also increased by 20%-40% compared to the weedy fallow. Kouyaté *et al.,* (2012) found that the yield of sorghum under a rotation with dolichos green manure improved by 145 kg ha^{-1} compared to the average 30 year yields of sorghum. Sieverding and Leihner (1984) found that rotating cassava with grain legumes enhances infection by the beneficial vesicular-arbuscular mycorrhiza, which is important for healthy growth and good yield.

2.1.2.2 Effect of intercropping on soil fertility and yields of crops

Intercropping is the practice of cultivating two or more crops in the same space at the same time (Anil *et al.,* 1998). It usually involves one main crop (of primary importance for economic or food production reasons) and one or more added crops. The crops in an intercrop are normally from different species or plant families. Intercropping is most common among small-scale farmers in tropical countries (Altieri, 1991) and has the advantage of being more efficient in utilization of available resources and increased productivity compared to the sole crop of the mixture (Mucheru- Muna *et al.*, 2010).

Because of the ability of pigeon pea to meet a proportion of its own N requirements through BNF, the inclusion of pigeon pea in an intercrop system minimizes competition with the cereal component as well as improving the soil organic status (Kumar Rao *et al.,* 1987). Egbe (2007) working in Southern Guinea savanna of Nigeria found that 14 newly introduced pigeon pea varieties of different maturity ratings could fix Nitrogen ranging from 37.52 kg ha^{-1}to 164.82 kg ha^{-1} when intercropped with sorghum though the total nitrogen of the soil under intercrop and sole crop showed no significant difference. Short duration pigeon pea fixed higher levels of total N per hectare per year (96.40 kg ha^{-1}) compared to medium duration (68 kg ha^{-1}) and long duration (55.69 kg ha^{-1}). Egbe and Kali (2009) while evaluating various pigeon pea genotypes for intercropping with tall sorghum in the same area found that most of the intercropped pigeon pea produced lower dry grain yield (1590kg ha^{-1}) compared to the sole cropped pigeon pea which had mean dry grain yield of 2720 kg ha^{-1}.

Egbe and Adeyemo (2006) found that comparable dry grain yields, 100-grain weight of maize in both sole and intercrop systems. In addition, increased dry stover yield of maize associated with pigeonpea genotypes under intercropping was realised. Rao and Willey (1980) showed that sorghum growth was not affected by the presence of pigeon pea and full sorghum yield could be obtained if the density of the intercropped sorghum is equivalent to the sole cropped optimum. Subramanian and Rao (1988) reported that intercropping pigeon pea and sorghum resulted in lower grain yields for both components crops compared to the yields of the sole crops of both sorghum and pigeon pea.

Rao and Willey (1980) also tried to evaluate yield stability of sorghum was under intercropping and sole cropping. They found that sole pigeon pea would fail one year in five, sole sorghum one year in eight, while intercropping only one year in thirty-six. They also found that intercropping gave yield advantages over a wide range of environmental conditions.

Osundare (2007) found that intercropping cassava and pigeon pea differed significantly to sole cropping cassava. Intercropping pigeon pea with cassava resulted in a 35% increase in organic carbon, 46% increase in total N and a 30 % decrease in exchangeable P. Sole cropping on the other hand resulted in a 24% decrease in organic C, 33% decrease in total N and a 13% decrease in exchangeable P. The tuber yield of sole cassava was 6.950 kgha^{-1}while tuber yield cassava/pigeon pea intercrop was 8660kgha^{-1}. Paisancharoen *et al.*, (1997) in Thailand observed that planting legumes (cowpea and sword beans) as intercrops 2-3 weeks after cassava led to a higher tuber yields compared to cassava sole crop. Kokram *et al.*, (1996) also observed that tuber yields were higher when cassava was intercropped with cowpea compared with sole cropped cassava.

Nzabi *et al.*, (2000) working in Kisii district at two sites (Nyamionyo and Nyatieko) found that dolichos when intercropped with maize and the residue incorporated into the soil found that dolichos lablab/maize intercrop could give maize yield of 3350 kgha^{-1} and 3320kgha^{-1}in Nyamionyo and Nyatieko respectively. This yield was higher than maize sole crop with residue incorporation, which gave a yield of 3061 kg ha^{-1}and 3345kg ha^{-1}for the same sites. Soil analysis revealed higher values of N (0.22%), P (17.00 ppm) and C (2.23%) for the intercrop compared to the monocrop N (0.19%), P (5.00 ppm) and C (2.02%). Panneer selvum *et al.*, (1993) also reported that higher grain number and weight of grains per year were realised when under sole sorghum compared to intercropping sorghum with dolichos.

2.1.3 Potential of organic inputs in increasing soil fertility and productivity of crops

Organic inputs are important alternatives to the expensive fertilizers in Africa (Reinjitjes *et al*., 1992). Organic inputs contain most essential nutrients and benefits occurring from their use can result in the elimination of the use of chemical fertilizers, as well as facilitating nutrient cycling and sequestration of carbon (Sanchez *et al.*, 1997).

P and K availability in manure could be comparable to that of inorganic fertilizers (Müller-Sämann and Kotschi, 1994). Residual effects of manure, especially on physical parameters, is important due to its ability to increase soil organic matter which is important in sustaining soil fertility (Woomer and Swift, 1994). Adekoyade and Ogunkoya (2011) found that application of compost increased the organic matter content of the soil by 23.3% in the first year and 0.6% in the second year. SOM helps in the retention of nutrients over a long time and making them available in small environmentally beneficial amounts as it undergoes mineralization (Gruhn *et al.,* 2000). SOM also increases the Cation Exchange Capacity of soil, their water holding capacity as well as enhancing the capacity of low activity clays to buffer changes in pH (Woomer and Swift, 1994).

Organic inputs can increase the yields of crops depending on the rates of organic amendments applied and agro-ecological setting (Schlecht *et al.,* 2006) with higher success rates in the tropics compared to temperate environments due to higher rates of decomposition (Mueller-Harvey *et al.,* 1985). Besides improving soil fertility status, organic inputs also enhance the water and nutrient use efficiency of crops and decrease incidence and abundance of *Striga* weeds (Esilabe *et al.,* 2000; Juo and Kang, 1989). Well-aged manures and composts can also produce substances such as humic and fulvic acids and indolea-3-acetic acid which stimulate growth (Magdoff and van Es, 2000).

Higher SOM content in the soil has been demonstrated to enhance yield and yield components of cereals (Görlitz, 1986). Experiments in Tigray, Ethiopia have shown use of compost can have similar yield increases to that of chemical fertilizers. The same experiment also demonstrated that long term use of compost could result in higher crop yields of durum wheat, barley, finger millet, maize, sorghum, faba beans, hanfets and field pea. In some instances it doubled yields compared to fields treated with chemical fertilizers (Araya and Edwards, 2006; Edwards *et al.,* 2008). Gateri *et al.,* (2006) showed that FYM could increase the yield of sorghumand 20 sites cutting across various agro-ecological zones of Kenya. Abdel-Rahman (2009) in Burkina Faso also found that sorghum yields could be tripled when 10000 kg ha^{-1} of compost was applied compared to the no-compost treatments. There was also a 45% increase in the yield of sorghum when 5 kg ha^{-1}compost was used. When applied over several seasons, organic manure can also enhance the yield of maize by 40%-60% (Lampkin, 2002). Diop et *al.,* (1997) showed that use of compost gave higher maize yield compared to boma manure combined with DAP. In Nyeri, the performance was lower when compost was used than boma manure combined with DAP.

Chompoonukulrat *et al.,* (1996) working with cow manure and Rammachat *et al.,* (2001) working with chicken manure in Thailand observed that both manures significantly increased the yield of cassava tubers compared to when no manure was used. Kokram *et al.,* (2002) also observed that combining chicken manure and rice husks in equal proportions increased the fresh tuber yield of cassava compared to chemical fertilizer treatment.

2.2 Decision support tools and their use in Agriculture

Decison Support Tools (DSTs) can be defined as any guidance, procedure or analysis tool that can be used to help support a decison. DSTs allow the decision making process to be made more transparent and allows for the quantitative assessment of effects any uncertainity on the decision (Sullivan, 2004). Use of Decision support tools has become a vital aspect of agricultural decision-making. Some of the reasons include: increased understanding of functioning of systems and increase in new technologies; increasing complexity of decisions due to the need to take into consideration not only the productivity of certain management decisions but also the social and environmental impacts; and the need to professionalise approaches to agroecosystems management (Walker, 2002). Various DSTs have been developed to assist in various decision-making options, which may range from short to long term. Bontkes and Wopereis, 2003 attempted to categorize different DSTs according to their use. These included: 1) Decision support trees that utilize quantitative information of rules of thumb that are available fromdatabases 2) Separate or intergraded databases that provide vital information, some of which might be geo-referenced, for decision making (e.g ORD, PRDSS) 3)cropping calendars 4) calculating optimal fertilizer ratios (e.g QUEFTS, NuMaSS) 4) models which are dynamic in nature used to mimic the development of a certain aspects of an agroecosysem (e.g. the Rothamsted Carbon model) 5) simulation models that show how important processes in nature such as climate, soil, crop characteristics and management affect crops yield (e.g. DSSAT, COTONS, APSIM and RIDEV) 6) those that allow the estimations of certain data that are required by other more complex DSTs 7) DSTs that monitor flow of products, money and nutrients to and from the farms and between the different units of production. These subsequently quantify calculate and visualize the various flows (e.g. NUTMON).

NUTMON is widely considered as a useful DST in the small holder agriculture as it it is easier to use, its data requirements are easy to obtain and allows for the capturing of complexities associated with the small holder agriculture (Vlaming *et al.,* 2001). It also allows for targeting different factors in the process of managing plant nutrient. Nutmon calculates the resulting effects of nutrient management startegies through quantification of nutrient balances as well as quantifying the financial implications of these strategies (De Jager *et al.*, 1998).

2.2.1 Calculation of Nutrient balances using NUTMON

Nutrient balances can be used as quantifiable indicators of sustainability of an agricultural system (Smaling *et al.,* 1996). Soil fertility management decisions to improve sustainability are determined by the available resources, the socioeconomic environment and the household objectives (e.g. profit maximization, food security and risk aversion) of the household (Van den Bosch *et al.,* 1998). Strategies to manage soil fertility therefore require a long-term holistic approach which appreciates the nutrient stocks within the farm and their flow between the farm activities as well as the nutrient balances resulting from differences in nutrient exports and imports into the farm (Vlaming *et al.,* 2001). Bio-economic models such as NUTMON are meant to examine the interaction between agro-ecological and socioeconomic processes (Reuben *et al.,* 2000). NUTMON is useful in assessing the effect of introduced nutrient management initiatives on the soil nutrient stocks and flows as well as the resultant economic performance of the farm (Van den Bosch*et al.,* 1998). Using empirical measurements from a given farm, NUTMON models stocks, flows of nutrients and financial resources, and hence serves to evaluate the balance of major nutrient and financial flows. This helps in making decisions that will ensure long-term sustainability of the farm (Brown, 2000). NUTMON as a DST has been widely used in at different regions in determining the effect of different soil fertility management options on nutrient balances which in turn inform the user on the sustainability of the agroecosystems (De Jagger *et al.,* 2001). Negative balances indicate more losses than gains from the systems and would indicate an unsustainable agroecosysem. Positive balances would mean more additions into the systems than losses (Nandwa and Bekunda, 1998).

Farm NUTMON consists of a structured questionnaire, a database and two static models: NUTCAL and ECCAL. A user interface facilities data entry and extraction of data from the database to provide input for the NUTCAL and ECCAL.NUTCAL calculates balances nutrient flows of NPK while ECCAL calculates economic parameters (Van den Bosch *et al.,* 1998). The concept is evaluated as input-output analysis. Inputs include fertilizers, deposition, nitrogen fixation and sedimentation. Outputs include harvested crops and their products, leaching denitrification and erosion. Flows which are difficult to quantify (leaching, erosion and denitrification) are modelled using transfer functions while nutrient flows such as fertilizers and harvested crops are obtained from interviews using the structured questionnaires (Smaling and Fresco, 1993).

NUTMON has been applied at various scales ranging from crop activity to regional scale to determine nutrient balance. De Jager *et al.,* (1999) found that farm level nutrient balances in Machakos and Embu were negative for both nitrogen (-53 Kg $ha^{-1}yr^{-1}$) and -55 Kg $ha^{-1}yr^{-1}$ respectively) and potassium (-10 Kg ha^{-1} $yr^{-1}$and -15 Kg ha^{-1} yr^{-1}). However, Phosphorous balances were neutral to positive. In Embu De Jager *et al.*, (1998) found there was spatial variations in nutrient balances depending on the type of crop produced. Where high earning cash crops were being produced, nutrient balances were neutral to positive. This was caused by application of considerable amounts of mineral nutrients due to the ability of these crops to give the high economic returns. Negative balances were realized in fields of staples such as maize and beans mainly due to application of very few inputs and removal of all crop residues.

In a study in four farmer field schools in two districts, van Beek *et al.*, (2009) found that partial balances were positive in Kiambu but slightly negative for N and P in Mbeere. However when losses due to erosion, volatilization,denitrification and leaching were included, balances in Kiambu showed negative balances while those in Mbeere showed minor or no depletion. This shows that application of high amounts of inputs or positive nutrient balance can lead to a high level of hard to manage nutrient losses. In a study to assess sustainability of various traditional soil fertility management practices (specifically crop residue and animal manure), Onwonga *et al.,* (2008) found that the N balances were -70.9, -80.2 and -99.8 kg ha^{-1} $yr^{-1}$for Gilgil, Lare and Molo divisions respectively. In a different study in the same area between April 2003 to march

2004, Onwoga and Freyer (2006) sought to find out the impact of traditional farming practices on nutrient balances in small-scale farming systems. Full farm nutrient NPK balances were 55, 40, 25 kg ha^{-1} yr^{-1} respectively for Gilgil -86, -4, 4 kg ha^{-1} yr^{-1}respectivelyfor Molo and -60, 5, 4kg ha^{-1} yr^{-1}respectively for Lare. NPK balances in cropping activities were all negative. In Kisii district, Smalling *et al.*, (1993) calculated negative nutrient balances for NPK of -112, -3 and -70 kg ha^{-1} yr^{-1}respectively in the year 1990. The average inputs by fertilizer for NPK in the area in that year were 18, 13 and 3 kg ha^{-1} yr^{-1}respectively while by manure was 112, 3 and 703 kg ha^{-1} yr^{-1}.Nutrient balances of 74 farms in Machakos, Mwingi and Makueni districts in Kenya, showed negative balances for NPK (Gachimbi *et al.*, 2005). In a study to compare nutrient flows and balances and economic performance indicators of subsistence farms practicing low-external input agriculture technologies with those practicing conventional farm management, De Jager *et al.*, (2001) concluded that both farming systems led to N depletion and 60%-80% of the of farm income is based upon nutrient mining.

CHAPTER THREE: GENERAL MATERIALS AND METHODS

3.1 Site description

On-farm trials were conducted in Katangi and Ikombe divisions of Yatta Sub-County of Machakos County (between 1.16^0 – 1.42^0 S and 36.50^0 – 37.79^0 E), which lies in agroclimatic zone IV classified as semi-arid (Sombroek *et al.*, 1982) (Fig 1)

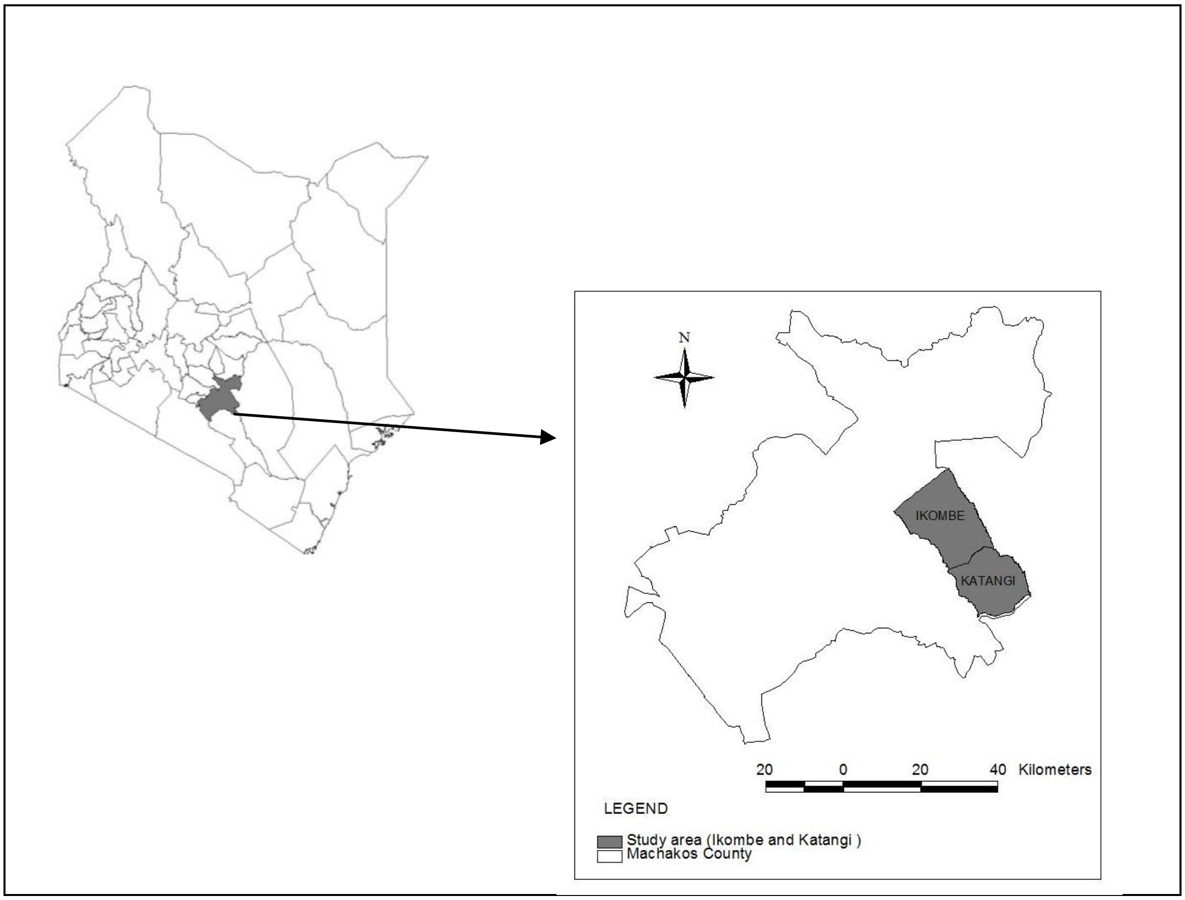

Figure 1: Map of the study area

The total population of Yatta is 147,579 people and has a population density of in 139.59 people per km^2 (GOK, 2009). Availability of water and soils to sustain agricultural production is the principle factor affecting population distribution. Available land for agricultural production per household is 4.09 ha (Jaetzold *et al.*, 2006) and farming is mainly subsistence-oriented mainly consisting of maize, beans, cowpea, pigeon pea, cassava, cotton and sunflower crops. Livestock kept consist of mainly local breeds of cattle, sheep and goats. Land preparation, planting and cultivation is done using oxen plough while in the drier areas, hand hoes and digging sticks are utilized (Onduru *et al.,* 1998; De Jagger *et al.,* 1999; Gachimbi *et al.,* 2005).

The mean annual temperatures of the area vary from 17ºC to 24ºC. The study was conducted for 2 years (from October 2010 to August 2012) which constituted four seasons of experimentation. The two seasons in a year are the short (SRs) occurring from October to December and Long rain season (LRs) from march/April to May (Table 1)

Table 1: Total rainfall received during the four experimental seasons (mm)

Season	Short Rain Season			*Dry period		Long Rain Season			*Dry period			
YEAR/ Month	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
2010	15.30	411.40	112.70	35.70	3.00	206.10	294.60	1.00	4.20	1.00	0.00	0.00
2011	0.00	164.30	7.00	103.60	33.20	65.40	20.00	5.20	0.00	0.00	128.60	0.00
2012	26.50	306.20	196.50	0.00	0.00	0.00	176.00	7.80	0.00	0.00	12.50	0.00

*Dry period with intermittent or no rains

Cumulative rainfall received during the SRS of 2010 (season 1) was 539.4 mm; LRS of 2011 (season 2) 501.7 mm; SRS of 2011 (season 3) 171.3; and LRS of 2012 (season 4) 90.6 mm.

The soils are generally a combination of Ferric Luvisols, Lithosols and Rhodic Ferralsols (FAO, 1974; WRB, 2006). Most of the soils are low in Nitrogen, Phosphorous and organic matter (Jaetzold *et al.,* 2006). Analysed soil properties prior to experimental set-up in Katangi were: of clay texture, moderate bulk density (Hazelton and Murphy, 2007), moderate organic C, Low Nitrogen, high Potassium and moderate phosphorus (Table 2). For Ikombe, the initial soil properties were: sandy clay loam texture, low bulk density (Hazelton and Murphy, 2007), low OC, low Nitrogen, high Phosphorous and moderate Potassium (Table 2) according to Landon (1991).

Table 2: Initial physical and chemical soil properties at the experimental sites

Soil properties	Katangi	Ikombe
Bulk density	1.36	1.11
Sand (%)	40	58
Silt (%)	17	19
Clay (%)	43	23
Textural class	Clay	Sandy clay loam
pH (H_2O)	6.31	6.49
pH ($CaCl_2$)	5.67	5.89
EC (dsm^{-1})	0.2	0.2
C (%)	1.17	0.74
N (%)	0.18	0.09
Na (cmol/kg)	0.38	0.38
K (cmol/kg)	0.98	0.75
CEC (cmol/kg)	20.1	8.1
P (ppm)	5.25	26.25

3.2 Treatments and experimental design

The treatments consisted of three cropping systems and two organic inputs with a control. The cropping systems were monocropping, intercropping and rotation of a test crop with either dolichos or pigeon pea. The Test Crops (TC) were sorghum and cassava. Organic inputs used were compost and Farmyard manure (FYM). This resulted in fifteen treatments combinations (Table 3). All crops had above ground biomass incorporated after harvest in the same plot they were harvested from.

Table 3: Treatments in the trial fields

	Treatment no.	Cropping system	Organic input (5tha^{-1})
Monocrop	1	Sorghum or Cassava	FYM
	2	Sorghum or Cassava	Compost
	3	Sorghum or Cassava	Control
Rotation	4	Pigeon pea-Sorghum or Cassava rotation	FYM
	5	Pigeon pea-Sorghum or Cassava rotation	Compost
	6	Pigeon pea-Sorghum or Cassava rotation	Control
	7	Dolichos-Sorghum or Cassava rotation	FYM
	8	Dolichos-Sorghum or Cassava rotation	Compost
	9	Dolichos-Sorghum or Cassava rotation	Control
Intercropping	10	Sorghum or Cassava intercropped with pigeon pea	FYM
	11	Sorghum or Cassava intercropped with pigeon pea	Compost
	12	Sorghum or Cassava intercropped with pigeon pea	Control
	13	Sorghum or Cassava intercropped with Dolichos	FYM
	14	Sorghum or Cassava intercropped with Dolichos	Compost
	15	Sorghum or Cassava intercropped with Dolichos	Control

The experimental setup was a Randomized Complete Block Design (RCBD) with a split plot arrangement replicated three times. The main plots (10m x 10m) were the cropping systems while the split-plots (3m x 10m) were organic inputs each applied at the rate of 5 tha^{-1} (Fig 2)

			2010		2011	2012
			SRS	LRS	SRS	LRS
Cropping system	Description	Crops				
Monocrop	Sorghum monocrop	Sorghum	▨	▨	▨	▨
	Cassava monocrop	Cassava	▨	▨	▨	▨
Rotation	Dolichos-sorghum rotation	Dolichos	▨		▨	
		Sorghum		▨		▨
	Pigeon pea-sorghum rotation	Pigeon pea	▨		▨	
		Sorghum		▨		▨
	Dolichos-cassava rotation	Dolichos	▨			▨
		Cassava		▨	▨	
	Pigeon pea- cassava rotation	Pigeon pea	▨			▨
		Cassava		▨	▨	
Intercropping	Legume sorghum intercrop	Dolichos/sorghum	▨	▨	▨	▨
		Pigeon pea/sorghum	▨	▨	▨	▨
	Legume cassava intercrop	Dolichos/cassava	▨	▨	▨	▨
		Pigeon pea/sorghum	▨	▨	▨	▨

Figure 2: Spatial and temporal distribution of the crops during the experimental period

Notes: 1. SRS = Short Rain Season, LRS = Long rain season

3.3 Agronomic practices

Oxenploughs were used for land preparation. Planting was done by direct placement of the seeds or cuttings in the case of cassava by hand.

3.3.1 Cassava

Mucericeri variety of cassava was through cuttings of 20-30 cm long and 20-25 mm in diameter (with 5-8 nodes). The cassava cuttings were placed at a depth of between 10 cm to 15 cm with the budding parts facing upwards at a spacing of 1m by 1m for sole cassava. Weeding was done every 3 weeksuntil 3 months after planting. Harvesting was done 11 months after planting.

3.3.2 Sorghum

The *Gandam* variety, which is an early maturing variety (3 months) was used. Three to four seeds were sown per hole at a depth of about 5 cm with a spacing of 0.75m by 0.25m but were later thinned to two plants. Weeding was done every 4 weeks and harvesting was done by hand after 3 months when the crop had reached maturity.

3.3.3 Dolichos

Dolichos *black* variety was planted in intercrops as well as in rotation with both sorghum and cassava. In rotation with either sorghum or cassava, two seeds of Dolichos wasplanted at a depth of about 5 cm with a spacing of 0.75 m by 0.30 m. For intercropping Dolichos was sown in rows between sorghum and cassava at the same inter-plant spacing as in pure stands.

3.3.4 Pigeon pea

The three month maturing variety of Pigeon pea *KAT 60/8* was used. Pigeon pea was also planted in intercrops as well as in rotation of both sorghum and cassava. In rotation with either sorghum or cassava, two seeds of pigeon pea wereplantedat a depth of about 5 cm with a spacing of 0.75m by 0.5m. For intercropping pigeon pea were sown in rows between sorghum and cassava at the same inter-plant spacing as in pure stands

3.3.5 Application of Organic inputs

FYM or compost was applied in the respective subplot by placing them in planting holes before seeds were sown. The control treatment had no application of organic inputs.15 Kg of FYM and compost were applied in planting holes (Table 4) translating into a rate of 5t $ha^{-1.}$

Table 4: Chemical characteristics of compost and FYM used during the experimental period

Organic input property	FYM	COMPOST
N (%)	2.71	2.55
P (%)	1.01	0.74
K (%)	3.9	1.81
OC (%)	35	35.60
pH(H_2O)	8.6	9.26
C:N Ratio	12.92	13.96

During the subsequent planting seasons, land preparation was done using hand hoes. This was done to avoid mixing of organic inputs from one plot to another. Immediately after harvesting, above ground biomass of the crops were chopped into small pieces and incorporated in the same plots that they were harvested from.

3.4 Soil moisture content determination

Soil moisture was determined by gravimetric method (Black, 1965). Soil samples were collected at sorghum harvest using an auger within the 0.3m depth. In the cassava based cropping systems, augering was also done at sorghum harvest, as this coincided with the end of a season, and at cassava harvest. Samples were put in a pre-weighed metal can and sealed tightly to minimize evaporation. They were then weighed (*mass of wet soil + container*). In the laboratory, the samples were placed in an oven at 105^0C for 24 hours. The dried samples were removed from the oven allowed to cool and re-weighed as weight of (*mass of dry soil + container*). The percent soil moisture content in dry weight basis was determined using the following formula:

$$\%MC = \frac{(M_w + M_c) - (M_d + M_c)}{(M_d + M_c) - M_c}$$

Where:

$\% MC$- percent moisture content
M_w-mass of wet soil
M_d-mass of dry soil
M_c-mass of container

3.5 Soil, Plant sampling and analysis

Soil samples were collected within the 0.2m depth using an auger. In the sorghum based cropping systems samples were collected at harvest (after 3 months) while in cassava this was done at 3 months as well as at cassava harvest (11 months). For determining the nutritional status, four sorghum crops were harvested by cutting the stem immediately above ground, and threshed to separate the grains from the panicles. For cassava, two cassava plants were randomly selected and harvested by digging around the base of individual plants within the net plot area using hand tools and then uprooting the whole plant. Thereafter, the tuber and stem were separated. The grains and tuber were then oven dried at 60^0C to a constant weight.

Soil OC was determined by titration (Nelson and Sommers, 1982). Soil and plantnitrogen was determined by the Kjeldahl digestion method followed by distillation (Black, 1965), P by Mehlich 3 Double Acid method (Mehlich *et al.*, 1962) while K was measured by flame photometry.

3.6 Methodology for monitoring resource flows, Quantification of nutrient balances

Resource flows in and out of the farms for the quantification of nutrient balances was monitored for two years (October 2010 to August 2012) using the farm-NUTMON approach (Fig 3) (Van den Bosch *et al.,* 1998).

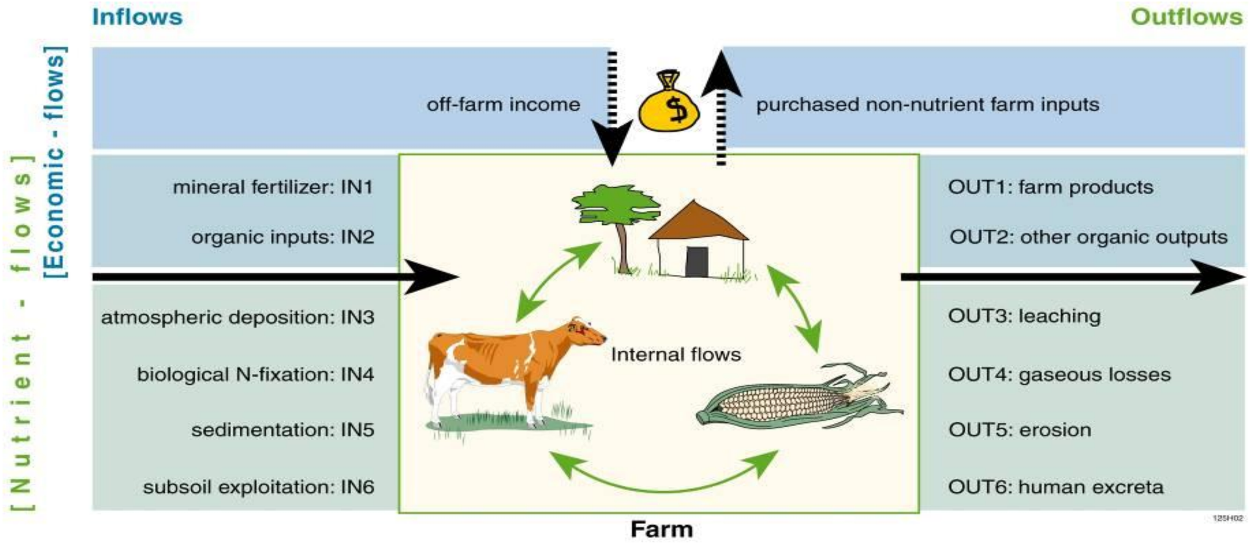

Figure 3: Conceptual framework for calculating nutrient balances using farm-NUTMON

(Adapted from Van den Bosch *et al.*, 2001)

The approach was modified to suit its application in an experimental set-up. Data collected from sampling of soil and plant material was fed into NUTMON toolbox where in-built transfer functions, equations and assumed values detailed by Vlaming *et al.*, (2001) were used to quantify nutrient balances. The material flows was converted to nutrient contents while flows such as atmospheric deposition, gaseous losses, leaching and erosion were quantified using measurable site characteristics transfer functions (Van den Bosch *et al.*, 1998). The NUTMON tool was then used to calculate the flow and balances of NPK and

$$\text{Net Full balance} = (Nutrient\ INPUTS) - (Nutrient\ OUTPUTS)$$

$$=(IN1 + IN2 + IN3 + IN4 + IN5) - (OUT1 + OUT2 + OUT3 + OUT4 + OUT + OUT6)$$

Where:

IN 1-mineral fertilizer, IN2-organic inputs, IN3-atmospheric deposition, IN-biological nitrogen fixation and IN5-sedimantation and six outflows. Inflows; OUT 1-farm products, OUT2-other organic inputs, OUT3-leaching, OUT4-volatization, OUT 5-erosion and OUT6-human execrate.

CHAPETR FOUR: RESULTS AND DISCUSSIONS

4.1 INFLUENCE OF SELECTED ECOLOGICAL FARMING PRACTICES ON SOIL MOISTURE RETENTION AND YIELD OF SORGHUM (*Sorghum bicolor (L.) Moench*) AND CASSAVA (*Manihot esculanta Crantz*) IN SEMI-ARID YATA SUB-COUNTY, KENYA

Abstract

Soil moisture stresses combined with negative effects of climate change are fundamental factors limiting land productivity in the ASALs posing a serious threat to food security. Ecological farming practices have proven to be successful in improving moisture retention and crop yields. In this study, the influence of cropping systems and organic inputs on soil moisture and yield of cassava (*Manihot esculanta Crantz*) and sorghum (*Sorghum bicolor (L.) Moench*) was investigated. The study was conducted in semi-arid Katangi and Ikombe divisions of Yatta sub-county between October 2010 and August 2012. A randomised complete block design with a split plot arrangement was used. The main plots were three cropping systems: (i) Intercropping; (Dolichos [*Lablab purpureus*]/Cassava, Dolichos/Sorghum, Pigeon pea [*Cajanus cajan (L.*) Millsp.]/Sorghum, Pigeon pea/Cassava); (ii) Rotation; Dolichos-Cassava, Dolichos-Sorghum, Pigeon pea-Cassava, Pigeon pea-Sorghum and (iii) Monocrop (pure cassava and sorghum). The split plots were organic inputs; Farm Yard manure (FYM), compost and control. Sorghum/pigeon pea intercrop+FYM treatment recorded high moisture levels during the SRS of 2010 at Katangi (5.21%), SRS of 2011 at Ikombe (5.19%) and LRS of 2011 at both sites (5.83%, 12.30%). Grain yields were highest under sorghum/dolichos intercrop+ FYM during the LRS of 2011 (Katangi 1.36 tha^{-1}, Ikombe 1.48 tha^{-1}) and SRS of 2010 (1.39 tha^{-1}) at Katangi only. Cassava/dolichos intercrop produced high soil moisture levels in both sites under sorghum/dolichos intercrop during SRS of 2010 (Katangi 6.48%, Ikombe 8.35%), LRS of 2011 (Katangi 7.63%, Ikombe 8.77%) and LRS of 2012 (Katangi 6.41%, Ikombe 3.65%). Tuber yields were higher under cassava/pigeon intercrop in Katangi and Ikombe during the SRS of 2010-LRS of 2011 (Katangi 18.63tha^{-1}, Ikombe 28.73tha^{-1}) and the SRS of 2011-LRS of 2012 at Katangi (20.86tha^{-1}). For enhanced performance of sorghum and cassava, it is recommended that the

former be intercropped with dolichos while the latter is intercropped with pigeon pea amid application of FYM in the farming systems of resource-poor smallscale farmers.

Key words: Compost; Intercropping; Farm Yard manure; Moisture; Organic inputs; Rotation

4.1.1 Introduction

Low agricultural productivity presents a serious threat to food security in Sub Saharan Africa (SSA) where agricultural productivity needs to increase by 4% annually by 2030 to keep up with population growth as opposed to the current 2% rate (FAO, 1996). Soil moisture stress which, affects growth and development of crops (Agili and Pardales, 1999; Akram, 2008 Ashraf *et al.*, 2007), has been identified as the most limiting factor to land productivity in semiarid lands of Kenya (Itabari *et al.*, 2004). In most of the ASALs, low and often erratic rainfall, high rates of evaporation and in some cases, high atmospheric temperatures coupled with sandy soils which retain high amounts of heat and light create a difficult environment for crop growth (Lawson and Sivakumar, 1991). Loss of soil moisture by evaporation and runoff alone has been estimated at 50% and 10 % respectively (Kinama *et al.*, 2005). This situation could be worsened by effects of climate change (Funk *et al.*, 2008; Lobell *et al.*, 2008). Strategies that make economic sense to the farmers but at the same time ensure that crop productivity is not compromised are therefore needed.

Agronomic practices aimed at reducing moisture stress offer greater potential benefits to improving crop productivity in rain-fed agriculture compared to improved crop varieties (Lobell, 2009). Ecological farming practices which include application of organic fertilizers i.e. manures and compost and intercropping or rotation with legumes have proven to be successful in improving the physical productivity of soil (Weil and Magdof, 2004; Altieri *et al.*, 1998). These practices also improve yields through enhancement of the occurrence of mycorrhizal associations which have positive effects on water uptake ability of crops and their ability to withstand drought (Syliva and Williams, 1992; Mäder *et al.*, 2000).

Drought resistant crops such as cassava and sorghum which are highly adaptable to the harsh environments of the ASALs (El-Sharkawy, 2003; Dicko *et al.*, 2005) when grown using organic fertilizers (Kihanda and Gichuru, 1999) and integrating legumes in production increase crop yields. This is in addition to improvement of the physical, chemical and biological properties of the soil (Haque *et al.,* 1995; SIWI, 2001). Application of organic inputs and use of legumes in rotations or intercrop are thus practices which are instrumental in building up soil organic matter. Organic matter has desirable effects on physical properties of soil including improving the structure which translates into better infiltration capacity, higher and longer moisture storage capacity and improving overall resistance of soil to drought and erratic rainfall (Makumba *et al.,* 2006; Rilley *et al.,* 2008).

Though it has been previously demonstrated that intercropping, rotation and use of organic inputs can result in increased soil moisture status and yield, there is still scanty information on the combined comparative advantages of intercropping and crop rotation with application of different organic inputs in the ASALs. The purpose of the study was therefore to assess the influence of different cropping systems and organic inputs on soil moisture and yields of sorghum and cassava in semi-arid Yatta sub-County.

4.1.2 Materials and methods

4.1.2.1 Site description

Site characteristics is as described in section 3.1

4.1.2.2 Treatments and experimental design

Treatments and experimental design is a describe in section 3.2

4.1.2.3 Agronomic practices

Agronomic practices are as decribed in section 3.3

4.1.2.4 Soil, Plant Sampling and Analysis

Soil samples were collected within the 0.2 m depth using an auger. In the sorghum based cropping systems samples were collected at harvest (after 3 months). In the cassava based systems, soil sampling was done after 3 months as well as at cassava harvest (11 months). Soil moisture was determined by gravimetric method (Black, 1965). Sorghum, dolichos and pigeon pea crops were harvested at physiological maturity (approximately 3 months after planting) from the inner 1 m^2 of each subplot. Plants from the net plot area were harvested by cutting stem immediately above the ground when plants were partially dried. They were then heaped and sundried to a constant weight. The dried plants were threshed, winnowed and weighed. For cassava, harvesting was done at physiological maturity (11 months after planting) from 4 m^2 area of each subplot. Hand-hoe was used to dig around the base of individual plants within the net plot area and then uprooting whole plant. Thereafter, the stem was separated from the tuber and fresh tuber weight taken using digital weighing scale. The grains and tuber of harvested crops was later extrapolated to t ha^{-1}

4.1.3 Results and discussions

4.1.3.1 Effect of cropping systems and organic inputs on soil moisture in sorghum based cropping systems

In the SRS of 2010 and, LRS and SRS of 2011 there were significant interaction effects between cropping systems × organic inputs in the sorghum based cropping systems at both Ikombe and Katangi. In the LRS of 2011 however, only the main effects of cropping systems and organic inputs were significant at $P \leq 0.05$ (Table 5 and 6). In the SRS of 2010, LRS of 2011 and SRS of 2011, sorghum/pigeon pea intercrop+FYM resulted in higher soil moisture compared to sorghum/dolichos+FYM and sorghum monocrop+FYM in both Ikombe and Katangi although the differences between sorghum/pigeon pea intercrop+FYM and sorghum/dolichos+FYM were not significant in Katangi. Similar trends between the cropping systems were noted under compost application and control (Table 5 and 6).

Table 5: Soil moisture as affected by cropping systems and organic inputs in sorghum based cropping systems at Katangi

	KATANGI							
	SR 2010			mean	LR 2011			mean
Crop	FYM	COMP	CTRL		FYM	COMP	CTRL	
Sorghum	4.07^{g}	4.47^{ef}	3.98^{g}		5.47^{b}	4.90^{c}	4.07^{i}	
Sorghum/dolichos	5.04^{ab}	4.7^{dce}	4.48^{ef}		5.71^{a}	5.36^{b}	4.56^{f}	
Sorghum/pigeon pea	5.21^{a}	4.98^{b}	4.91^{bc}		5.83^{a}	5.44^{b}	4.71^{e}	
Dolichos-Sorghum	4.33^{ef}	3.93^{gh}	3.60^{h}		4.73^{de}	4.18^{hi}	4.07^{i}	
Pigeon pea-Sorghum	4.45^{ef}	4.03^{g}	3.71^{h}		4.84^{cd}	4.43^{g}	3.94^{j}	
mean								
LSD $^{0.05}$	Cropping systems (C)							
	Organic inputs (O)							
	(C *O		0.256				0.127	
CV%			4.9				3.1	
	SR 2011				LR 2012			
Crop	FYM	COMP	CTRL		FYM	COMP	CTRL	
Sorghum	7.51^{d}	7.15^{d}	5.71^{e}		6.84	6.51	5.98	6.44^{d}
Sorghum/dolichos	10.42^{abc}	10.37^{abc}	10.30^{abc}		9.25	8.73	8.27	8.75^{b}
Sorghum/pigeon pea	9.92^{bc}	9.81^{bc}	9.68^{c}		8.89	8.22	7.87	8.33^{c}
Dolichos-Sorghum	10.32^{abc}	10.00^{bc}	9.52^{c}		9.58	9.00	8.49	9.02^{b}
Pigeon pea-Sorghum	11.00^{a}	10.91^{ab}	10.83^{ab}		10.88	10.50	10.27	10.55^{a}
mean					9.09	8.59^{b}	8.18^{c}	
LSD $^{0.05}$	Cropping systems (C)						0.356	
	Organic inputs (O)						0.281	
	(C *O)		1.103					
CV%			15.8				15.3	

Table 6: Soil moisture (%) as affected by cropping systems and organic inputs in sorghum based cropping systems at Ikombe

	SR 2010			mean	LR 2011			mean
Crop	FYM	COMP	CTRL		FYM	COMP	CTRL	
Sorghum	11.50^{b}	11.00^{c}	10.30^{e}		11.89^{b}	11.50^{c}	10.90^{e}	
Sorghum/dolichos	11.50^{b}	10.90^{cd}	10.40^{e}		11.90^{b}	10.60^{f}	10.90^{e}	
Sorghum/pigeon pea	11.90^{a}	11.10^{c}	10.30^{e}		12.30^{a}	11.40^{cd}	10.80^{e}	
Dolichos-Sorghum	11.50^{b}	10.90^{cd}	10.40^{e}		11.80^{b}	11.30^{d}	10.40^{g}	
Pigeon pea-Sorghum	11.99^{a}	10.95^{c}	10.43^{e}		11.91^{b}	11.45^{cd}	10.38^{g}	
mean								
LSD $^{0.05}$	Cropping systems (C)							
	Organic inputs (O)							
	C*O		0.176				0.155	
CV%			1.60				2.00	
	SR 2011				LR 2012			
Crop	FYM	COMP	CTRL		FYM	COMP	CTRL	
Sorghum	3.58^{e}	3.32^{ef}	3.01^{f}		3.53	3.40	3.02	3.32^{d}
Sorghum/dolichos	4.36^{cd}	4.29^{cd}	4.22^{cd}		4.40	3.82	3.70	3.97^{b}
Sorghum/pigeon pea	5.19^{a}	5.05^{ab}	4.64^{bc}		4.83	4.61	4.30	4.58^{a}
Dolichos-Sorghum	3.56^{e}	3.43^{e}	3.18^{ef}		3.25	3.15	3.08	3.16^{d}
Pigeon pea- Sorghum	4.31^{cd}	4.24^{cd}	4.18^{cd}		4.12	3.76	3.58	3.82b
mean					4.03^{a}	3.75^{b}	3.54^{b}	
LSD $^{0.05}$	Cropping systems (C)						0.262	
	Organic inputs (O)						0.215	
	C*O		0.418					
CV%			59.10				50.30	

Higher soil moisture when intercropping with pigeon pea could be as a result of increased shading provided by sorghum/pigeon pea intercrop which reduced evaporation from the soil surface. Ghanbari *et al*., (2010) also observed that increased shading under intercropping caused low evaporation from the soil hence more moisture. Lower soil moisture under sorghum/Dolichos intercrop compared to sorghum/pigeon pea intercrop under a given organic input could be attributed to heavy soil water usage by dolichos component. Eskandari (2012) also observed that intercrops which form intensive canopies extract more water from the soil profile resulting in a drier profile than the sole crops. Sorghum/dolichos intercrop did not significantly increase soil moisture (P≤0.05) compared to sorghum monocrop during the SRS of 2010 and LR of 2011 at Ikombe regardless of the organic input. For example, in SRS of 2010 intercropping with dolichos with FYM (11.50%) applied resulted in similar soil moisture levels as monocrop with FYM while sorghum/dolichos with compost (10.90%) had lower soil moisture though not significantly (P≤0.05) different to sorghum monocrop (Table 6). This could be attributed to the sandy nature of the soil which allowed more moisture depletion by the intercrop in addition to the more intensive canopy development. Miriti *et al*., (2012) also observed reduced soil moisture in sandy clay loam soil under cowpea/maize intercrop compared to maize monocrop suggesting that the added legume crop increased the plant density hence increasing extraction of soil water. Rotation with legumes reduced soil moisture at Katangi in SRS of 2010 and LRS 2011 compared to monocrop. For example, during SRS of 2010 Dolichos-sorghum rotation+FYM (4.33%) resulted in significantly lower moisture levels compared to Monocropping+FYM (4.07%). This could have been possibly caused by the legumes in rotation utilizing moisture for development hence depleting the profile ofmoisture. Hoyt and Leich (1983) observed lower soil moisture in plots following legumes attributing this to moisture depletion by the legumes. Another reason could have been that dolichos develops ground cover more rapidly but maintain it for a shorter time hence protects the soil least at harvest (Maina *et al*., 2000) while Pigeon pea does not offer sufficient enough canopy to protect the soil from evaporation. Rotating with dolichos under a given inputs had lower levels of soil moisture compared to rotating with pigeon pea probably because of the less ground cover offered by dolichos at harvest hence exposing the soil surface. Another explanation could be that dolichos might have had superior ability to deplete the rhizosphere soil moisture compared to pigeon pea.

Some legumes are heavy water users and hence can heavily deplete soil moisture (Miriti *et al*., 2012). This is especially the case if they develop intensive canopies (Eskandari, 2012). In the LRS of 2012, it was observed that inclusion of legume into the cropping systems either in rotation or intercropped resulted in higher soil moisture regardless of the legume used at both sites. Wortman *et al*., (2012) also noted increase in soil moisture under legume based plots only in the subsequent seasons. He attributed this to improved soil physical properties such as improved water infiltration and water holding capacity. Combination of any given cropping systems with FYM application increased soil moisture content relative to Compost and control respectively at both sites in SRS of 2010 and, LRS and SRS of 2011. This was probably due to improved physical properties of the soil, which enhanced moisture holding ability of the soil. Other authors such as Gicheru *et al*., (2004) and Chakraborty *et al*. (2010) have similarly observed increases in moisture storage with application of manure attributing this to improved physical characteristics such as soil structure, infiltration and storage capacity. Compost application has also been shown improve the physical condition of the soil (Abdel-Rahman, 2009).

4.1.3.2 Effect cropping systems and organic inputs on soil moisture in the cassava based cropping systems

In the cassava based cropping systems, significant interaction effects between cropping systems × organic inputs occurred only at Katangi during the SRS of 2011. Main effects of cropping systems and organic inputs were observed with the other seasons at both sites except at Ikombe where cropping systems and organic inputs did not have any significant effects ($P \leq 0.05$) in SRS of 2011 and LRS of 2012 respectively (Table 7 and 8).

Table 7: Soil moisture (%) as affected by cropping systems and organic inputs in cassava based cropping systems at Katangi

		KATANGI						
	SR 2010			mean	LR 2011			mean
Cropping system	FYM	COMP	CTRL		FYM	COMP	CTRL	
Cassava	5.79	5.50	5.00	5.43^{b}	6.27	5.93	5.40	5.87^{c}
Cassava/dolichos	7.53	7.13	6.61	7.09^{a}	8.10	7.60	7.20	7.63^{a}
Cassava/pigeon pea	7.53	7.02	6.42	6.99^{a}	7.72	7.48	6.71	7.30^{b}
Dolichos-Cassava	5.73	5.41	5.36	5.50^{b}	6.35	6.02	5.49	5.95^{c}
Pigeon pea-Cassava	5.81	5.59	5.01	5.47^{b}	6.34	6.01	5.45	5.93^{c}
mean	6.48^{a}	6.13^{b}	5.68^{c}		6.96^{a}	6.61^{b}	6.05^{c}	
LSD $^{0.05}$	Cropping systems (C)		0.228				0.109	
	Organic inputs (O)		0.177				0.103	
	C*O							
CV%			12.7				8.5	
	SR 2011				LR 2012			
Crop	FYM	COMP	CTRL		FYM	COMP	CTRL	
Cassava	7.80^{a}	6.93^{ab}	6.40^{bc}		7.05	6.30	5.63	6.32^{ba}
Cassava/dolichos	7.05^{ab}	6.97^{ab}	6.87^{ab}		6.70	6.49	6.03	6.41^{ba}
Cassava/pigeon pea	6.62^{abc}	6.43^{bc}	5.59^{c}		7.35	7.05	6.73	7.04^{a}
Dolichos-Cassava	7.07^{ab}	6.59^{abc}	5.60^{c}		5.64	5.44	5.10	5.39^{c}
Pigeon pea-Cassava	7.35^{ab}	7.05^{ab}	6.73^{abc}		6.18	5.45	5.04	5.56^{bc}
mean					6.58^{a}	6.15^{b}	5.71^{c}	
LSD $^{0.05}$	Cropping systems (C)		1.249				0.889	
	Organic inputs (O)		0.211				0.239	
	C*O		1.276					
CV%			25.3				26.8	

Table 8: Soil moisture (%) as affected by cropping systems and organic inputs in cassava based cropping systems at Ikombe

IKOMBE									
		SR 2010			mean	LR 2011			mean
Cropping system		FYM	COMP	CTRL		FYM	COMP	CTRL	
Cassava		8.10	7.76	7.44	7.77^{c}	8.60	8.30	7.20	8.03^{cb}
Cassava/dolichos		8.73	8.37	7.95	8.35^{a}	10.30	9.80	9.20	8.77^{a}
Cassava/pigeon pea		8.40	8.10	7.60	8.03^{b}	9.00	8.40	7.50	8.30^{b}
Dolichos-Cassava		8.20	7.67	7.63	7.83^{cb}	8.63	8.29	7.26	8.06^{cb}
Pigeon pea-Cassava		8.14	7.65	7.14	7.64^{c}	8.51	8.11	7.14	7.91^{c}
mean		8.31^{a}	7.91^{b}	7.55^{c}		9.01^{a}	8.58^{b}	7.66^{c}	
LSD $^{0.05}$	Cropping systems (C)			0.229				0.372	
	Organic inputs (O)			0.173				0.148	
	C*O							0.434	
CV%				8.6				5.0	
		SR 2011				LR 2011			
Crop		FYM	COMP	CTRL		FYM	COMP	CTRL	
Cassava		3.91	3.55	3.02		3.58	3.39	3.03	3.33^{ab}
Cassava/dolichos		3.73	3.62	3.46		3.75	3.41	3.21	3.46^{ab}
Cassava/pigeon pea		3.67	3.45	2.82		3.93	3.66	3.36	3.65^{a}
Dolichos-Cassava		3.70	3.41	2.77		3.08	2.71	2.48	2.76^{c}
Pigeon pea-Cassava		3.93	3.66	3.36		3.31	3.14	2.89	3.11^{bc}
mean		3.79^{a}	3.54^{b}	3.09^{c}					
LSD $^{0.05}$	Cropping systems (C)							0.392	
	Organic inputs (O)			0.154					
	C*O								
CV%				78.2				57.6	

During the SRS of 2010 and LRS of 2011, intercropping cassava with either pigeon pea intercrop or and dolichos resulted in significantly higher soil moisture compared to monocropping at both sites (Table 7 and 8). This may be due to increased shading which provided better protection to the soil surface against evaporation. Other avenues such as reduction of runoff and erosion could also have contributed to the enhanced soil moisture under intercropping. El-Swaify (1988) suggested that enhanced soil moisture when intercropping cassava with legumes could be because of reduction of runoff and erosion. Cassava/pigeon pea intercrop had lower moisture levels compared to cassava/dolichos intercrop. This may have been due to reduced canopy provided by cassava/pigeon pea intercrop compared to cassava/dolichos intercrop hence exposing the soil to evaporation. Gichangi *et al.*, (2006) also noted that pigeon pea has a tendency to depress cassava leaf growth when the two are intercropped. Lower moisture levels occurred under rotation with both legumes compared to monocropping in LRS of 2012 at both sites though not significant in Ikombe ($P \leq 005$). This could probably be because cassava had stayed in the field for longer time in the case of monocrop, and had hence developed larger canopy than rotations i.e. at the time of soil moisture determination at the end of the 11 month period, cassava crop in the rotation had only been in the field for four months and had hence not development sufficient ground cover. FYM application led to higher soil moisture compared to compost and control respectively mainly due to improved physical properties of the soil brought about by the use of organic manures. Other studies (Gicheru *et al.,* 2004; Chakraborty *et al.*, 2010) have demonstrated improvement in physical characteristics of the soil as a result of organic input application. Soil moisture increased from SRS of 2010 through to SRS of 2011 but declined regardless of the cropping systems in LRS of 2012. In the cassava cropping systems, it was also observed that soil moisture similarly decreased in LRS of 2012 at Katangi while in Ikombe the decrease started in SRS of 2011. Initial increase in soil moisture could be attributed to increased organic matter in the soil, which increased the moisture holding capacity of soil. The decline in soil moisture in the subsequent seasons was mainly because of decline in amount of received rainfall as rainfall during SRS of 2010 and LRS of 2011 was 439 mm and 179 mm respectively but declined to 90 mm during the SRS of 2011. Though in LRS 2012 it slightly increased to 183 mm, it did not reach the levels of the SRS of 2010. Ngeve (2003) also opined that soil moisture is primarily determined by amount and in intensity of received rainfall. During the first two seasons, plots in Katangi exhibited less moisture compared to those in Ikombe mainly because more clay (43%) in Katangi soils could have hampered water infiltration into soil. Another reason might be that the increased rainfall could have led to more raindrop impact on the heavier clay soil which produced crusts and retarded infiltration (Miriti, 2010). However, during the seasons with limited rainfall, soils in Katangi had higher moisture content compared to Ikombe probably due to the ability of the clayey soils to hold more moisture for longer periods (Rahn, 1979). Since soils with less clay retain less soil moisture, this could have been a contributing to the more dramatic decline in soil moisture at Ikombe once the amount of rainfall received declined.

4.1.3.3 Effect of cropping systems and organic inputs on grain and tuber yield

Sorghum grain yields: Significant interaction effects of cropping systems and organic inputs on sorghum grain yield occurred in SRS of 2010 and LRS of 2011 in Katangi. At Ikombe, the interaction effects of cropping systems and organic inputs on sorghum grain occurred in LRS of 2011. Cropping systems did not significantly affect grain yield in LRS of 2012 and SRS of 2011 at Katangi and Ikombe respectively (Table 9 and 10).

Table 9: Sorghum grain yields (tha^{-1}) as affected by cropping systems and organic inputs in Katangi

	KATANGI							
	SR 2010			mean	LR 2011			mean
Crop	FYM	COMP	CTRL		FYM	COMP	CTRL	
Sorghum	1.26^{b}	0.98^{d}	1.00^{d}		1.30^{b}	1.07^{g}	1.00^{h}	
Sorghum/dolichos	1.39^{a}	1.20^{bc}	1.15^{bc}		1.36^{a}	1.21 ^{cd}	1.14^{f}	
Sorghum/pigeon pea	1.25^{b}	1.16^{bc}	1.16^{bc}		1.35^{a}	1.16^{ef}	1.13^{f}	
Dolichos-Sorghum					1.23^{c}	1.13^{f}	1.03^{gh}	
Pigeon pea-Sorghum					1.43^{a}	1.20^{cde}	1.18^{def}	
mean								
LSD $^{0.05}$	Cropping systems (C)							
	Organic inputs (OI)							
	(CxOI)		0.074				0.045	
	CV%		8.8				7.0	
	SR 2011				LR 2012			
Crop	FYM	COMP	CTRL		FYM	COMP	CTRL	
Sorghum	1.62	1.37	1.14	1.38^{c}	2.33	1.48	1.32	
Sorghum/dolichos	2.11	2.00	1.67	1.93^{a}	2.23	1.93	1.75	
Sorghum/pigeon pea	1.92	1.64	1.5	1.68^{b}	1.66	1.22	0.92	
Dolichos-Sorghum					1.95	1.85	1.67	
Pigeon pea-Sorghum					1.93	1.51	1.10	
mean	1.88^{a}	1.67^{b}	1.38^{a}		2.02^{a}	1.60^{b}	1.35^{a}	
LSD $^{0.05}$	Cropping systems (C)		0.16					
	Organic inputs (OI)		0.181				0.187	
	(CxOI)							
	CV%		48.9				57.7	

Table 10: Sorghum grain yields (tha^{-1}) as affected by cropping systems and organic inputs in Ikombe

IKOMBE								
	SR 2010			mean	LR 2011			mean
Crop	FYM	COMP	CTRL		FYM	COMP	CTRL	
Sorghum	1.31	1.04	1.00	1.12^{c}	1.36^{b}	1.12^{ef}	1.00^{g}	
Sorghum/dolichos	1.43	1.26	1.13	1.27^{a}	1.48^{a}	1.14^{e}	1.30^{c}	
Sorghum/pigeon pea	1.37	1.18	1.01	1.18^{b}	1.42^{a}	1.20^{d}	1.20^{d}	
Dolichos-Sorghum					1.24^{d}	1.19^{de}	0.93^{h}	
Pigeon pea-Sorghum					1.49^{a}	1.17^{e}	0.96^{gh}	
mean	1.37^{a}	1.16^{b}	1.05^{c}					
LSD $^{0.05}$	Cropping systems (C)		0.029					
	Organic inputs (O)		0.033					
	(C*O)						0.051	
CV%			0.2				6.6	

	SR 2011				LR 2012			
Crop	FYM	COMP	CTRL		FYM	COMP	CTRL	
Sorghum	1.56	1.41	1.20	1.39	2.33	1.53	2.03	1.96^{a}
Sorghum/dolichos	1.72	1.54	1.45	1.57	2.00	1.75	1.79	1.85^{a}
Sorghum/pigeon pea	1.68	1.61	1.46	1.58	1.39	1.25	1.14	1.26^{b}
Dolichos-Sorghum					1.82	1.60	1.38	1.60^{ab}
Pigeon pea-Sorghum					1.88	1.65	1.34	1.62^{ab}
mean	1.65^{a}	1.52^{b}	1.37^{c}		1.88^{a}	1.55^{b}	1.53^{b}	
LSD $^{0.05}$	Cropping systems (C)						0.442	
	Organic inputs (O)		0.057				0.263	
	(C*O)							
CV%			47.2				37.5	

Sorghum/dolichos intercrop+FYM significantly ($P \leq 0.05$) increased sorghum grain yields (by 10%) relative to sorghum monocrop+FYM application in the SRS of 2010 at Katangi. Similar trends were observed under compost and control i.e. intercropping with pigeon pea and compost applied increased sorghum grain yield by 4% at both sites while intercropping with dolichos and compost applied increased sorghum grain yields by 5% in Katangi and 9% in Ikombe (Table 9 and 10). The observed increases in sorghum grain yield under intercropping were contrary to expectation that sorghum grain yields would be lower under intercropping due to competition between the cereal and legume component. A possible explanation is that other factors could have played a greater role than competition in influencing the yield of sorghum grain. Lower sorghum yields under monocropping have also been previously observed by Kouyat´e *et al.*, (2000). He attributed this to presence of phenolic compounds in the monocropped fields, which resulted in allelopathic effects causing poor germination and stand establishment. More moisture under the intercrop could have further contributed to increased grain yield of sorghum. Enhanced yields could also be attributed to other factors which may not necessarily be soil dependent. Weisskopf *et al.*, (2009) found out that other factors such as weed suppression could be the main factors that contribute to enhanced yield of cereals in a legume/cereal intercrop. During the SRS of 2011, rotating sorghum with either legume resulted in lower yields than intercropping with the same legume under a given input. For example, at Katangi sorghum-dolichos rotation+FYM and sorghum/dolichos intercrop+FYM resulted in grain yields of 1.36 tha^{-1} and 1.23 tha^{-1} respectively. This was most likely due to enhanced soil moisture that had been observed under intercropping compared to rotation. Natarajan and Willey (1986) observed that in moisture stressed environments, depression of yields could be less pronounced under intercropping compared to continuous cropping. It was observed that sorghum/pigeon pea intercropping had lower sorghum grain yields compared to sorghum/dolichos intercrop. For example, during the SRS of 2010 at Katangi, grain yield in sorghum/pigeon pea with FYM (1.25 tha^{-1}) was significantly lower than sorghum/dolichos with FYM (1.39). Main effects of sorghum/dolichos (1.93 tha^{-1}) on sorghum grain yield were significantly higher than sorghum/pigeon pea (1.68 tha^{-1}). In Ikombe 2010, main effects sorghum/dolichos intercrop had similarly higher sorghum grain yield (1.27 tha^{-1}) than sorghum/pigeon pea intercrop (1.18 tha^{-1}). This was probably due to more competition offered by pigeon pea for resources to sorghum compared to dolichos. This observation is supported by findings by Ito *et al*., (1993) who concluded that pigeon pea roots are physiologically more active compared to sorghum roots hence making the pigeon pea more competitive than sorghum when intercropped. Arshad and Ranamukhaarachchi (2012) also observed significant decline in sorghum grain yield when intercropped with soybean compared to mungbean attributing this to differences in the competitive abilities of the two legumes depending on the environment.

Application of organic inputs (FYM and/or compost) generally significantly increased ($P \leq 0.05$) the yield of sorghum (Table 9 and 10). This may be attributed to the ability of organic inputs to provide plant nutrients and increase nutrient holding capacity of soil, as less nutrients are lost through avenues such as leaching, in adddtion to increasing water holding capacity and infiltration rates (Gateri *et al*., 2006; Fening *et al*., 2005). Higher yields were obtained under FYM application compared to Compost as a result of slower decomposition which caused longer lasting effects on soil properties (Brady and Weil, 1996). Sorghum grain yields were significantly higher ($P \leq 0.05$) in SRS 2010 compared to LRS 2012 at both sites. Reduction in yield during the LRS 2012 could be attributed to lower soil moisture due to lower rainfall during the LRS of 2012 compared to SRS 2010.

Cassava Tuber Yields: No significant effects of cropping systems × organic inputs interactions on tuber yield were observed at both sites. At Ikombe, tuber yield during the SRS of 2011and LRS of 2012 period was not significantly affected by cropping systems. Tuber yield was significantly higher under cassava/pigeon pea compared to cassava monocrop during SRS of 2010 and LRS of 2011 at both sites (Table 11 and 12).

Table 11: Tuber yields (tha^{-1}) as affected by cropping systems and organic inputs in Katangi

	SR 2010-LR 2011			mean	SR 2011-LR 2012			mean
Cropping system	FYM	COMP	CTRL		FYM	COMP	CTRL	
Cassava	15.02	14.92	11.1	13.68^{b}	18.85	14.63	12.47	15.31^{b}
Cassava/dolichos	13.47	12.35	10.61	12.14^{b}	9.06	6.39	5.14	6.86^{c}
Cassava/pigeon pea	20.77	18.22	16.92	18.63^{a}	23.53	18.97	20.06	20.86^{a}
Dolichos-Cassava	16.36	12.81	11.74	13.64^{b}				
Pigeon pea-Cassava	18.91	11.88	10.33	13.70^{b}				
mean	16.90^{a}	14.03^{b}	12.14^{c}		17.15^{a}	13.33^{b}	12.56^{b}	
LSD $^{0.05}$	Cropping systems (C)		2.979				4.902	
	Organic inputs (O)		40.4				44.4	
	(C*O)							
CV%			1.74				2.636	

Table 12: Tuber yields (tha^{-1}) as affected by cropping systems and organic inputs in Ikombe

	SR 2010-LR 2011			mean	SR 2011-LR 2012			mean
Cropping system	FYM	COMP	CTRL		FYM	COMP	CTRL	
Cassava	22.47	17.04	11.79	17.10^{bc}	28.40	21.50	13.20	
Cassava/dolichos	19.92	15.81	11.18	15.64^{c}	38.10	30.60	14.50	
Cassava/pigeon pea	33.98	30.97	21.23	28.73^{a}	37.80	34.10	25.60	
Dolichos-Cassava	25.80	21.25	18.50	21.85^{b}				
Pigeon pea-Cassava	31.32	20.02	17.68	23.01^{ab}				
mean	26.70^{a}	21.02^{b}	16.08^{c}		34.76^{a}	28.76^{b}	17.77^{c}	
LSD $^{0.05}$	Cropping systems (C)		5.954					
	Organic inputs (O)		4.122					
	(C*O)						5.90	
CV%			35.50				49.9	

Higher yields were observed under cassava/pigeon pea intercrop than monocrop during the SRS of 2011 and LRS of 2012 at Katangi. This may be attributed to reduction in soil fertility decline due to continuous cultivation. Cassava also tends to deplete heavily soil nutrients especially when both stems and tubers are harvested. Poor performance of continually cultivated cassava fields was observed by Fening *et al*., (2009) specifically in the subsequent years after the first harvest attributing this to soil fertility decline. In Vietnam, Cong Doan Sat and Pole de Turk, 1998 and Nguyen huu Hy *et al.,* 2001 found a significant deterioration in soil physical, chemical and biological properties under continuous cassava compared to other crops. Cassava/pigeon pea intercrop resulted in higher cassava tuber yields than cassava/dolichos intercrop at both sites. This could be probably because of efficient utilization of growth resources when cassava was intercropped with pigeon pea. Dalal, (1974) opined that initial slow growth of pigeon pea reduces competition for water, nutrients and light when intercropped. Polthanee *et al.,* (1998) also observed that intercropping cassava with one row of peanuts would result in highest tuber yields. Similar to the case in the sorghum cropping systems, application of FYM increased tuber yield compared to compost and control respectively due to improved physical and chemical characteristics (Gateri *et al*., 2006; Fening *et al*., 2005; Brady and Weil, 1996). There were no significant differences in tuber yields between the two years in Katangi. At Ikombe during the SRS of 2011-LR 2012 significantly higher tuber yields were observed compared to SRS of 2010and LRS of 2011. This was contrary to expectations that tuber yields would reduce once rainfall reduced. No robust explanation could be found for the increased yield in spite of reduced rainfall other than the initially higher rainfall received when cassava was being planted could have led to better establishment. In his review of cassava agronomy research in Asia, Howeler, (2000) opined that cassava yields were higher when planting was done at onset of the rainy season probably due to the need for sufficient moisture for the stakes to germinate.

4.1.4 Conclusion

Soil moisture and yield of cassava and sorghum varied according to cropping system, type of legume chosen and the organic input used. Soil moisture retention was higher when the two test crop (sorghum and cassava) were intercropped and FYM applied. If sorghum is to be grown, then dolichos would be applicable as an intercrop while with cassava, pigeon pea would be the ideal legume. However, yields generally followed the rainfall patterns with lower rainfall resulting in yield depression. There appears to be a mismatch between the moisture content of the soil and the yield. For example while cassava/dolichos intercrop had the highest moisture content, cassava/pigeon pea intercrop led to higher yields. With sorghum, the results indicated that sorghum/dolichos intercrop as having higher yields despite the highest moisture being recorded under sorghum/pigeon pea intercrop. This could suggest that moisture content alone did not determine yields of the test crops as factors like competition for the available resources also played a part. With the prime objective of maximizing yield given the limited soil moisture levels in mind, then it is recommended that intercropping sorghum with dolichos and cassava with pigeon pea amid FYM application as the method of choice. Further research is recommended to establish reasons why soil higher moisture did not did not translate into the highest yields of sorghum and cassava and how the additional soil moisture could be utilized to increase productivity in the intercropping systems.

4.1.5 References

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4.2 CROPPING SYSTEMS AND USE OF ORGANIC FERETLIZERS EFFECTS ON SOIL AND PLANT TISSUE NUTRIENT CONCENTRATION IN SORGHUM (*Sorghum bicolor (L.) Moench*) AND CASSAVA (*Manihot esculenta Crantz*) BASED CROPPING SYSTEMS IN THE SEMI-ARID YATTA SUB-COUNTY, KENYA

Abstract

Inherent low soil fertility combined with unsustainable agricultural practices are some of the main contributors to low productivity of sorghum and cassava in the arid and semi-arid areas. The current study investigated the influence of cropping systems and organic inputs on soil organic carbon (OC), Nitrogen (N), Phosphorous (P) and Potassium (K). Effect of cropping systems and organic inputs on plant tissue NPK was also investigated. The study was conducted in Katangi and Ikombe divisions of Kitui Sub-County between October 2010 and August 2012 which covered the Short rain seasons of 2010 and 2011 and the Long Rain seasons of 2011 and 2012. A randomised complete block design with a split plot arrangement was used. The main plots were three cropping systems: (i) Intercropping (Dolichos [*Lablab purpureus*]/Cassava, Dolichos/Sorghum, Pigeon pea [*Cajanus cajan (L.*) Millsp.]/Sorghum, Pigeon pea/Cassava); (ii) Rotation (Dolichos-Cassava, Dolichos-Sorghum, Pigeon pea-Cassava, Pigeon pea-Sorghum); (iii) Monocrop (pure cassava and sorghum). The split plots were; Farm Yard manure (FYM), compost and control. Soil NPK and OC status as well as NPK content in sorghum grains and cassava tuber was determined.

Sorghum/dolichos+FYM had highest soil OC in LRS of 2011 at both sites and SRS of 2011 and 2010 at Katangi and Ikombe respectively. Cassava/dolichos+FYM had the highest soil OC in the SRS of 2011 and LRS of 2012 and 2011 at both sites. Sorghum/dolichos+FYM had highest soil N in LRS and SRS of 2011 in Katangi. Cassava-dolcihos rotation produced highest soil N in SRS of 2010 and LRS of 2011 at both sites. Sorghum/dolichos intercrop produced higher soil P in LRS of 2012 at both sites; and SRS of 2010 and LRS of 2011 in Katangi and Ikombe respectively. Cassava/dolichos intercrop produced higher soil P during the SRS of 2010 at both sites; and LRS of 2011 and SRS of 2011 in Katangi and Ikombe respectively. Higher soil K was observed under sorghum/dolichos inetcrop in SR 2010 at both sites and LRS 2011, SRS 2011 and LRS 2012 in Ikombe. Cassava/dolichos intercrop also had higher soil K during SRS 2010, LRS 2011 at both sites; LRS 2012 at Katangi and SRS 2011 at Ikombe. N content of tuber and grain was highest under sorghum monocrop and cassava/pigeon pea intercrop and cassava/dolichos intercrop during the SRS of 2010 following FYM application. Tuber P was significantly higher under cassava/dolichos intercrop+FYM during SRS 2010-LRS 2011 at both sites and SRS 2011-LRS 2012 in Ikombe. Grain P was higher during LRS 2012 under sorghum/dolichos intercrop+FYM in Katangi and under sorghum monocrop+FYM in Ikombe though this was not significantly different to sorghum/dolichos intercrop+FYM. Though not significant, K on the other hand was highest under cassava/pigeon pea intercrop during SRS 2010-LRS 2011 at both sites and SRS 2011-LRS 2012 at Ikombe. Cassava/dolichos+FYM also produced higher tuber K in SR2011-LRS 2012 in Katangi. Sorghum/dolichos intercrop also produced higher grain K during LRS 2012 at both Katangi and Ikombe although in the former the difference was not significantly different to Sorghum/pigeon pea intercrop. To optimize NPK concentration in plant tissue and soils, to ensure soil health and at the same time nutritional quality of the tuber and sorghum grain, intercropping sorghum with dolichos and cassava with pigeon pea amid application of FYM is a viable and sustainable option for resources-poor smallscale farmers.

Key words: Compost; Farm Yard manure; Intercropping; Rotation; Nitrogen; Organic carbon; Phosphorous; Potassium; Sorghum;

4.2.1 Introduction

Sorghum (*Sorghum bicolor (L.) Moench*) and Cassava (*Manihot esculanta Crantz*) are some of the most important food crops in Sub-Saharan Africa (SSA) contributing significantly to food security for the poor in this region (Khizzah *et al.,* 2003; Smith and Frederiksen, 2000). Their ability to grow in marginal lands where soil fertility is limited, adaptability to drought, minimum input requirement are some of the reasons they are attractive to farmers. Cassava is also known to be attractive to small-scale farmers in the Arid and Semi-Arid Lands (ASALs) due to its harvest flexibility (El-Sharkawy, 2003; Gobeze *et al.,* 2005; World Bank, 2005).

Despite their importance to food security in the ASALs, and even though both sorghum and cassava can grow in soils with low fertility, their production potential may be limited by Potassium and Nitrogen deficiency (Janssens, 2001; Shittu *et al.,* 2004; Pholsen and Sornsungnoen, 2004; Mengel, 2001). This may be pronounced in the SSA where soils have inherently low soil fertility. High population growth rate, increased demand for food and resultant unsustainable agricultural production practices that fail to replenish soil nutrients lost from soil during crop production have also induced soil fertility decline. This more often than not is the fundamental biophysical cause of low productivity of most crops in SSA hence undermining efforts to end food insecurity and poverty (Smaling *et al.,* 1997; Stoorvogel and Smaling, 1998; Morris *et al.,* 2007). In order to maximize and sustain high crop yields especially in the continuous cultivation systems, application of both organic and inorganic fertilizers as well as use of high yielding improved crop varieties is imperative (Kydd *et al.,* 2004; Hartemik *et al.*, 2000).

In most cases however, these external inputs are often unavailable or cost prohibitive for the resource poor small-scale farmers. In addition, these farmers are often reluctant to invest in long term soil conservation and improvement initiatives which do not have medium or short term benefits resulting in failure to use or use of suboptimal levels inputs (Cooper *et al.,* 1996; Smestad *et al.,* 2002) especially in environments with higher risks (Mwanga, 2004). Furthermore, ecological and environmental concerns have emerged regarding the indiscriminate use of inorganic fertilizers (Giller and Cadisch, 1995). It is therefore essential that alternative and sustainable soil fertility management options such as Agreoecolgical Intensification of land use are explored to improve crop production and consequently enhance food security.

Agroecological intensification (AEI) which embraces practices such use of legumes either as intercrop or in rotations with other crops, as well as application of organic inputs (e.g. manure and compost) has been suggested as one such alternative which can inprove soil fertility and and ultimately stabilize yields especially in the marginal environments (Altieri *et al.*, 1998; Place *et al.,* 2003). Dual purpose, drought resistant legumes such as Dolichos and pigeon pea when incorporated into cropping system can substitute for inorganic fertilizers as they can improve physical, chemical and biological properties of soils (Rao and Mathuva, 2000; Giller, 2001;

Haque *et al.*, 1995; Cheruiyot *et al.*, 2001). Compost and Farm Yard manure can also be used to improve soil properties and increase the yields of crops (Ouédraogo *et al.*, 2001; Schlecht *et al.*, 2006; Juo and Kang, 1989). Despite their obvious utility to small-scale farmers, the ability of organic resources to supply nutrients to crops has been put in doubt. Some of the reasons advanced include the variable quality of organic resources available to farmers (Mugwira and Murwira, 1997; Vanlauwe *et al.*, 2005a); long periods of immobilization and release of nutrients to the crops (Palm *et al.*, 1997; Vanlauwe *et al.*, 2005b); inherent soil properties such as soil texture which influences losses of nutrients and hence may have a bearing on the availability of nutrients to crops (Bationo *et al.*, 2007; Fofana *et al.*, 2005); variability of cropping systems used and environmental factors (Kang, 1993; Schroth *et al.*, 1995). Consequently, there is a need to understand and improve the efficiency of organic nutrient sources under site specific conditions. There is also insufficient information on the responses of soil and tissue nutrient content to combined effects of different legumes integrated in cassava and sorghum cropping systems with application of organic fertlizers. The current study aimed to evaluate the effects of sorghum and cassava grown in rotation and/or intercropped with dolichos and pigeon pea with application of FYM and compost on soil and plant tissue nutrient concentration.

4.2.2 Materials and methods

4.2.2.1 Site description

Site characteristics is as described in section 3.1

4.2.2.2 Treatments and experimental design

Treatments and experimental design is a describe in section 3.2

4.2.2.3 Agronomic practices

Agronomic practices are as decribed in section 3.3

4.2.2.4 Soil, plant sampling and analysis

Soil samples were collected within the 0.2 m depth using an auger. In the sorghum based cropping systems samples were collected at harvest (after 3 months) while in cassava this was done at 3 months as well as at cassava harvest (11 months). For determining the nutrient status, four sorghum crops were harvested by cutting the stem immediately above ground, and threshed to separate the grains from the panicles. For cassava, two cassava plantswere randomly selected and harvested by digging around the base of individual plants within the net plot area using hand tools and then uprooting the whole plant. Thereafter, the tuber and stem were separated. The grains and tuber were then oven dried at 60^{0}C to a constant weight.

Soil OC was determined by titration (Nelson and Sommers, 1982). Soil and plantnitrogen was determined by the Kjeldahl digestion method followed by distillation (Black, 1965), P by Mehlich 3 Double Acid method (Mehlich *et al.*, 1962) while K was measured by flame photometry.

4.2.3 Results and Discussion

4.2.3.1 Influence of cropping systems and fertilizers inputs on soil Organic carbon

When classified according to Landon (1991), Soil OC values across four seasons ranged from low (0.81) to adequate (2.91) in Katangi in the sorghum based cropping systems. Values in Ikombe lay within a similar range (0.89 and 2.31). In the cassava based cropping systems, soil OC values in Katangi across the four seasons also ranged from low to adequate in the two sites (0.81-2.86 in Katangi and 0.53-2.12 in Ikombe).

Table 13: Soil NPK and OC levels across seasons in sorghum cropping systems

Soil Property	Site	Initial	SR 2010	LR 2011	SR 2011	LR 2012
OC	KATANGI	1.17	1.38^{b}	1.41^{b}	1.24^{c}	2.63^{a}
	IKOMBE	0.74	1.47^{b}	1.51^{b}	0.93^{c}	2.06^{a}
N	KATANGI	0.18	0.10^{a}	0.12^{a}	0.17^{a}	0.18^{a}
	IKOMBE	0.09	0.11^{b}	0.16^{ab}	0.21^{a}	0.19^{a}
P	KATANGI	5.25	30.36^{a}	28.94^{a}	25.11^{b}	29.03^{a}
	IKOMBE	26.25	31.25^{a}	31.3^{a}	31.24^{a}	29.29^{a}
K	KATANGI	0.98	0.99^{b}	1.01^{b}	1.03^{b}	1.61^{a}
	IKOMBE	0.75	1.02^{a}	1.07^{a}	0.86^{b}	0.97^{ab}

Table 14: Soil NPK and OC levels across seasons in cassava cropping systems

Soil Property	Site	Initial	SR 2010	LR 2011	SR 2011	LR 2012
OC	KATANGI	1.17	1.30^{b}	1.31^{b}	1.28^{b}	2.43^{a}
	IKOMBE	0.74	1.35^{a}	1.37^{a}	1.14^{b}	1.19^{b}
N	KATANGI	0.18	0.14^{a}	0.14^{a}	0.16^{a}	0.11^{a}
	IKOMBE	0.09	0.12^{a}	0.13^{a}	0.14^{a}	0.10^{a}
P	KATANGI	5.25	30.75^{ab}	31.24^{a}	29.24^{b}	29.36^{b}
	IKOMBE	26.25	30.88^{b}	32.24^{a}	32.74^{a}	30.40^{b}
K	KATANGI	0.98	0.53^{c}	0.56^{c}	0.69^{b}	1.06^{a}
	IKOMBE	0.75	0.56^{c}	0.61^{bc}	0.66^{b}	1.18^{a}

Generally, soil OC increased significantly compared to initial levels across sites in both sorghum and cassava based cropping systems. The increase continued from SRS of 2010 to the LRS of 2012 although there was a slight decline in SRS 2011 (Table 13 and 14). The increase in Soil OC is attributable to organic input addition as well as incorporation of residues into the plots, which lead to gradual build up of soil OC over time. Ghimire *et al.*, (2012), have also observed a build up of soil OC with organic fertilizer addition and incorporation of residues over time. The slight decline in soil OC during the SRS of 2011 across the treatments at both sites could be attributed to reduced plant productivity occasioned by lower rainfall and high temperatures, which in turn affected the quantity of crop residue returned to the soil. The typically high temperatures experienced in the area also have led to increased decomposition rates. Bates *et al.*, (2006) and Lovett *et al.*, (2006) observed that soil OC is affected by plant productivity and decomposition rates both of which are influenced by changes in rainfall with time and soil moisture.

Soil OC was significantly higher ($P \leq 0.05$) at Katangi compared to Ikombe during the SRS of 2011 and LRS of 2012. This may probably be due to more soil moisture retention by the Katangi soils which had higher clay content (Table 2) which in turn affected decomposition. Weil and Magdoff (2004) and Nichols (1984) opined that inherent soil properties, specifically texture, may influence to large extent soil OC content. They observed that coarse textured soils tend to allow faster decomposition of organic matter due to less water being held within the pores and allow more air circulation. Fine texture soils also provide large amounts of surfaces that chemically bind with organic compounds forming aggregates that protect organic matter from microbial decomposition (Oades, 1995).

Though all the plots had crop residue returned to the soil, plots with additional application of FYM resulted in higher OC across cropping systems compared to compost and control respectively in both sorghum and cassava based cropping systems at both sites (Fig 4 and 5).

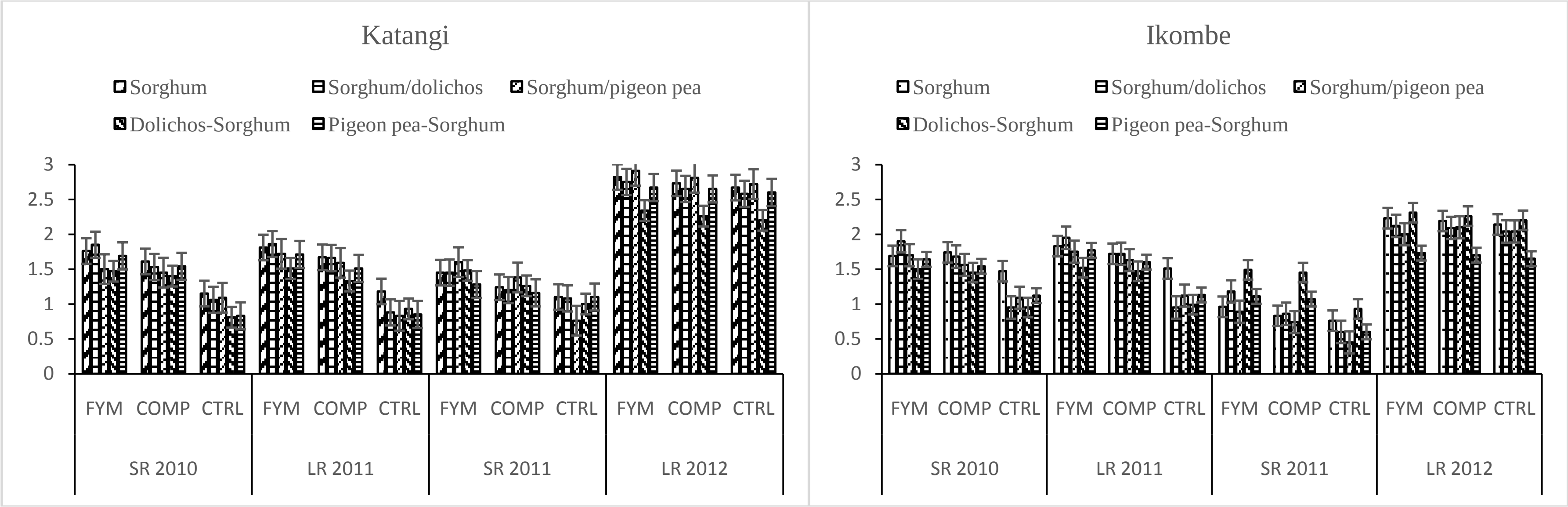

Figure 4: Soil Organic carbon as affected by cropping systems and organic inputs at Katangi and Ikombe in sorghum based cropping systems for four seasons

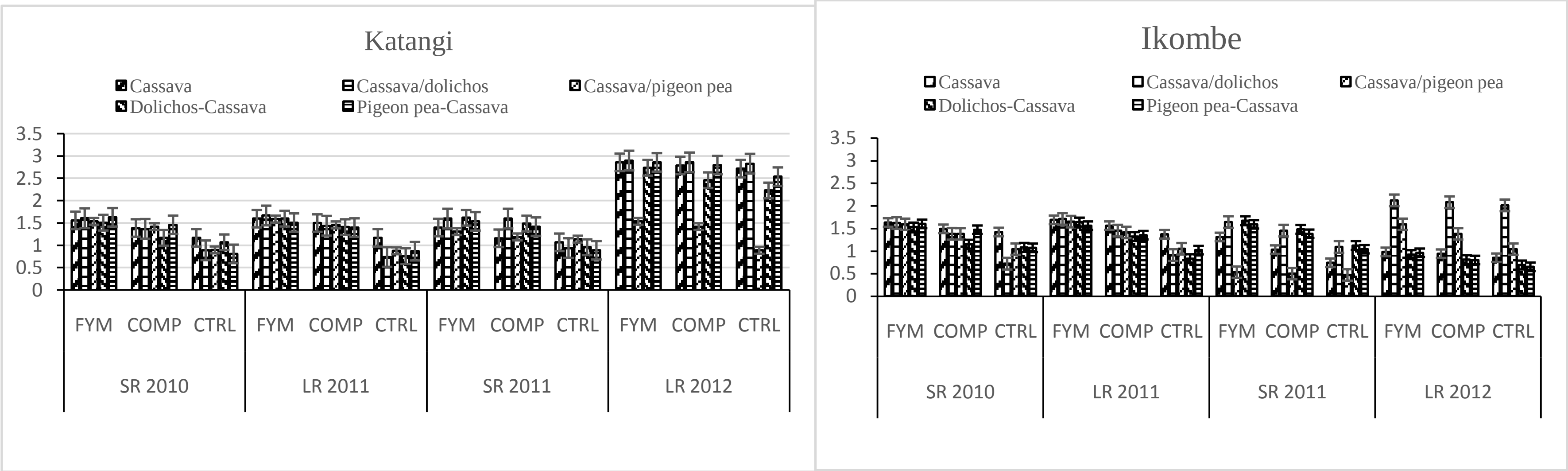

Figure 5: Soil Organic carbon as affected by cropping systems and organic inputs at Katangi and Ikombe in the cassava based cropping systems for four season

High Soil OC under FYM application could be attributed to the direct additional organic matter added through FYM as well as the increase of biomass production stimulated by the addition of FYM. Addition of organic manure has been shown to increase soil OC by Adekoyade and Ogunkonya, (2011) and Ali *et al.,* (2009). Ouédraogo *et al.,* (2001) also observed higher dry matter production under compost compared to non-application of organic fertilizers. Kapkiyai *et al.,* (1999) similarly concluded that return of crop residue to the soil may not be as effective in restocking soil OC compared to addition of manure. More OC in FYM treated plots compared to compost may be attributed to slower release of nutrient over time by the former, as FYM being less decomposed could have had more materials, which are resistant to decomposition which ensured more productivity.

Sorghum/pigeon pea intercrop and pigeon pea-sorghum rotation did not significantly increase the soil OC compared to Monocropping at both sites (Fig 4). Similar results were obtained in the cassava based cropping systems except during the SRS of 2011 (Fig 5). This could be attributed to high levels of decomposition, which could have been further enhanced by oxen-plough tillage in addition to the fact that soil OC could sometimes take a longer time to start building up. Kouyaté *et al.,* (2012) and Myaka *et al.,* (2006) have also observed that legumes integration within cropping systems may not improve soil OC. Tiessen *et al.,* (2001) opined that the soils in the tropics have little stable carbon and cultivation could enhance destabilisation and further losses of Soil OC even when residues are incorporated into soil regularly. Diallo *et al.,* (2007) cited in, Kouyaté *et al.,* (2012) also reported that soil OC can fail to build up under conventional tillage due to losses through erosion. However, since erosion losses were not quantified in the current study, this conclusion could not authoritatively arrived at.

Sorghum/dolichos intercrop yielded significantly ($P \leq 0.05$) higher soil OC compared to sorghum/pigeon pea across organic inputs during the LRS of 2011 at both sites. Cassava/dolichos also yielded significantly ($P \leq 0.05$) higher OC compared to cassava/pigeon pea intercrop during the LRS of 2011, SRS of 2011 and LRS of 2012 at both sites. Higher OC under plots involving dolichos than pigeon pea could be attributed to higher biomass production when sorghum and cassava was intercropped with dolichos. This could have arisen from dolichos offering less competition to the companion crop compared to pigeon pea, hence allowing the companion crop to develop more biomass. The competitiveness of pigeon pea has been documented by Ito *et al*., (1993), noting that pigeon pea when intercropped with sorghum would outcompete sorghum for growth resources hence reducing sorghum yields, while Gichangi *et al.*, (2006) also reported that pigeon pea tended to depress the leaf production of cassava. Dolichos has also been reported to produce a higher amount of biomass compared to other legumes by Mbaga and Friesen, (2003). Cheruiyot *et al.*, (2001) also observed greater increases in biomass production in maize following dolichos compared to other legumes. Sorghum/Dolichos intercrop yielded higher OC compared to Dolichos-Sorghum rotation at both sites during SRS of 2010 at both sites, LRS of 2012 at Katangi and LRS of 2011 at Ikombe. Cassava/Dolichos intercrop also had higher soil OC during LRS of 2012 at both sites. Additionally, in Katangi cassava/dolichos intercrop was higher than rotation during SRS of 2010 and SRS of 2011 while in Ikombe the same was observed during LRS of 2011. This may have been due to the high amount of biomass produced under intercropping leading to more residues available for decomposition. Ngome *et al.*, (2012), though working with pinto peanut (*Arachis pintoi*) legume, showed that its use as permanent cover in maize plots could increase soil C attributing this to above and below ground biomass, residues of the companion maize as well as weed residues.

4.2.3.2 Influence of cropping systems and organic inputs on N content in soil and grain/tuber

Influence of cropping systems and organic inputs on Soil N: According to the Landon (1991) soil nutrient classification, soil N (%) in sorghum based cropping systems at both sites ranged from low to moderate (0.13-0.37 in Katangi and 0.04-0.21 in Ikombe) (Table 15 and 16). In both cassava and sorghum based cropping systems, Soil N levels declined relative to the pre-experiment levels at Katangi when averaged across the treatments (Table 13 and 14). Closer observation revealed that the lower average N values in the four seasons at Katangi mainly were due to control experiments which had no organic fertilizers added (Table 15 and 17).

Table 15: Soil and grain N as affected by cropping systems and organic inputs in sorghum based cropping systems at Katangi

	Soil N								Sorghum Grain N							
	SR 2010			mean	LR 2011			mean	SR 2010			mean	LR 2011			mean
Crop	FYM	COMP	CTRL		FYM	COMP	CTRL		FYM	COMP	CTRL		FYM	COMP	CTRL	
Sorghum	0.18	0.18	0.16	0.18^{bc}	0.25^{a}	0.23^{ab}	0.15^{g}		3.18	3.16	3.13		3.23	3.16	3.15	
Sorghum/dolichos	0.21	0.19	0.17	0.19^{a}	0.24^{a}	0.21^{bcd}	0.17^{efg}		2.82	2.82	2.78		2.91	2.98	2.93	
Sorghum/pigeon pea	0.21	0.19	0.15	0.17^{c}	0.22^{bc}	0.20^{cd}	0.16^{fg}		2.70	2.69	2.70		2.65	2.71	2.67	
Dolichos-Sorghum	0.21	0.19	0.18	0.17^{c}	0.23^{ab}	0.20^{cd}	0.17^{efg}						2.44	2.41	2.38	
Pigeon pea-Sorghum	0.18	0.17	0.17	0.19^{ab}	0.21^{bc}	0.19^{de}	0.17^{efg}						3.94	3.88	3.79	
mean	0.20^{a}	0.18^{b}	0.17^{c}						2.90^{a}	2.89^{a}	2.87^{b}					
LSD $^{0.05}$	Cropping systems (C)		0.01													
	Organic inputs (OI)		0.012								0.019					
	(CxOI)						0.024									
	CV%		15.3				13.3				27				26.4	
	SR 2011				LR 2012				SR 2011				LR 2012			
Crop	FYM	COMP	CTRL	mean	FYM	COMP	CTRL	mean	FYM	COMP	CTRL	mean	FYM	COMP	CTRL	mean
Sorghum	0.22^{de}	0.17^{e}	0.14^{e}		0.20	0.20	0.18	0.19^{b}	1.52^{a}	1.52^{a}	1.48^{a}		1.64^{bc}	1.59^{c}	1.53^{c}	
Sorghum/dolichos	0.27^{a}	0.21^{cd}	0.17^{e}		0.15	0.13	0.14	0.22^{a}	1.31^{b}	1.25^{bc}	1.22^{bcd}		1.36^{d}	1.32^{d}	1.12^{e}	
Sorghum/pigeon pea	0.37^{b}	0.19^{de}	0.17^{e}		0.21	0.19	0.18	0.16^{c}	1.52^{a}	1.18^{cd}	1.11^{d}		1.58^{c}	1.13^{e}	0.94^{f}	
Dolichos-Sorghum	0.25^{de}	0.20^{de}	0.17^{e}		0.25	0.23	0.18	0.19^{b}					1.86^{a}	1.76^{ab}	1.64^{bc}	
Pigeon pea-Sorghum	0.23^{de}	0.19^{de}	0.16^{e}		0.18	0.16	0.15	0.14^{d}					1.36^{d}	1.34^{d}	1.30^{d}	
mean					0.20^{a}	0.18^{b}	0.17^{c}									
LSD $^{0.05}$	Cropping systems (C)						0.016									
	Organic inputs (OI)						0.013									
	(CxOI)		0.033								0.124				0.131	
	CV%		31.9				18.9				11.1				9.4	

Notes: Soil N: SR 2010 and LR 201-main effects of CS and OI significant but CS*OI not significant; LR 2011-CS*OI significant; SR 2011-CS*OI significant.

Grain N: SR 2010-only OI significant; SR 2011 and LR 2011-CS*OI significant; LR 2011-treatment effects not significant

Table 16: Soil and grain N as affected by cropping systems and organic inputs in sorghum cropping systems at Ikombe

	Soil N								Grain N							
	SR 2010				LR 2011				SR 2010				LR 2011			
Crop	FYM	COMP	CTRL	mean	FYM	COMP	CTRL	mean	FYM	COMP	CTRL	mean	FYM	COMP	CTRL	mean
Sorghum	0.13^{ef}	0.10^{hi}	0.11^{gh}		0.16	0.12	0.09	0.12^{bc}	2.56	2.49	2.46		2.62^{ab}	2.51^{ab}	2.48^{ab}	
Sorghum/dolichos	0.15^{cd}	0.14^{de}	0.12^{fg}		0.21	0.17	0.12	0.17^{a}	2.40	2.36	2.33		2.43^{ab}	2.43^{ab}	2.35^{ab}	
Sorghum/pigeon pea	0.14^{de}	0.10^{hi}	0.10^{hi}		0.18	0.13	0.10	0.14^{b}	1.90	1.86	1.82		1.93^{ab}	1.89^{ab}	1.84^{ab}	
Dolichos-Sorghum	$0.11g^{h}$	0.10^{hi}	0.09^{i}		0.12	0.12	0.09	0.11^{c}					2.29^{ab}	2.26^{ab}	2.21^{ab}	
Pigeon pea-Sorghum	0.20^{a}	0.17^{b}	0.11^{gh}		0.19	0.12	0.10	0.14^{b}					3.68^{a}	3.62^{a}	3.59^{a}	
mean					0.17^{a}	0.13^{b}	0.10^{c}		2.29^{a}	2.24^{b}	2.21^{c}					
LSD $^{0.05}$	Cropping systems (C)						0.014									
	Organic inputs (OI)						0.021				0.015					
	(CxOI)		0.019												1.471	
	CV%		23.9				22.5				44.2				38.8	
	SR 2011				LR 2012				SR 2011				LR 2012			
Crop	FYM	COMP	CTRL	mean	FYM	COMP	CTRL	mean	FYM	COMP	CTRL	mean	FYM	COMP	CTRL	mean
Sorghum	0.11	0.08	0.05		0.10	0.07	0.04	0.07^{b}	2.04^{a}	1.99^{abc}	1.94^{bc}		2.10	2.00	1.96	2.02^{a}
Sorghum/dolichos	0.16	0.13	0.10		0.12	0.11	0.10	0.11^{a}	1.30^{c}	1.26^{c}	1.24^{c}		1.36	1.33	1.16	1.28^{b}
Sorghum/pigeon pea	0.13	0.13	0.12		0.15	0.13	0.13	0.14^{a}	2.07^{a}	2.02^{ab}	1.90^{c}		2.12	2.04	1.91	2.02^{a}
Dolichos-Sorghum	0.13	0.10	0.08		0.15	0.14	0.11	0.14^{a}					2.13	2.00	1.94	2.02^{a}
Pigeon pea-Sorghum	0.12	0.17	0.14		0.07	0.06	0.06	0.06^{b}					1.19	1.16	1.12	1.16^{c}
mean	0.13^{a}	0.12^{a}	0.10^{b}		0.12^{a}	0.10^{b}	0.09^{b}						1.78^{a}	1.71^{b}	1.62^{c}	
LSD $^{0.05}$	Cropping systems (C)						0.031								0.082	
	Organic inputs (OI)		0.025				0.014								0.034	
	(CxOI)										0.096					
	CV%		48.3				83.2				5.4				4.9	

Notes: Soil N: SR 2010-CS*OI significant; LR 2011 and LR 2012-CS*OI significant; SR 2011-only main effects of OI significant.

Grain N: SR 2010-only OI significant; SR 2011 and LR 2011-CS*OI significant; LR 2011-main effects of CS and OI significant

Table 17: Soil and tuber N as affected by cropping systems and organic inputs in cassava based cropping systems at Katangi

	Soil N								Tuber N			
	SR 2010				LR 2011				SR 2010-LR 2011			
Crop	FYM	COMP	CTRL	mean	FYM	COMP	CTRL	mean	FYM	COMP	CTRL	mean
Cassava	0.13	0.07	0.07	0.09^{c}	0.12	0.07	0.16	0.12^{b}	1.35	1.34	1.25	1.31^{b}
Cassava/dolichos	0.10	0.13	0.10	0.11^{b}	0.11	0.08	0.13	0.11^{b}	1.22	1.17	1.11	1.17^{c}
Cassava/pigeon pea	0.11	0.12	0.09	0.11^{b}	0.14	0.09	0.13	0.12^{b}	1.53	1.48	1.41	1.47^{a}
Dolichos-Cassava	0.16	0.13	0.13	0.14^{a}	0.15	0.11	0.17	0.14^{a}	1.51	1.46	1.42	1.46^{a}
Pigeon pea-Cassava	0.14	0.11	0.09	0.11^{b}	0.11	0.07	0.09	0.09^{c}	1.59	1.55	1.5	1.55^{a}
mean	0.13^{a}	0.11^{a}	0.09^{b}		0.14^{a}	0.13^{a}	0.08^{b}		1.44^{a}	1.40^{b}	1.34^{c}	
LSD $^{0.05}$	Cropping systems (C)			0.015				0.016				0.085
	Organic inputs (OI)			0.017				0.014				0.024
	(C*OI)											
	CV%			20.5				24.2				12.8

	SR 2011				LR 2012				SR 2011-LR 2012			
Crop	FYM	COMP	CTRL	mean	FYM	COMP	CTRL	mean	FYM	COMP	CTRL	mean
Cassava	0.12	0.18	0.15		0.14	0.12	0.10		1.43^{b}	1.38^{bc}	1.31^{cd}	
Cassava/dolichos	0.14	0.16	0.14		0.12	0.11	0.09		1.26^{d}	1.26^{de}	1.22^{e}	
Cassava/pigeon pea	0.16	0.13	0.11		0.11	0.12	0.09		1.71^{a}	1.68^{a}	1.65^{a}	
Dolichos-Cassava	0.16	0.19	0.16		0.13	0.10	0.07					
Pigeon pea-Cassava	0.11	0.12	0.09		0.15	0.13	0.09					
mean					0.13^{a}	0.12^{a}	0.09^{b}					
LSD $^{0.05}$	Cropping systems (C)											
	Organic inputs (OI)							0.019				
	(C*OI)											0.084
	CV%			26.1				24.7				8.1

Notes: Soil N: SR 2010and LR 2011- main effects of C and OI significant; SR 2011-treatment effects not significant; LR 2012-only main effects of C significant

Tuber N: SR 2010-LR 2011-main effects of C and OI; SR 2011- LR 2011-C*OI significant

Table 18: Soil and tuber N as affected by cropping systems and organic inputs in cassava based cropping systems at Ikombe

	Soil N								Tuber N			
	SR 2010			mean	LR 2011			mean	SR 2010-LR 2011			mean
Crop	FYM	COMP	CTRL		FYM	COMP	CTRL		FYM	COMP	CTRL	
Cassava	0.04	0.04	0.03	0.03^{c}	0.07	0.05	0.02	0.05^{b}	1.46	1.43	1.41	1.43^{b}
Cassava/dolichos	0.08	0.04	0.03	0.05^{bc}	0.11	0.07	0.04	0.08^{a}	0.97	0.92	0.86	0.92^{c}
Cassava/pigeon pea	0.08	0.04	0.06	0.06^{b}	0.11	0.07	0.06	0.08^{a}	1.58	1.52	1.46	1.52^{a}
Dolichos-Cassava	0.10	0.08	0.07	0.08^{a}	0.12	0.10	0.05	0.09^{a}	1.55	1.51	1.43	1.50^{ab}
Pigeon pea-Cassava	0.08	0.05	0.07	0.06^{b}	0.05	0.03	0.03	0.04^{b}	1.60	1.53	1.52	1.55^{a}
mean	0.07^{a}	0.05^{b}	0.05^{b}		0.09^{a}	0.07^{b}	0.04^{c}		1.43^{a}	1.38^{b}	1.34^{c}	
LSD $^{0.05}$	Cropping systems (C)			0.017				0.017				0.079
	Organic inputs (OI)			0.016				0.017				0.036
	(C*OI)											
	CV%			49.7				35.3				4.7
	SR 2011				LR 2012				SR 2011-LR 2012			mean
Crop	FYM	COMP	CTRL		FYM	COMP	CTRL		FYM	COMP	CTRL	
Cassava	0.08	0.07	0.04		0.04	0.04	0.02	0.04^{b}	1.53	1.47	1.44	1.48^{a}
Cassava/dolichos	0.11	0.09	0.09		0.08	0.05	0.04	0.06^{a}	1.01	0.97	0.94	0.97^{b}
Cassava/pigeon pea	0.06	0.04	0.03		0.08	0.04	0.05	0.06^{a}	1.65	1.62	1.6	1.62^{a}
Dolichos-Cassava	0.09	0.09	0.10		0.03	0.03	0.02	0.03^{b}				
Pigeon pea-Cassava	0.08	0.04	0.05		0.03	0.02	0.01	0.02^{b}				
mean	0.09^{a}	0.07^{b}	0.06^{b}		0.05^{a}	0.04^{b}	0.03^{b}		1.40^{a}	1.35^{b}	1.33^{b}	
LSD $^{0.05}$	Cropping systems (C)							0.018				0.139
	Organic inputs (OI)			0.012				0.012				0.034
	(C*OI)											
	CV%			46.4				67.1				4.6

Notes: Soil N: SR 2010, LR 2012and LR 2011-main effects of C and OI significant; SR 2011-only main effects of OI significant

Tuber N: SR 2010-LR 2011 and SR 2011-LR 2012-C*OI significant

Even at Ikombe where soil N values increased compared to the initial values, it was observed that the control experiment still had lower N values compared to the FYM and compost (Table 16 and 17). This could be attributed to direct addition of N to the soil as the FYM and compost mineralized as well as the added crop residues. Higher soil organic matter due to addition of FYM and compost has been previously been proven to closely correlate with the amount of N in the soil (Kapkiyai *et al.,* 1999). FYM treated plots had significantly ($P \leq 0.05$) higher N content compared to compost across the cropping systems. This may be attributed to compost undergoing faster decomposition and hence N release to the soil and therefore its effects may not be long lasting. It has also been observed that some ammonia-N may be lost through volatization in the process of composting hence the N content may be much lower than FYM hindering its ability to supply enough N (Rosen and Bierman, 2014). Adekayode and Ogunkoya (2011) observed higher N content in plots treated with organic fertilizer attributing this to direct input of N and ability of manure to make N available for a long time due to slower release of N from the high residual pool.

Though not significant ($P \leq 0.05$), soil N was highest during the SRS of 2011 (Table 13 and 14). This was contrary to expectation that low rainfall during this period would lead to low biomass production and nitrogen fixation hence low soil N. This would possibly be because the higher temperatures enhanced decomposition, which led to rapid N release. Because of limited rainfall, then loss of mineralized N through leaching and erosion reduced. It has previously been observed by Gachimbi *et al.,* (2005) that most of the losses of N from the soil could mainly be as a result of factors which are difficult to control such as erosion, leaching and volatization.

Only sorghum/dolichos intercrop consistently produced significantly ($P \leq 0.05$), higher soil N compared to monocropping at both sites across seasons (Table 15 and 16). Higher N in dolichos plots compared to monocrop could be attributed to nitrogen fixation by the legume component. Higher N under sorghum/dolichos compared to sorghum/pigeon pea could be attributed to higher fixation of nitrogen by dolichos compared to pigeon pea as well as superior litter quality. Ayoub (1986) also observed higher rates of nitrogen release through biological fixing and decomposition under dolichos compared to pigeon pea. Higher soil N under intercropping with dolichos compared to rotation could be attributed to better nitrogen fixation that may occur under intercropping compared to when monocropping legumes occurs as well as the higher amount of residue available for decomposition. It has also been reported that intercropping may result in increased amount of nitrogen fixed by legumes as the companion non-fixing crop utilizes excess nitrates in the root zone which would otherwise retard N fixation if they accumulate (Li *et al.*, 2003). Sorghum/pigeon pea intercrop did not produce significantly higher soil N compared to sorghum monocrop in SRS of 2010, LRS of 2011, SRS of 2011and LRS of 2012 at Katangi as well as SRS of 2012 and LRS of 2011 at Ikombe. This could be attributed to competition for N between sorghum and pigeon pea component. IITA (1990) reported faster nutrient uptake and hence competition under intercropping systems. Another explanation is that, apart from the poor litter quality of pigeon pea, the deep roots of pigeon pea may have fixed N beyond the sampled 15 cm depth hence underestimating its effects. Myaka *et al.*, (2006) found that intercropping with pigeon pea may not show any significant impact on soil N. He attributed this to among other factors, the deep rooting nature of pigeon pea leading to N occurring below the 0.15 m depth and impact of N from pigeon pea occurring in the resistant pool and therefore the effects investigated may more likely be due to the previous seasons. This conclusion is reinforced by the fact that even under rotation, pigeon pea field had lower soil N than sorghum monocrop in most of the seasons.

In the cassava based cropping systems N was low (0.07-0.19) in Katangi and (0.02-0.1) in Ikombe (Table 17 and 18). The lower levels of N in the cassava based cropping systems may have been caused by export of N through removal of tubers and above ground biomass. Pypers *et al.*, (2011) had also observed high nutrient mining under cassava production. Similar to sorghum cropping systems, soil N levels reduced relative to initial values with the most reduction in the control experiment probably due to absence of direct input of N from the mineralised FYM and compost as well as low OM content. FYM also had higher N levels compared to compost. Dolichos-cassava rotation yielded significantly ($P \leq 0.05$) higher soil N values during the SRS of 2010 and LRS of 2011 at both sites compared to intercropping and monocropping. Lower soil N under intercropping could be as a result of higher levels of competition for nutrients under intercopping systems (IITA, 1990). Rotation with dolichos yielded higher soil N comnpared to monocropping mainly due to symbiotic nitrogen fixation by legume. The ability of legumes to fix N symbiotically has been previously observed by Adjei- Nsiah, (2012) and Baldwin and Creamer, (2014).

Effect of cropping systems and organic inputs on N status of tuber and sorghum grain

Tuber and sorghum N content was significantly ($P \leq 0.05$) higher under FYM application compared to compost and control across the cropping systems at both sites (Table 15, 16, 17 and 18). Higher N content in under application of organic fertilizers could be due to soil physical properties brought about by organic manure, which allowed increased uptake of N by crops. Organic inputs have been proven to improve physical characteristics of the soil which enhances uptake of nutrients (Elsheikh and Alzidany, 1997) as well as reducing losses (Buerkert *et al.*, 2000). Lehrsch and Kincaid (2007) also observed a 15% increase in N uptake of crops with addition of compost or FYM regardless of the quantities of these amendments. Higher grain and tuber N under FYM compared to compost could have been due to the slower but much steadier mineralization of N from the more resistant material in FYM compared to compost.

During the SRS of 2011 at both sites, monocropping yielded higher sorghum grain N content compared to intercropping with dolichos regardless of the organic input used (Table 15 and 16). This can be explained in terms of competition between sorghum and dolichos for Nitrogen. As reported by Ahlawat *et al.*, (1985) efficiency of utilization of resources in intercrops depends to a large degree on the rooting behavior and especially depth of the crops. Dolichos roots could therefore have offered more competition to sorghum crops since their rooting depths are more or less similar. No significant differences ($P \leq 0.05$) in grain N were observed between intercropping with pigeon pea and sorghum monocrop under either compost or FYM mainly due to complementarity in root zone exploration. Myaka *et al.*, (2006) also reported no significant differences in grain N content between maize monocrop and maize/pigeon pea intercrop. Pigeon pea is known to be deep-rooted and can have the added benefit of bring up N lower down the soil profile hence making it accessible to companion crops (Kumar Rao *et al.*, 1983; Skerman *et al.*, 1988) which could have reduced the effects of competition on the sorghum crop. During the LRS of 2012, at both sites, rotation with dolichos resulted in higher grain N compared to monocrop and rotation with pigeon pea respectively across organic inputs. For example, at Katangi, sorghum-dolichos rotation+FYM (1.86) resulted in significantly higher grain N compared to sorghum monocrop+FYM (1.64) which was however lower than the pigeon pea-sorghum rotation+FYM (1.36) (Table 15). Higher grain N under dolichos rotation could be attributed to more N fixed in the preceding season as well as the N released due to decomposition of residues from legumes (Rao and Mathuva, 2000). Lower Grain N content in pigeon pea-sorghum rotation was probably because N occurring was less available for uptake by sorghum crop. Pigeon pea residues have been found to be of poor quality in terms of N mineralization. In addition, pigeon pea fixes part of N below the root depth of sorghum (Myaka *et al.,* 2006). Giller *et al.* (1997) also observed that residual effects of grain legumes rarely meet the N requirements of subsequent cereal crop especially in favourable seasons since most of the biologically fixed N is translocated to the grain.

Tuber N content was significantly higher under cassava/pigeon pea intercrop compared to monocropping during the SRS 2010-LRS2011 and SRS 2011-LRS 2012 at both sites (Table 17 and 18). This could be attributed to N fixation by legume component which increased availability of N. Further, tuber N was significantly higher under sorghum/pigeon pea intercrop compared to cassava/dolichos intercrop despite the fact that soil N was higher in the latter. This observation could probably due to complementarity in root zone exploration between pigeon pea and cassava which reduced competition for N between the two crops. Apart from being deep rooted, pigeon pea has also been shown to recycle nutrients from deep down the soil profile (Kumar Rao *et al.,* 1983; Skerman *et al.,* 1988). These observations could also appear to confirm the assertion that the benefits of N due to use of pigeon pea could occur below the sampled depth and hence the cassava tuber was able to utilize it as they grew beyond this depth. Intercropping cassava with dolichos resulted in lower tuber N compared to monocropping. This could be attributed to competition for N between the two crops. Though not significantly different to intercropping with pigeon pea, rotation of cassva with either legume produced significantly higher tuber N conetnet compared to monocropping. This could be attributed to the positive effects of nitrogen fixation by the legumes (Giller, 2001) as well as their N cycling abilities of the legume roots (Lelei *et al.,* 2009; Adjei-Nsiah (2012) which made it available for the subsequent crop.

The results showed a negative correlation between soil N and grain N across both sites (r=-0.06 in Katangi and r=-0.06 in Ikombe). Tuber N and soil N also showed a weak correlation (r=-0.02 and r=-0.06). This observation could be because there might be other factors other than the imposed treatments that could be influencing the content of N in the tuber and grains. Bationo *et al.,* 2007 and Fofana *et al.,* 2005 have also observed soil related factors such as texture having a bearing on nutrient uptake in crops. Environmental factors could also play a part in nutrient uptake (Kang, 1993; Schroth *et al.*, 1995) as well as different nutrient partitioning between the various crop parts.

4.2.3.3 Influence of cropping systems and organic inputs on soil and grain/tuber P content

Influence of cropping systems and organic inputs on Soil P: Soil P values increase significantly ($P \leq 0.05$) in comparison to the initial values at the beginning of the experiment during the SRS of 2010 and LRS of 2011 across all cropping systems (Table 13 and 14). This could be attributed to direct input of organic fertilizers, as well as the decomposition of organic residues that were ploughed into the soil. It has previously been shown that decomposing crop residue can release organic acids, which may increase the availability of bound P hence increasing it content in the soil (Zsolnay and Gorlitz, 1994). There was however a significant decline in soil P at Katangi during the SRS of 2011 in the sorghum based cropping systems (Table 13). In the cassava based cropping systems, a significant decline in soil P also occurred across cropping systems in the LRS of 2012 at both sites and in the SRS of 2011 at Katangi (Table 14). Decline in soil P could be attributed to the lower biomass productivity due to reduced amount of rainfall which ultimately affcetd the amount of residues available for decomposition. Significantly ($P \leq 0.05$) higher soil N levels were observed with FYM application compared to compost and control experiment respectively across all cropping systems and seasons. Higher levels of soil P under FYM and compost could be as a result of direct input of P into the soil through decomposition of the organic fertilizers. It has been previously observed by Eghball and Power, (1999) that application of FYM and compost could improve the P status of soil. Further increases in soil P could have been caused by mineralization of high amounts of crop residues that had been returned to the soil compared to the control. Higher soil P under FYM compared to compost could be attributed to the slower decomposition rates and slower release of P over time as well as decomposition of higher amounts of crop residue that were produced with FYM application.

Soil P levels at Katangi in sorghum based cropping systems ranged from low (19.24 ppm) to moderate (43.67 ppm) (Table 15). In Ikombe, P levels were all moderate ranging from 20.52 ppm to 43.65 ppm (Table 16).

Table 19: Soil and sorghum grain P (ppm) as affected by cropping systems and organic inputs in sorghum based cropping systems at Katangi

	Soil P								Grain P							
	SR 2010				LR 2011				SR 2010				LR 2011			
Crop	FYM	COMP	CTRL	mean	FYM	COMP	CTRL	mean	FYM	COMP	CTRL	mean	FYM	COMP	CTRL	mean
Sorghum	27.31	25.15	25.73	31.80^{b}	34.03^{b}	31.64^{c}	29.44^{e}		892.15	813.18	820.77		776.83	746.59	697	
Sorghum/dolichos	28.54	26.65	23.11	41.70^{a}	37.04^{a}	34.23^{b}	31.05^{c}		923.49	820.54	838.05		797.84	723.74	739.82	
Sorghum/pigeon pea	33.93	32.04	29.43	26.16 ^{c}	28.81^{e}	26.72^{g}	23.14^{j}		1049.37	986.49	927.10		910.96	877.14	801.9	
Dolichos-Sorghum	43.67	41.82	39.60	26.07^{c}	27.35^{fg}	26.87^{g}	25.72^{hi}						1030.11	964.28	853.54	
Pigeon pea-Sorghum	27.06	26.59	24.82	26.10^{c}	29.50^{de}	25.21^{i}	23.32^{j}						1071.13	950.13	869.88	
mean	32.10^{a}	30.45^{b}	28.54^{c}						955.00^{a}	873.40^{b}	862.00^{b}		917.40^{a}	852.40^{b}	792.40^{c}	
LSD $^{0.05}$	Cropping systems (C)		0.611													
	Organic inputs (OI)		0.89								315.513				32.801	
	(C*OI)						0.83									
	CV%		6.6				16.4				43.8				30.7	

	SR 2011				LR 2012				SR 2011				LR 2012			
Crop	FYM	COMP	CTRL	mean	FYM	COMP	CTRL		FYM	COMP	CTRL	mean	FYM	COMP	CTRL	mean
Sorghum	34.77^{ab}	32.01^{bc}	29.84^{cd}		31.60	28.64	27.34	29.19^{b}	1025.42	959.64	862.69		1084.48^{bcd}	1007.36^{cdef}	941.09^{ef}	
Sorghum/dolichos	23.18^{ef}	20.19^{fg}	16.62^{g}		37.28	34.86	32.15	34.76^{a}	1112.61	1051.02	886.90		1281.69^{a}	1053.40^{cde}	905.70^{f}	
Sorghum/pigeon pea	26.05^{de}	37.07^{a}	32.37^{bc}		32.00	29.69	27.94	29.88^{b}	1207.46	1018.47	943.18		1282.21^{a}	912.90^{f}	747.72^{g}	
Dolichos-Sorghum	25.84^{de}	23.09^{ef}	18.99^{fg}		20.83	20.09	19.24	20.06^{c}					1190.03^{ab}	1030.33^{cde}	980.59^{def}	
Pigeon pea-Sorghum	21.76^{ef}	18.79^{fg}	16.08^{g}		33.59	30.78	29.48	31.28^{b}					1103.39^{bc}	1038.88^{cde}	977.70^{def}	
mean					31.06^{c}	28.81^{b}	27.23^{c}		1115^{a}	1010^{b}	898^{c}					
LSD $^{0.05}$	Cropping systems (C)						2.09									
	Organic inputs (OI)						0.92				85.435					
	(C*OI)		4.694												112.48	
	CV%		22.9				8.1				8.5				9.4	

Notes: Soil P: LR 2011, SR 2011 and LR 2012- C*OI significant; SR 2010 -main effects of C and OI significant

Grain P: SR 2010, LR 2011 and SR 2011-only main effects of OI significant; LR 2012- C*OI significant

Table 20: Soil and grain P (ppm) as affected by cropping systems and organic inputs in sorghum based cropping systems at Ikombe

	Soil P								Grain P							
	SR 2010				LR 2011				SR 2010				LR 2011			
Crop	FYM	COMP	CTRL	mean	FYM	COMP	CTRL	mean	FYM	COMP	CTRL	mean	FYM	COMP	CTRL	mean
Sorghum	34.70^{c}	35.04^{c}	31.23^{d}		27.77	27.36	26.76	33.41^{b}	1027.48	975.89	947.13		1002.67	929.37	860.18	
Sorghum/dolichos	43.65^{a}	41.73^{b}	42.32^{b}		27.83	27.53	25.31	42.44^{a}	1139.79	1070.34	1029.89		989.6	927.35	881.74	
Sorghum/pigeon pea	27.76^{e}	27.32^{ef}	25.19^{gh}		34.91	34.09	31.22	26.50^{d}	1063.57	995.76	915.07		965.6	899.24	900.2	
Dolichos-Sorghum	27.75^{e}	27.37^{ef}	26.71^{ef}		43.69	41.81	41.81	27.29^{c}					1015.53	998.65	964.5	
Pigeon pea-Sorghum	27.50^{ef}	26.31^{fg}	24.19^{h}		27.71	26.6	25.18	26.89^{dc}					1077.15	1036.65	1020.96	
mean					32.38^{a}	31.48^{b}	30.06^{c}		1077^{a}	1014^{b}	964^{a}		1010.10^{a}	958.20^{b}	925.50^{c}	
LSD $^{0.05}$	Cropping systems (C)						0.526									
	Organic inputs (OI)						0.59				22.804				19.674	
	(C*OI)		1.319													
	CV%		3.9				3.5				8.5				9.2	
	SR 2011				LR 2012				SR 2011				LR 2012			
Crop	FYM	COMP	CTRL	mean	FYM	COMP	CTRL	mean	FYM	COMP	CTRL	mean	FYM	COMP	CTRL	mean
Sorghum	35.38^{c}	34.31^{cd}	31.39^{f}		24.29	22.69	21.58	32.13^{a}	1119.80^{a}	993.370^{bc}	879.83^{d}		1161.75	1082.3	927.21	
Sorghum/dolichos	39.37^{a}	34.63^{cd}	31.74^{ef}		31.11	29.97	28.06	30.79^{a}	1070.28^{ab}	991.67^{bc}	912.87^{cd}		1101.97	1013.02	926.34	
Sorghum/pigeon pea	40.23^{a}	37.08^{b}	33.26^{d}		35.77	31.65	28.98	30.97^{a}	1042.70^{ab}	927.53^{cd}	948.10^{c}		1186.17	1033.8	949.57	
Dolichos-Sorghum	27.73^{gh}	27.34^{h}	26.70^{h}		33.05	30.84	28.48	22.85^{b}					1162.43	979.94	924.87	
Pigeon pea-Sorghum	26.39^{h}	22.51^{i}	20.52^{j}		33.97	30.68	28.25	29.71^{a}					984.01	940.35	933.07	
mean					31.64^{a}	29.17^{b}	27.07^{c}						1119^{c}	1010^{b}	932^{c}	
LSD $^{0.05}$	Cropping systems (C)						3.091									
	Organic inputs (OI)						0.816								65.14	
	(C*OI)		1.467								88.51					
	CV%		5.4				9				14.1				13.9	

Notes: Soil P: SR 2010 and LR 2012-C*OI significant; LR 2011 and SR 2011 main effects of C and OI significant

Grain P: SR 2010, LR 2011 and LR 2012-only main effects of OI significant; LR 2011- C*OI significant

Monocropping sorghum led to significantly ($P \leq 0.05$) higher soil P compared to sorghum/pigeon pea intercrop, and rotation with either pigeon pea or dolichos during the SRS of 2010 at both sites (Table 19 and 20). Similar results were observed during the LRS of 2011 and SRS of 2011 at both sites. Higher P in sorghum monocrop compared to sorghum/pigeon pea intercrop, pigeon pea-sorghum rotation and dolichos-sorghum rotation could be due to export of P to the legumes grains. Kouyaté *et al.*, (2012) observed higher soil P under monocropped sorghum compared to rotation with legumes attributing this to export of P to grains. They further noted that P losses from soil increase with increasing grain yields due to most of the P being transported to the grain. Involvement of legumes could also have resulted in less soil P due to higher uptake of P by legume crops, which is essential in BNF and root development (Cassman *et al.,* 1981). Furthermore, it has been demonstrated that legumes can increase uptake of P for the companion crop when intercropped or rotated (Li *et al.,* 2004; Nuruzzaman *et al.,* 2005). Intercropping sorghum with dolichos however resulted in significantly ($P \leq 0.05$) higher soil P compared to either monocropping during the SRS of 2010 and LRS of 2012 at both sites and during the LRS 2012 at Katangi only. This was probably due to the ability of legumes to solubilize insoluble P. As the processes of nitrogen fixation progresses, excess cations are taken up by legume roots over anions releasing protons (Lui *et al.,* 1989). Proton release leads to dissolution of insoluble P causing an increase in concentration of soil P in the root zone (Hinsinger, 2001). Higher P under legumes has also been reported by Bagayoko *et al.,* (2000), Rusinamhodzi, (2006) and Li *et al.*, (2008) attributing this to mobilization of the sparingly soluble P by legumes exudates. Addition of P through decomposition of residues could also be another avenue through which the P levels increased. Higher soil P when dolichos was uses compared to pigeon pea may be attributed to higher biomass production under dolichos compared to pigeon pea hence more nutrient release upon decomposition. Better litter quality of dolichos may also have been contributing factor to the enhanced levels of P. Higher rates of nutrient release under dolichos compared to pigeon pea have been observed by Ayoub (1986) who attributed this to better mineralization.

In cassava based cropping systems, levels of P were moderate at Ikombe (21.55ppm to 39.61ppm) (Table 21) while at Katangi, they ranged from low (15.77ppm) to moderate (38.78ppm) (Table 22) (Landon 1991).

Table 21: Soil and tuber P as affected by cropping systems and organic inputs in cassava based cropping systems at Katangi

	Soil P								Tuber P			
	SR 2010				LR 2011				SR 2010-LR 2011			
Crop	FYM	COMP	CTRL	mean	FYM	COMP	CTRL	mean	FYM	COMP	CTRL	mean
Cassava	26.26	23.83	20.72	23.60^{e}	25.89	24.36	20.75	23.67^{d}	625.36^{hij}	604.95^{ijk}	571.82^{jk}	
Cassava/dolichos	38.80	38.17	33.98	36.98^{a}	38.78	37.2	32.34	36.11^{a}	1139.80^{a}	1047.22^{b}	930.69^{c}	
Cassava/pigeon pea	32.71	31.72	30.81	31.75^{c}	32.78	31.77	30.80	31.78^{bc}	761.51^{d}	702.83^{def}	651.01^{fghi}	
Dolichos-Cassava	37.57	34.76	34.42	35.58^{d}	38.66	35.56	31.00	35.07^{ab}	673.48^{fgh}	615.34^{hijk}	554.77^{k}	
Pigeon pea-Cassava	28.25	26.14	23.15	25.85^{d}	32.69	25.17	30.84	29.56^{c}	720.30^{d}	677.93^{efg}	599.57^{ijk}	
mean	32.72^{a}	30.92^{b}	28.62^{c}		33.76^{a}	30.81	29.14^{b}					
LSD $^{0.05}$	Cropping systems (C)		1.004				3.829					
	Organic inputs (OI)		1.375				2.323				65.004	
	(C*OI)											
	CV%		4.7				8.2				19.3	
	SR 2011				LR 2012				SR 2011-LR 2012			
Crop	FYM	COMP	CTRL	mean	FYM	COMP	CTRL		FYM	COMP	CTRL	mean
Cassava	22.58^{d}	19.25^{e}	15.77^{f}		31.47	29.17	26.07	28.91^{b}	699.03^{e}	599.13^{f}	560.39^{f}	
Cassava/dolichos	32.77^{ab}	31.12^{bc}	30.86^{c}		31.17	29.57	28.23	29.66^{b}	1239.78^{a}	920.63^{b}	883.13^{bc}	
Cassava/pigeon pea	33.47^{a}	31.49^{bc}	31.17^{bc}		32.71	31.72	30.82	31.75^{a}	815.34^{cd}	795.54^{d}	742.89^{de}	
Dolichos-Cassava	32.79^{ab}	31.14^{bc}	30.88^{c}		29.93	26.47	23.32	26.57^{c}				
Pigeon pea-Cassava	32.71^{ab}	31.72^{abc}	30.81^{c}		32.19	29.34	28.18	29.90^{ab}				
mean					31.49^{a}	29.25^{b}	27.32^{c}					
LSD $^{0.05}$	Cropping systems (C)						2.01					
	Organic inputs (OI)						0.994					
	(C*OI)		1.754								74.059	
	CV%		6.9				8.4				16.3	

Notes: Soil P: SR 2010, LR 2011and LR 2012- main effects of C and OI significant; SR 2011- C*OI significant

Tuber P: SR 2010-LR 2011 and SR 2011-LR 2012- C*OI significant

Table 22: Soil and tuber P as affected by cropping systems and organic inputs in cassava based cropping systems at Ikombe

	Soil P								Tuber P			
	SR 2010			mean	LR 2011			mean	SR 2010-LR 2011			mean
Crop	FYM	COMP	CTRL		FYM	COMP	CTRL		FYM	COMP	CTRL	
Cassava	25.99	24.06	21.99	24.02^{d}	26.06^{g}	24.55^{h}	21.55^{i}		690.51^{cde}	550.76^{efg}	524.84^{fg}	
Cassava/dolichos	39.43	36.75	31.81	36.00^{a}	39.61^{a}	36.60^{b}	33.27^{d}		952.66^{a}	924.24^{a}	897.59^{ab}	
Cassava/pigeon pea	34.83	32.23	31.34	32.80^{b}	34.88^{c}	32.06^{de}	31.35^{ef}		751.27^{bc}	743.95^{bcd}	710.42^{cde}	
Dolichos-Cassava	38.30	34.63	34.12	35.69^{a}	39.02^{a}	35.37^{c}	30.75^{f}		676.70^{cdef}	620.9^{cdefg}	575.38^{efg}	
Pigeon pea-Cassava	27.75	25.62	24.37	25.91^{c}	34.80^{c}	32.37^{de}	31.31^{ef}		689.04^{cde}	582.20^{defg}	470.36^{g}	
mean	33.26^{a}	30.66^{b}	28.73^{c}									
LSD $^{0.05}$	Cropping systems (C)		0.906									
	Organic inputs (OI)		1.248									
	(C*OI)						1.223				163.988	
	CV%		5.2				4.8				8.8	
	SR 2011				LR 2012				SR 2011-LR 2012			mean
Crop	FYM	COMP	CTRL		FYM	COMP	CTRL		FYM	COMP	CTRL	
Cassava	34.25	32.17	29.13	31.85^{c}	28.34^{fg}	26.76^{gh}	24.61^{i}		738.56	712.81	546.55	666.00^{c}
Cassava/dolichos	34.89	32.29	31.37	32.85^{ab}	33.19^{bc}	31.38^{cde}	29.28^{ef}		977.5	959.47	925.02	954.00^{a}
Cassava/pigeon pea	35.31	33.09	32.14	33.52^{a}	34.83^{ab}	32.23^{cd}	31.35^{cde}		846.02	828.23	761.50	811.90^{b}
Dolichos-Cassava	34.24	32.32	31.4	32.65^{b}	32.60^{cd}	29.64^{ef}	25.95^{hi}					
Pigeon pea-Cassava	34.83	32.23	31.34	32.80^{ab}	36.77^{a}	31.08^{de}	28.05^{fgh}					
mean	34.70^{c}	32.42^{b}	31.08^{a}						854^{a}	833.50^{a}	744.40^{b}	
LSD $^{0.05}$	Cropping systems (C)		0.801								97.794	
	Organic inputs (OI)		0.638								61.739	
	(C*OI)						2.101					
	CV%		6.7				8.2				8.7	

Notes: Soil P: LR 2011 and LR 2012-C*OI significant; SR 2010 and SR 2011- main effects of C and OI significant

Tuber P: SR 2010-LR 2011-C*OI significant; SR 2011-LR 2012- main effects of C and OI significant

In cassava cropping systems, inclusion of legumes significantly ($P \leq 0.05$) increased soil P relative to cassava monocropping across all sites and seasons except during the LRS of 2012 at Katangi where only dolichos-cassava rotation had significantly lower soil P than monocrop. Higher soil P under legume plots could be attributed to the solubilising effect of legume exudates on insoluble soil P (Li *et al.,* 2008; Bagayoko *et al.,* 2000). Decomposing legume residues could also have contributed to the increased soil P either through mineralisation of release of organic acids which increase desorption of P (Ogunwole *et al.,* 2010; Zsolnay and Gorlitz, 1994) as opposed to monocrop where there was no legume residues being returned to the soil.

Intercropping cassava with legumes had higher soil P levels compared to rotation across the season and sites though this was not significant during the LRS of 2011 at both sites and the SRS of 2011 at Katangi (Table 21 and 22). This is contrary to expectations that combined uptake of P under intercropping coupled with cassava biomass not being returned to the soil would have led to lower soil P under intercropping. A possible explanation could be that P uptake could have been enhanced under rotation compared to intercropping hence the reduced soil P under rotation. Sierverding and Leihner, (1984) found that rotating cassava with grain legumes could enhance the occurrence of root vesicular-arbuscular (VA) mycorrhiza infection, which has the effect of increasing the uptake of P from the soil. This is especially under soils that are acidic and low in available P. Inclusion of dolichos resulted in higher soil P compared to pigeon pea probably due to more biomass and hence crop residue production and better quality litter of dolichos (Ayoub 1986).

Influence of cropping systems and organic inputs on P status of Tuber and sorghum grain: Application of FYM enhanced the tuber and sorghum grain P content compared to compost and control experiment respectively across the seasons and site (Table 19, 20, 21 and 22). Higher P content under application of organic fertilizers could be attributed to the enhanced availability of P with application of organic fertilizers. Organic fertilizers can improve the physical properties of soil which enhances P uptake (Elsheikh and Alzidany, 1997; Buerkert *et al.*, 2000; Adekayode and Ogunkoya, 2011). Application of manure has also been shown to improve the solubility of insoluble forms of P (Akande *et al.,* 2006). FYM application led to higher levels of grain and tuber P mainly due to its longer lasting effects on soil physical structure as it took longer to decompose as well as its slow release of P to plants.

Sorghum grain P was significantly ($P \leq 0.05$) higher under sorghum/dolichos intercrop compared to sorghum monocrop though this was not significant under compost and control at Katangi (Table 19). Higher grain and tuber P content when dolichos was used as an intercrop may be attributed to the ability of legumes to enhance P uptake by crops. Legumes have been shown to have a facilitative effect on uptake of P by the companion crop through acidification of the rhizosphere hence mobilizing sparingly soluble P (Whitehead and Isaac, 2012; Li *et al.*, 2008; Li *et al.*, 2007). Eskandari (2012) also found greater P uptake for intercrops than for monocrop attributing this to complementarily exploration of the soil profile by roots of the two crops.

Similar to sorghum cropping systems intercropping with dolichos resulted in higher tuber N compared to monocropping during SRS 2010-LRS 2011 and SRS 2011-LRS 2012 at both sites (Table 20 and 21). Intercropping dolichos with cassava however resulted in significantly higher tuber P compared to intercropping with pigeon pea (Table 21 and 22). This could be attributed to facilitative effect that legumes may have on P uptake by the companion crop (Eskandari, 2012). Higher tuber and grain P was observed when dolichos was used in intercropping than when pigeon pea was used. This may be attributed to differences in ability of the two legumes in taking up P. Pigeon pea has been found to be efficient in P uptake (Ae *et al.*, 1990) and could have competed with the companion crop better than dolichos. Myaka *et al.* (2006) though working with maize, also reported that including pigeon pea in cropping systems may not mobilize large amounts of P for the companion maize crop.

Soil P and grain P correlated weakly in Katangi and Ikombe (0.13 and 0.01) respectively. This could be attributed to the environmental and soil related factors that could have affected uptake of P. It has been demonstrated previously that though P may be abundant in soils, its availability is usually constrained by its occurrence in insoluble forms (Holford, 1997). Soil P and tuber P however had a moderate correlation (0.31 and 0.4). A possible explanation may be that the organic fertilizers that were supplied could have enhanced the uptake of P by the cassava crop. The ability of fertilizers to improve uptake of P by cassava has been proven by Sierverding and Leihner, (1984)

4.2.3.4 Influence of cropping systems and organic inputs on soil and grain/tuber K content

Influence of organic fertilizers on soil K in sorghum and cassava based cropping system: Soil K levels in sorghum based cropping systems were moderate at Ikombe (0.53 cmol/kg to 1.21 cmol/kg). At Katangi, they ranged from moderate (0.93 cmol/kg) to high (2.23 cmol/kg) (Table 23 and 24).

Table 23: Soil K (cmol/kg) as affected by cropping systems and organic inputs in sorghum based cropping systems at Katangi

	Soil K								Grain K							
	SR 2010			mean	LR 2011			mean	SR 2010			mean	LR 2011			mean
Crop	FYM	COMP	CTRL		FYM	COMP	CTRL		FYM	COMP	CTRL		FYM	COMP	CTRL	
Sorghum	0.99	1.05	0.85	0.96^{b}	0.88^{h}	1.02^{d}	0.88^{gh}		0.37	0.36	0.33		0.42	0.36	0.34	
Sorghum/dolichos	1.21	1.153	0.98	1.11^{a}	1.13^{a}	1.12^{ab}	0.93^{fgh}		0.47	0.44	0.47		0.59	0.59	0.55	
Sorghum/pigeon pea	0.933	1.02	0.95	0.97^{b}	1.04^{cd}	1.05^{cd}	0.94^{fg}		0.67	0.67	0.66		0.74	0.69	0.65	
Dolichos-Sorghum	1.028	0.96	0.95	0.98^{b}	1.08^{abc}	0.95^{f}	0.97^{ef}						0.30	0.26	0.24	
Pigeon pea-Sorghum	1.012	0.99	0.91	0.97^{b}	1.07^{bcd}	1.06^{cd}	0.96^{f}						0.55	0.53	0.49	
mean	1.04^{a}	1.03^{a}	0.93^{b}										0.52^{a}	0.49^{b}	0.45^{c}	
LSD $^{0.05}$	Cropping systems (C)		0.0754													
	Organic inputs (OI)		0.0751												0.024	
	(C*OI)						0.0563									
	CV%		13.7				12.1				43.6				50.6	
	SR 2011				LR 2012				SR 2011				LR 2012			
Crop	FYM	COMP	CTRL	mean	FYM	COMP	CTRL	mean	FYM	COMP	CTRL	mean	FYM	COMP	CTRL	mean
Sorghum	0.99	1.03	0.88		1.52	1.43	1.39		0.16	0.14	0.11	0.14^{b}	0.18	0.17	0.13	0.16^{b}
Sorghum/dolichos	1.05	1.07	1.11		1.53	1.47	1.44		0.27	0.24	0.22	0.24^{a}	0.26	0.20	0.17	0.21^{ab}
Sorghum/pigeon pea	1.04	1.06	1.01		1.52	1.5	1.48		0.30	0.25	0.20	0.25^{a}	0.30	0.22	0.19	0.24^{a}
Dolichos-Sorghum	1.04	1.044	0.98		2.23	2.13	2.02						0.23	0.18	0.17	0.19^{bc}
Pigeon pea-Sorghum	1.13	1.09	1.05		1.62	1.58	1.40						0.13	0.11	0.09	0.11^{a}
mean					1.68^{a}	1.62^{b}	1.55^{c}		0.24^{a}	0.21^{b}	0.18^{c}		0.22^{a}	0.18^{b}	0.15^{a}	
LSD $^{0.05}$	Cropping systems (C)										0.059				0.039	
	Organic inputs (OI)						0.055				0.02				0.021	
	(C*OI)															
	CV%		16				59.5				25.2				14.6	

Notes: Soil K: SR 2010-main effects of C and OI significant; LR 2011-C*OI significant; SR 2011- treatment effects not significant; LR 2012-only main effects of OI significant

Grain K: SR 2010-treatment effects not significant; LR 2011-only main effects of OI significant; SR 2011 and LR 2012- C*OI significant

Table 24: Soil K (cmol/kg) as affected by cropping systems and organic inputs in sorghum based cropping systems at Ikombe

	Soil K								Grain K							
	SR 2010				LR 2011			mean	SR 2010				LR 2011			
Crop	FYM	COMP	CTRL	mean	FYM	COMP	CTRL		FYM	COMP	CTRL	mean	FYM	COMP	CTRL	mean
Sorghum	0.98^{de}	1.04^{bcde}	1.13^{a}		1.07	1.04	1.06	1.06^{bc}	0.34	0.3	0.28		0.36	0.31	0.28	
Sorghum/dolichos	1.10^{ab}	1.07^{abc}	0.97^{e}		1.23	1.17	0.99	1.13^{a}	0.35	0.32	0.28		0.37	0.35	0.31	
Sorghum/pigeon pea	1.00^{cde}	0.98^{de}	1.06^{abcd}		1.21	1.00	1.05	1.08^{ab}	0.23	0.20	0.18		0.26	0.22	0.33	
Dolichos-Sorghum	1.03^{bcde}	1.00^{cde}	1.04^{bcde}		1.05	1.00	0.95	1.00^{c}					0.17	0.14	0.11	
Pigeon pea-Sorghum	0.98^{de}	0.96^{e}	0.99^{de}		1.13	1.00	1.1	1.08^{ab}					0.45	0.42	0.39	
mean					1.14^{a}	1.04^{b}	1.03^{b}		0.61^{a}	0.58^{b}	0.55^{c}					
LSD $^{0.05}$	Cropping systems (o)						0.0685									
	Organic inputs (o)						0.0816				0.013					
	(c xo)		0.0811													
	CV%		10.9				14.2				56.2				62.2	

	SR 2011				LR 2012				SR 2011				LR 2012			
Crop	FYM	COMP	CTRL	mean	FYM	COMP	CTRL	mean	FYM	COMP	CTRL	mean	FYM	COMP	CTRL	mean
Sorghum	0.89	0.80	0.73	0.81^{b}	0.67	0.65	0.63	0.65^{d}	0.21	0.18	0.17		0.24	0.20	0.17	0.20^{a}
Sorghum/dolichos	0.97	0.90	0.91	0.93^{a}	1.34	1.32	1.28	1.31^{a}	0.40	0.33	0.32		0.22	0.17	0.32	0.24^{a}
Sorghum/pigeon pea	1.04	1.03	0.94	1.00^{a}	0.76	0.73	0.70	0.73^{c}	0.26	0.22	0.21		0.26	0.22	0.20	0.23^{a}
Dolichos-Sorghum	1.04	0.90	0.98	0.97^{a}	0.93	0.92	0.98	0.94^{d}					0.23	0.22	0.19	0.21^{a}
Pigeon pea-Sorghum	0.61	0.53	0.54	0.56^{c}	1.24	1.21	1.18	1.21^{b}					0.11	0.09	0.06	0.09^{b}
mean					0.99^{a}	0.97^{b}	0.95^{c}									
LSD $^{0.05}$	Cropping systems (c)		0.1024				0.1264								0.098	
	Organic inputs (o)						0.0067									
	cxo															
	CV%		26.3				32.4				72				51.1	

Notes: Soil K: SR 2010- C*OI significant; LR 2011 and LR 2012-main effects of C and OI significant; SR 2011- only main effects of C significant

Grain K: SR 2010- only main OI significant; LR 2011 and SR 2011-treatment effects not significant; LR 2012-only main effects of C

Generally, soil K in the sorghum based cropping systems increased relative to the initial values across the seasons and sites (Table 13). This could be as a result of input of K through residue decomposition as well as organic fertilizers. Further, soil K increased though in some cases not significantly from SRS of 2010 to LRS of 2012 in the cassava based cropping systems. This could be as a result of the slow build up of organic matter due to incorporation of residues and organic manure which lead to an increase in soil K. Kapkiyai *et al.,* (1999) also observed a close relationship between amount of soil organic matter and the quantity of available K.

In cassava based cropping systems, K levels were all moderate to high at Katangi (0.31 cmol/kg to 1.37 cmol/kg) while at Ikombe they ranged from moderate (0.33 cmol/kg) to high (1.88 cmol/kg) (Table 25 and 26).

Table 25: Soil K (cmol/kg) as affected by cropping systems and organic inputs in cassava based cropping systems at Katangi

	Soil K								Tuber K			
	SR 2010			mean	LR 2011			mean	SR 2010-LR 2011			mean
Crop	FYM	COMP	CTRL		FYM	COMP	CTRL		FYM	COMP	CTRL	
Cassava	0.47	0.29	0.31	0.36^{d}	0.44^{i}	0.37^{j}	0.32^{j}		0.59	0.55	0.52	0.55^{d}
Cassava/dolichos	0.73	0.61	0.67	0.67^{a}	0.81^{a}	0.68^{cd}	0.52^{gh}		1.20	1.15	1.1	1.15^{a}
Cassava/pigeon pea	0.62	0.57	0.54	0.58^{b}	0.67^{cd}	0.60^{efg}	0.53^{g}		0.86	0.81	0.76	0.81^{b}
Dolichos-Cassava	0.64	0.57	0.56	0.60^{b}	0.71^{bc}	0.64^{de}	0.45^{i}		0.74	0.65	0.56	0.65^{c}
Pigeon pea-Cassava	0.49	0.44	0.37	0.43^{c}	0.60^{ef}	0.55^{fg}	0.50^{ghi}		0.79	0.71	0.62	0.71^{c}
mean	0.59^{a}	0.50^{b}	0.49^{b}						0.84^{a}	0.78^{b}	0.71^{c}	
LSD $^{0.05}$	Cropping systems (o)		0.028								0.061	
	Organic inputs (o)		0.052								0.038	
	(c xo)						0.069					
	CV%		19.9				20.7				7.7	

	SR 2011				LR 2012				SR 2011-LR 2012			mean
Crop	FYM	COMP	CTRL		FYM	COMP	CTRL		FYM	COMP	CTRL	
Cassava	0.70^{c}	0.63^{cde}	0.47^{e}		1.04	1.03	1.04	1.04^{c}	0.66^{e}	0.60^{g}	0.55^{h}	
Cassava/dolichos	0.67^{cd}	0.62^{cde}	0.57^{cde}		1.16	1.36	1.32	1.28^{a}	1.25^{a}	1.11^{b}	1.06^{c}	
Cassava/pigeon pea	1.37^{a}	0.95^{b}	0.69^{cd}		0.62	0.57	0.54	0.58^{d}	0.93^{d}	0.88^{e}	0.85^{e}	
Dolichos-Cassava	0.69^{cd}	0.64^{cd}	0.60^{cde}		1.18	1.17	1.06	1.14^{b}				
Pigeon pea-Cassava	0.62^{cde}	0.57^{cde}	0.53^{de}		1.34	1.32	1.22	1.29^{a}				
mean												
LSD $^{0.05}$	Cropping systems (c)						0.102					
	Organic inputs (o)											
	cxo		0.161								0.047	
	CV%		26.1				18				12.5	

Notes: Soil K: SR 2010-main effects of C and OI significant; SR 2011and LR 2011-C*OI significant; LR 2012-only main effects OI significant

Tuber K: SR 2010-LR 2011- main effects of C and OI significant; SR 2011-LR 2012- C*OI significant

Table 26: Soil K (cmol/kg) as affected by cropping systems and organic inputs in cassava based cropping systems at Ikombe

	Soil K								Tuber K			
	SR 2010			mean	LR 2011			mean	SR 2010-LR 2011			mean
Crop	FYM	COMP	CTRL		FYM	COMP	CTRL		FYM	COMP	CTRL	
Cassava	0.53^{def}	0.33^{g}	0.48^{ef}		0.55	0.44	0.40	0.47^{c}	0.58	0.53	0.49	0.54^{c}
Cassava/dolichos	0.73^{a}	0.63^{bc}	0.50^{ef}		0.72	0.66	0.64	0.68^{a}	0.86	0.81	0.76	0.81^{a}
Cassava/pigeon pea	0.67^{ab}	0.56^{cde}	0.69^{ab}		0.72	0.59	0.67	0.66^{a}	0.82	0.77	0.69	0.76^{a}
Dolichos-Cassava	0.64^{abc}	0.52^{ef}	0.62^{bcd}		0.75	0.57	0.63	0.65^{ab}	0.63	0.55	0.48	0.55^{bc}
Pigeon pea-Cassava	0.51^{ef}	0.46^{f}	0.49^{ef}		0.65	0.53	0.66	0.62^{b}	0.68	0.61	0.54	0.61^{b}
mean					0.68^{a}	0.56^{b}	0.60^{b}		0.72^{a}	0.65^{b}	0.59^{c}	
LSD $^{0.05}$	Cropping systems (o)						0.045				0.072	
	Organic inputs (o)						0.042				0.028	
	(c xo)		0.092									
	CV%		25.8				23.9				11.6	
	SR 2011				LR 2012				SR 2011-LR 2012			mean
Crop	FYM	COMP	CTRL		FYM	COMP	CTRL		FYM	COMP	CTRL	
Cassava	0.85^{a}	0.72^{abc}	0.68^{abcd}		1.05^{cde}	1.02^{cde}	1.01^{de}		0.64	0.6	0.54	0.59^{b}
Cassava/dolichos	0.73^{abc}	0.60^{bcd}	0.73^{abc}		1.22^{bcd}	1.27^{bcd}	1.45^{b}		0.91	0.87	0.82	0.87^{a}
Cassava/pigeon pea	0.35^{e}	0.49^{de}	0.72^{abc}		0.67^{ef}	0.56^{f}	0.60^{ef}		0.81	0.79	0.77	0.79^{a}
Dolichos-Cassava	0.76^{ab}	0.63^{bcd}	0.76^{ab}		1.36^{bcd}	1.41^{bc}	1.35^{bcd}					
Pigeon pea-Cassava	0.67^{abcd}	0.56^{cd}	0.69^{abc}		1.88^{a}	1.60^{ab}	1.34^{bcd}					
mean												
LSD $^{0.05}$	Cropping systems (c)										0.145	
	Organic inputs (o)										0.025	
	cxo		0.192					0.392				
	CV%		14.6					19.7			9.8	

Notes: Soil K: SR 2011, SR 2010 and LR 2012-C*OI significant; LR 2011- main effects of C and OI significant

Tuber K: SR 2010-LR 2011- main effects of C and OI significant; SR 2011-LR 2012- only C significant

Generally, soil K was lower in the cassava based cropping systems compared to the sorghum based cropping systems. This could be attributed to the ability of cassava to remove from the soil high quantities of K. Howeler, (2002) observed that cassava is highly response to K and hence mines the soil off high quantities. These losses are more pronounced especially when biomass is removed as most losses of K occur through removal of above ground biomass (Smalling, 1993). This could also be the primary reason why Soil K values reduced compared to initial values (Table 13). Additionally, removal of above ground biomass could have led to less marked increase in soil organic matter hence K decline. However, as the seasons progressed, soil K increase with time probably due to gradual increase in soil organic matter as residue from legumes as well as organic fertilizers contributed to the increase in soil organic matter and hence K (Kapkiyai *et al.,* 1999).

FYM treated plots had higher soil K compared to compost and control respectively across cropping systems and seasons at both sites. This could mainly due to slow release of K by organic fertilizers and higher productivity of crops which could have led to more residue available for decomposition hence more K. Kapkiyai *et al.,* (1999), Gikonyo and Smithson (2003), and Kanyanjua *et al.,* (1999) have shown that crop residue return and application of FYM can augment K levels in the soil. Kapkiyai *et al.,* (1999) linked the availability of organic matter to available K concluding that building practise that build up of organic matter could have a positive effect on soil K.

Only Intercropping with dolichos resulted in significantly higher K compared to Monocropping under both cassava and sorghum cropping systems (Table 23, 24, 25 and 26). This could be attributed to higher biomass production, which ensured more K release upon decomposition. Other cropping systems i.e intercropping with pigeon pea, and both rotations did not improve soil K. One of the reasons may be luxury consumption of K by most crops could have ensured that differences in soil K were not discernible. Results obtained by Bagayoko *et al.,* (1996) while working with pearl millet and cowpea also showed that sole cropping, intercropping and rotation of these crops led to a decline in K levels. Murugappan *et al.,* (1999) similarly reported that crops tend to have luxury consumption of K, which could therefore lead to decline in soil K. Plots with dolichos legume was used had higher soil K levels compared to pigeon pea plots. This may be attributed to lower litter quality of pigeon pea, which in turn slows down nutrient. The superiority of dolichos over pigeon pea in terms of nutrient release upon decomposition has been proven by Ayoub (1986).

Influence of cropping systems and organic fertilizers on K content of tuber and sorghum grain: In sorghum plots, cropping systems significantly affected sorghum K grain content only during the LRS of 2012 at both sites and SRS of 2011 in Katangi only. Organic inputs also did not affect grain K in Ikombe across seasons as well as during the SRS 2010 in Katangi (Table 16 and 17). Failure of the treatments to show any differences in tuber/grain K content could be attributed to luxury uptake of K by plants. It has been previously shown by Tang (1998) that under conditions of sufficient K, plants would proportionally increase uptake of K which is normally accompanied by decline in soil pH as the uptake of cations over anions is increased. As pointed out by Gikonyo and Smithson (2003), K is normally abundant in most SSA soils. The abundance of K coupled with the high intake of the crops could have played a major role towards reducing the effects that treatments could have had on the K content of the sorghum grains. However, since soil pH was not determined in the current study, this assertion could not be conclusively proved.

FYM increased significantly sorghum grain K during the LRS of 2011, SRS of 2011 and LRS of 2012 at Katangi (Table 23 and 24). Tuber K also increased in FYM significantly during the SRS 2010-LRS 2011 compared to compost and control respectively (Table 18 and 19). Apart from the enhanced physical properties that allowed better uptake of K, direct contribution of FYM as it decomposed and steadily realeased K for uptake could have led to the increased tuber K. Blake *et al.,* (1999) found that FYM application could increase the content of exchangeable K which increases with the rate of application. They further observed that K supplied through FYM at some sites in Lauchstaedt and Skierniewice was more available for uptake indicating that soil properties may have an effect on nutrient uptake.

In the cassava based cropping system, intercropping and/or rotation with either legume resulted in significantly higher tuber K during SRS 2010–LRS 2011 and SR 2011-LR 2012 at both sites (Table 25 and 26). Greater K uptake for intercrops than for monocrop could be attributed to complementarily in exploration of the soil profile by the roots of the two crops. Blake *et al.*, (1999) similarly observed that in plots under crop rotation, the K uptake by crops tended to be higher. It has also been reported that legumes help in the redistribution of soil K hence making it more available to the companion crop (Clark *et al.*, 1998).

4.2.4 Conclusion

Inclusion of legumes in cropping systems improved the soil nutrient status in the cassava and sorghum based cropping systems. Intercropping cassava and/or sorghum with dolichos proved better at enhancing soil OC and NPK levels compared to other cropping systems. N status in sorghum grain was higher under continuous cropping compared to intercropping. Since it may be preferable for farmers to choose monocropping as an alternative due to its high grain N content which has implications on the protein content, then other avenues of increasing N input into the soil such as return of cassava biomass to the soil and application of larger quantities of organic material rich in N could be explored. In addition, if legumes are preferred within the cropping system, then use of dolichos in rotation is recommended. Tuber N content had more consistent results with pigeon pea-cassava rotation. P and K status in sorghum grain and tuber was highest under intercropping. Use of dolichos also resulted in better levels in P and K grain status. However, K content in tuber was higher when pigeon pea was used in intercropping. Use of organic inputs increased soil nutrients as well as NPK content of grain and tuber. FYM proved superior to compost in both cases. To enhance fertility of the soil, it was therefore concluded that sorghum/cassava intercropped with dolichos amid application of FYM is recommended as a sustainable option.

Since correlation of soil nutrient values with tuber and grain content of NPK proved weak, it would thus be appropriate to find out the reasons that affect the uptake of these nutrients by the plants, which would be used in devising appropriate strategies that would boost the nutritional quality of these crops.

4.2.5 References

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4.3 ASSESSMENT OF SOIL NUTRIENT BALANCES IN ORGANIC BASED CASSAVA (*Manihot esculenta Crantz*) AND SORGHUM (*Sorghum bicolor (L.) Moench*) CROPPING SYSTEMS OF YATTA SUBCOUNTY, KENYA

Abstract

Long-term food production in developing countries is under threat due to soil nutrient mining resulting from unsustainable production practices. In this study, the sustainability of various cropping systems and organic input combinations were assessed through monitoring nutrient flows and balances at crop production level. The study was conducted in Katangi and Ikombe divisions of Kitui sub-county between October 2010 and August 2012. A randomised complete block design with a split plot arrangement was used. The main plots were three cropping systems: (i) Intercropping (Dolichos [*Lablab purpureus*]/Cassava, Dolichos/Sorghum, Pigeon pea [*Cajanus cajan (L.*) Millsp.]/Sorghum, Pigeon pea/Cassava); (ii) Rotation (Dolichos-Cassava, Dolichos-Sorghum, Pigeon pea-Cassava, Pigeon pea-Sorghum); (iii) Monocrop (pure cassava and sorghum). The split plots were; farm yard manure (FYM), compost and control. All crops had above ground biomass incorporated after harvest in the same plot they were harvested from. Nutrient flows; Nitrogen (N), phosphorus (P) and Potassium (K), were monitored for four seasons i.e. SRS of 2010, LR of 2011, SRS of 2011 and LRS of 2012 using NUTMON toolbox. There were no significant differences in Nutrient balances between the four seasons except in sorghum based cropping systems where N and P balances were significantly lower in the second year. Losses across the seasons occurred mainly through harvested products in both sorghum and cassava cropping systems while addition mainly occurred through biological N fixation and incorporation of crop residue. Negative NPK balances were found in cassava than sorghum-based cropping systems regardless of the legumes used in both sites. Dolichos rotation with sorghum and compost applied resulted in positive N balances. Dolichos-cassava rotation with compost also had reduced N losses compared to when pigeon pea was used. P losses were less negative under pigeon pea-sorghum and pigeon pea-cassava rotation with FYM applied. Pigeon pea rotation with sorghum and FYM applied resulted in reduced K losses while with cassava the same cropping system was superior but with application of compost. The choice of legume and organic input for use would depend on the environment the farmer operates in. In N, P and K

limited environments dolichos rotation with compost application, pigeon pea rotation with FYM and, pigeon pea-sorghum rotation with FYM and pigeon pea-cassava rotation with compost applied would, respectively be the technological packages of choice.

Key words: Agroecological intensification; Cassava; Intercropping; Nutrient balance; NUTMON Toolbox; Sorghum; Organic inputs; Rotation

4.3.1 Introduction

Per capita agricultural production in sub-Saharan Africa (SSA) continues to decline thus presenting a serious challenge to food security. Rapid population growth and the need to integrate into the monetary economy has forced farmers to increase production of staple food and cash crops which are heavily reliant on external inorganic inputs (De Jager *et al.,* 1998). However, these inorganic inputs are either not used at all or applied in suboptimal quantities due to their unavailability and high cost (Smestad *et al.*, 2002). As a result, most of the income in subsistence-oriented farms is based on nutrient mining putting in danger long-term sustainability of the agricultural production system (De Jager *et al.*, 2001).

To achieve sustainability, it is necessary that farming should make maximum use of nature's goods and services without destroying them (Altieri, 1999). This implies the use of agro-ecological intensification techniques, which call for promotion of biological diversity; use of locally available resources; non-use of synthetic inputs and incorporation of natural process into agricultural production (Altieri *et al.,* 1998; Place *et al.,* 2003). In addition, crop varieties produced should be adapted to harsh conditions that prevail in the SSA specifically low soil fertility (especially N and P deficiency) and low and erratic rainfall (Mokwunye *et al.,* 1996; Lawson and Sivukamar, 1991). Sorghum and Cassava are some of the recommended crops due to their adaptability to drought, ability to grow in low soil fertility and minimum input requirement. Cassava can also be particularly attractive to small-scale farmers due to its harvest flexibility (El-Sharkawy, 2003; Gobeze *et al.*, 2005; World Bank, 2005). Dual-purpose drought resistant legumes such as dolichos and pigeon pea when in rotation or intercropped with main crops can improve the physical, chemical and biological properties of soils. Organic fertilizers could also be used to improve the soil properties. This would go a long way into increasing food availability and incomes for small-scale farmers and hence improve sustainability of the agricultural system (Rao and Mathuva, 2000; Haque *et al.*, 1995; Cheruiyot *et al.*, 2001; Altieri, 2002).

Sustainability of agricultural production systems and its accurate assessment is crucial for continued food availability in the future (Tait and Morris, 2000). Quantification of nutrient balances can be used as quantifiable indicators of agricultural sustainability (Smaling *et al.*, 1996). NUTMON is widely considered as a particularly useful tool in this regard as it can be used to assess the effects of various nutrient management strategies on nutrient balances as it employs relatively easy to quantify data to estimate flows (Vlaming *et al.*, 2001). NUTMON has been applied at various levels to study ecological sustainability of various nutrient management strategies in different environments (De Jager *et al.*, 1998; Onwonga *et al.*, 2008; Surendran *et al.*, 2005; De Jager *et al.*, 2001; Ehabe *et al.*, 2010). However, limited studies under experimental conditions have been done to determine the combined effects of various cropping systems and organic inputs on nutrient balances at crop activity levels. The current study aimed at monitoring nutrient balances in organic based cassava and sorghum cropping systems as a basis for determining their sustainability.

4.3.2 Materials and methods

4.3.2.1 Site description

Site characteristics is as described in section 3.1

4.3.2.2 Treatments and experimental design

Treatments and experimental design is a describe in section 3.2

4.3.2.3 Agronomic practices

Agronomic practices are as decribed in section 3.3

4.3.2.4 Mapping Nutrient flows in and out of the farm

Resource flow monitoring for the quantification of nutrient balances, was monitored for four seasons at plot level (October 2010 to July 2012) using the farm-NUTMON approach (De Jager *et al.*, 2001). Under this methodology, the farm is conceptualised as a set of dynamic units which form the destination and/or source of nutrient flows depending on the type of management adopted. The farm units distinguished under this methodology are:

Farm Section Units (FSUs): Areas within the farm with relatively homogenous properties

Primary Production Units (PPUs)/Crop activities: Piece of land with different possible activities such as crops, pasture or fallow. Usually a PPU is located in one or more FSUs.

Secondary production Units (SPUs)/Livestock activities: Group of animals within the farms that are under the same type of management.

Redistribution Unit (RUs): These are nutrient storage locations within the farm from which nutrient gather and later on redistributed.

House Hold (HH): Group of people who usually live in the same house and share food regularly

Stock: These are the amount of crop products and chemical fertilizers stored for later use.

Outside (EXT): The external nutrient pool which are the source and destination of nutrient but is itself never monitored. It includes markets, other families and neighbours.

Under this approach, side boundaries of the farm are the physical borders of the farm with the upper boundary being the atmosphere-soil interface, the lower boundary is considered to be 30 cm below the soil surface. Calculation of nutrient balances takes into account a set of five inflows: IN 1-mineral fertilizer, IN2-organic inputs, IN3-atmospheric deposition, IN-biological nitrogen fixation and IN5-sedimantation and six outflows. Inflows; OUT 1-farm products, OUT2-other organic inputs, OUT3-leaching, OUT4-volatization, OUT 5-erosion and OUT6-human execrate.

Since the current study considered nutrient balances at only crop activity level under experimental conditions, the farm NUTMON approach needed to be customised. The external boundaries were the experimental area, whereas the Farm Section Units (FSUs) were the replicates/blocks, the primary production units (PPUs) were the plots (i.e. the fifteen cropping systems and organic input combinations).

In order to customize the study, certain elements of the concept by De Jager *et al.*, 1998 were ignored. This includes nutrient inputs through mineral fertilizer (IN 1) since the experiment did not involve use of any inorganic materials. De Jagger *et al.*, 1998 also envisions inputs of nutrient into a system through sedimentation (IN 5) can only occur under irrigation. The amount of nutrient supplied through subsoil exploitation (IN 6) is usually ignored due to difficulties in its determination and its relatively smaller contribution to the total nutrient balances. Since the experiment took place under rainfed conditions, IN 5 was similarly ignored. Nutrient flows into PPUs were identified as organic fertilizers (IN 2), atmospheric deposition (IN 3) and biological nitrogen fixation (IN 4) and returned plant residue (OUT 2). For cassava however, no plant residues were returned which represented the common practices of removing stems from the field after harvest and preserving them for the next planting, use as firewood or sold. Nutrient output flows were identified as crop harvest (OUT 1), leaching (OUT 3), volatization (OUT 4) and soil erosion (OUT 5) (Fig 6).

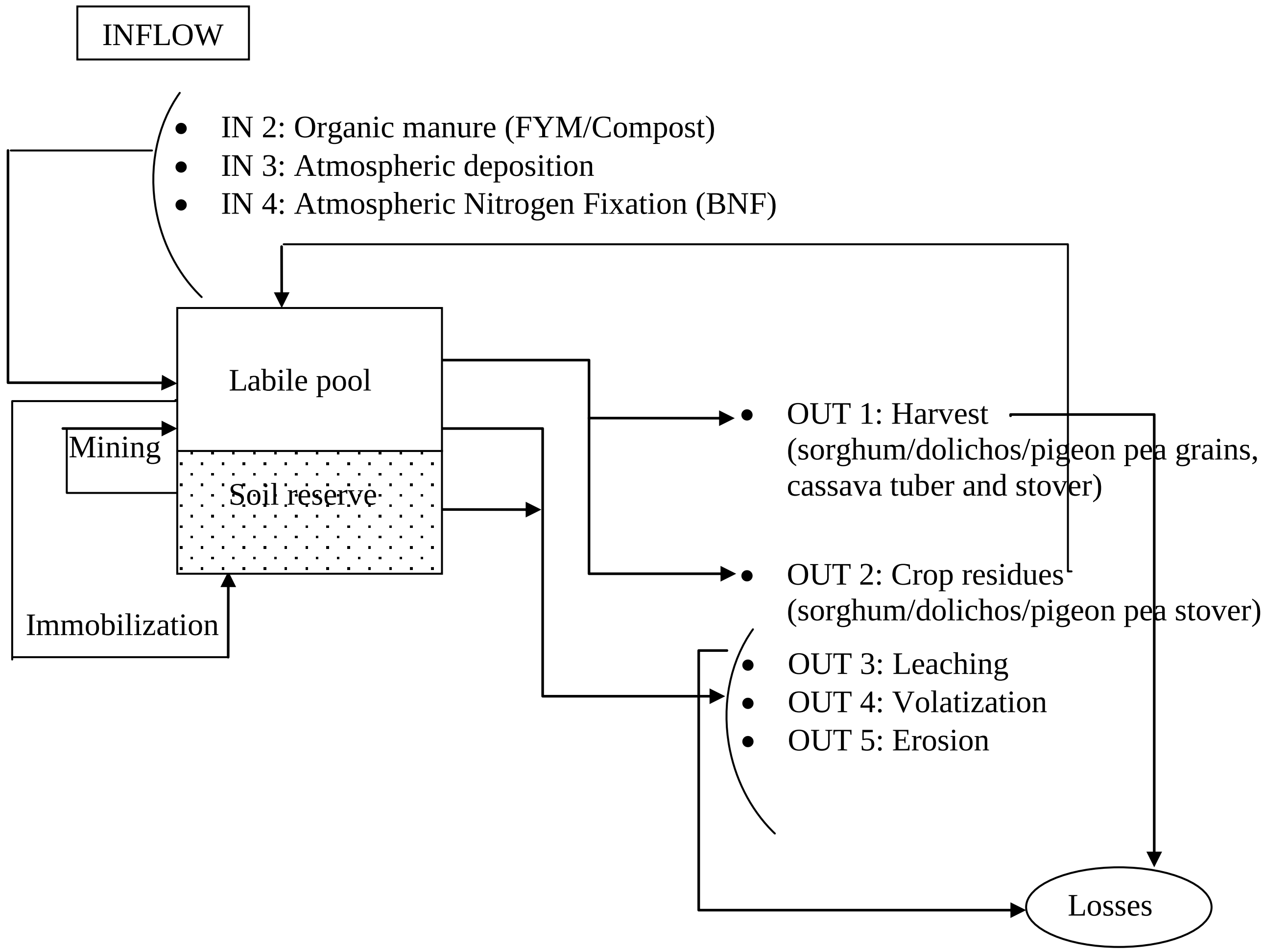

Figure 6: Modified Concept of on farm nutrient management

(Modified from Surendran and Mugurapan (2010))

4.3.2.5 Calculation of nutrient balances

For the quantification of nutrient flows for calculation of balances, methods utilized included (i) sampling and analysis of product flows for N, P and K, (ii) use of transfer functions and (iii) other approaches using sub-models and assumptions (van den Bosch *et al.,* 1998).

4.3.2.5.1 Soil sampling and analysis: Soil samples for quantification of stocks were randomly taken mixed thoroughly to make composite samples at 0-30 cm depth. The chemical parameters analysed included Total N, Phosphorous, soil organic carbon and Potassium. Physical properties analysed included bulk density and texture. Soil analysis was done according to the methods described by Okalebo *et al.,* (2002).

4.3.2.5.2 Plant sampling and analysis: Sampling and analysis of crop products was used to quantify flows such as IN 2, OUT 1 and OUT 2. Sorghum, pigeon pea and dolichos were harvested three months after planting while cassava was harvested eleven months after planting. Sampling for sorghum, pigeon pea and dolichos was done from the middle rows of each subplot while cassava was sampled from a quadrant area of $4m^2$. Plants from the net plot area within the inner rows were harvested by cutting the stem immediately above ground. They were then heaped and left for drying. The dried plants were threshed to separate seeds from pods. For cassava, harvesting required digging around the base of individual plants within the net plot area using hand tools and then uprooting the whole plant. Thereafter, the stem was separated from the tuber. The grain, stover and tuber yields were then weighed. Product flows were quantified by extrapolating the recorded yield to $Kgha^{-1}$. Absolute amounts of nitrogen, Potassium and phosphorous in the product flows were calculated using the nutrient contents of the organic inputs, tubers and seeds of sorghum, dolichos and pigeon pea. The sampled grain and tubers were oven dried at 60^0C to a constant weight and nutrient concentrations in seeds and tuber samples determined

4.3.2.5.3 Use of transfer functions and assumptions: Transfer functions are used in estimating those flows which cannot be obtained by simple measurements namely IN 3, IN 4, OUT 3, OUT 4 and OUT 5. Transfer functions explain variables that are difficult to obtain as a function of parameters which are easy to obtain (Stoovogel and Smalling, 1990; Smaling *et al.*, 1993).

The NUTMON-toolbox calculated the balances by subtracting the sum of the nutrient outputs from the sum of the nutrient inputs and presents then in Kg ha^{-1}

$$Nutrientbalance_{(N,P,K)} = \left[\sum Inputs(2,3,4)\right] - \left[\sum Outputs(1,2,3,4,5)\right]$$

Where:

Inputs 2-4 are nutrient contained in: *In 2- Organic inputs, IN 3-Atmospheric deposition, IN 4-Biological nitrogen fixation*

Outputs 1-5 are nutrients contained in: *OUT 1-Harvested products, OUT 2- Removed crop residues, OUT 3-Leaching, OUT 4-Volatization, OUT 5-Runoff/erosion*

Positive balances indicated that nutrients were accumulating in the soil and negative balances indicate that the soil is being mined off nutrients (Nandwa and Bekunda, 1998).

4.3.2.6 Statistical analysis

NPK balances for the various PPUs generated by NUTMON-toolbox were exported to genstat for further analysis. Analysis of variance for NPK balances at plot level was done and the treatment means separated using the Fisher's Protected Least Significant Difference (P = 0.05).

4.3.3 Results and discussions

4.3.3.1 Nitrogen balances

Comparison between the cassava based cropping systems and sorghum based cropping systems revealed N losses were significantly higher in cassava based cropping systems compared to sorghum based cropping systems (Table 27 and Table 28).

Table 27: N balances as influenced by cropping systems and organic inputs in the sorghum based cropping systems (Kg/ha/yr)

			KATANGI				
	YEAR 1 (SR 2010/LR 2011)			YEAR 2 (SR 2011/LR 2012)			MEAN
	FYM	COMP	CTRL	FYM	COMP	CTRL	
Sorghum monocrop	-25.90^{mn}	-1.00^{i}	-37.50^{o}	-35.77^{efg}	-1.20^{abcdef}	-36.77^{efgh}	
Sorghum/Dolichos intercrop	22.90^{e}	40.93^{c}	-4.70^{k}	6.40^{abcde}	29.9^{a}	-10.20^{bcdef}	
Sorghum/Pigeon pea intercrop	-4.10^{jk}	12.67^{f}	-26.23^{n}	-1.43^{ebcdef}	21.83^{abc}	-16.83^{bdef}	
Dolichos-Sorghum rotation	46.70^{b}	61.00^{a}	7.07^{g}	4.37^{abcdef}	25.03^{ab}	-20.2^{def}	
Pigeon pea-Sorghum rotation	0.53^{h}	20.17^{e}	-20.23^{l}	$-0.40^{abcdefg}$	24.43^{ab}	-12.57^{bcdef}	
LSD $^{0.05}$	Cropping systems (C)						
	Organic inputs (OI)						
	(C*OI)		2.74			36.88	
CV%			26.10			289.90	
	IKOMBE						
	FYM	COMP	CTRL	FYM	COMP	CTRL	
Sorghum monocrop	-27.33^{mn}	-2.60^{hj}	-37.10^{o}	-36.73	-4.53	-48.17	-29.81^{c}
Sorghum/Dolichos intercrop	22.17^{d}	41.2^{bc}	1.57^{h}	8.87	21.3	-23.67	-8.92^{bc}
Sorghum/Pigeon pea intercrop	-4.40^{kj}	10.20^{f}	-22.9^{m}	-9.37	9.67	-27.07	1.59^{bc}
Dolichos-Sorghum rotation	47.50^{b}	61.87^{a}	8.90^{fg}	2.37	23.3	-16.07	2.17^{b}
Pigeon pea-Sorghum rotation	0.33^{hi}	21.33^{de}	-15.23^{l}	1.17	22.37	-18.77	3.20^{a}
MEAN				-6.74^{c}	14.42^{a}	-26.75^{b}	
LSD $^{0.05}$	Cropping systems (C)					11.09	
	Organic inputs (OI)					4.061	
	(C*OI)		5.5				
CV%			30.40			83.90	

Table 28: N balances as influenced by cropping systems and organic inputs in the cassava based cropping systems

	KATANGI							
	YEAR 1 (SR 2010/LR 2011)				YEAR 2 (SR 2011/LR 2012)			MEAN
	FYM	COMP	CTRL	MEAN	FYM	COMP	CTRL	
Cassava monocrop	-71.70^{fghi}	-60.10^{efghi}	-57.10^{defghi}		-81.10	-60.60	-50.40	-64.01^{b}
Cassava/dolichos intercrop	-21.10^{bcd}	-15.00^{ab}	-15.5^{bc}		-11.60	2.00	-1.80	-3.82^{a}
Cassava/pigeon pea intercrop	-72.40^{fghij}	-52.30^{cdefghi}	-71.90^{fghij}		-76.10	-59.70	-91.30	-75.72^{b}
Dolichos-Cassava rotation	-0.60^{ab}	21.00^{a}	-4.20^{ab}					
Pigeon pea-Cassava rotation	-66.70^{efghi}	-30.30^{bcde}	-66.90^{efghi}					
LSD $^{0.05}$	Cropping systems (C)						20.74	
	Organic inputs (OI)							
	(C*OI)		38.17					
	CV%		20.1				26.9	
	IKOMBE							
	FYM	COMP	CTRL					
Cassava monocrop	-58.90	-35.60	-42.60	-45.70^{b}	-106.70	-85.60	-53.10	-81.80^{a}
Cassava/dolichos intercrop	-12.80	-1.80	-1.40	-5.37^{a}	-110.50	-77.50	-51.90	-80.00^{a}
Cassava/pigeon pea intercrop	-66.30	-59.50	-65.20	-63.68^{b}	-120.90	-108.50	-98.10	-109.2^{a}
Dolichos-Cassava rotation	-20.10	14.90	-41.50	-15.56^{a}				
Pigeon pea-Cassava rotation	-70.00	-39.10	-63.80	-57.63^{b}				
MEAN	-45.64^{a}	24.22^{b}	42.90^{a}		-90.50^{b}	-67.70^{c}	-112.70^{a}	
LSD $^{0.05}$	Cropping systems (C)		24.72					
	Organic inputs (OI)		11.36				22.88	
	(C*OI)							
	CV%		39.7				24.7	

Cassava based cropping systems occurred mainly through tuber and stem removal. This observations indicate that the amount of N added to the systems through organic inputs and legumes BNF could not compensate for the losses that occur through stover and tuber export. In fact, whenever legumes residual effects seemed to benefit the cassava crop, for example when intercropped, the increased tuber yield led to more extraction of the N from the soil. This observation is supported by Fermont *et al., (2007)* who demonstrated that cassava tends to heavily mine the soil off the nutrients especially when the variety used is improved and both the stem and tuber harvested. It was also observed that leaching was also a major contributor to the strong N losses in cassava based cropping system. This view is supported by Howeler (2001) who opined that wider crop spacing and slow initial development of cassava tends to leave most of the soil surface exposed. There were no significant differences in N balances between the two sites in both cassava and sorghum based cropping systems. Sorghum and cassava monocrop under the control experiment yielded significantly higher N losses compared to inclusion of legumes (Tables 27 and 28). The same observation was made even when organic inputs were applied though the differences under FYM were not all significant. This was due to N supplied to the systems through BNF and residue decomposition by the inclusion of legumes. Several authors have also reported that root N in legumes may significantly augment the N balance since they contain N derived from the soil as well as the atmosphere (Carsky, 2000; Nnadi and Balasubramanian, 1978).

Dolichos-sorghum rotation with FYM (46.70) and Dolichos-sorghum rotation with compost (61.00) had significantly higher N balances compared to pigeon pea–sorghum rotation with FYM (0.53) and compost (20.71) applied in Katangi. In the second year, similar observations were observed though the differences were not significantly different in this case. This pattern was also repeated in Ikombe. This observation indicated that dolichos fixes N in quantities that can have longer lasting effects on soil compared to pigeon pea. Comparison between the intercrops under the different organic inputs also revealed that sorghum/dolichos intercrop had significantly higher N balances compared to sorghum/pigeon pea intercrop under both FYM and compost application (Tables 27). In fact, inclusion of dolichos under FYM or compost consistently resulted in positive balances.

Under cassava cropping systems, N losses under dolichos based cropping systems under any given organic inputs were also significantly lower compared to those under pigeon pea based systems (Tables 28). This was attributed to differences in amount of fixed N and N input through residues as dolichos had higher N inputs into the systems through these avenues than pigeon pea. It has previously been observed that nitrogen fixing ability and quality and quantity of litter differ with the species of legume used (Giller *et al.*, 1997; Rao and Muthuva, 2000; Mafongoya *et al.*, 1998). Ayoub (1986) also found total N yield and biologically fixed N were higher with dolichos compared to pigeon pea. He also observed that dolichos contributed more to the total N budget than pigeon pea noting that pigeon pea gave the highest amount of non-recoverable N (lost to the atmosphere or not readily decomposable).

Sorghum/dolichos intercrop and sorghum/pigeon pea intercrop with either compost or FYM added led to significantly lower N balances compared to their respective rotations with either of the two organic inputs added. Cassava systems had similar observations though the differences were not significant. This indicated that intercropping led to lower N balances compared to rotation regardless of the organic input used. These losses were attributed the export of N through the combined harvest of the component crops in the intercrop. Fermont *et al.*, (2007) and Bagayoko *et al. (*1996) obtained similar results noting that nutrient removal from the system through harvest of the intercrops could still be higher than the monocrop. Rusinamhodzi *et al.*, (2006) also observed that sole cowpea had a more positive N balances compared to when cowpea was intercropped with cotton.

The result also show that application of compost regardless of the cropping system used resulted in significantly ($p \leq 0.05$) higher N balances compared to FYM and control respectively (Table 33 and 34). For example, monocrop sorghum with compost added (-1 in Katangi and -2.60 in Ikombe) had resulted in reduced N losses then monocrop with FYM (-25.90 in Katangi and -27.33 in Ikombe) and monocrop sorghum control (-37.50 -37.10). This indicates that N losses were higher when FYM was applied than compost though this may not be more than when no input is applied. Higher N balances application of FYM and compost have been observed by Thai Phien and Nguyen Cong Vinh (2001) who found that organic inputs could result in higher nutrient balances although this would not necessarily lead to positive balances. FYM had more negative N balances compared to compost due to it slow release of N over a long time (Murwira and Kirchmann, 1993) which would have stimulated higher crop yields hence more N removal through harvested products. De Jager *et al.,* (1998) also observed that higher plant productivity could enhance extraction of considerable quantities of nutrients from the soil. N balances in the second season were significantly lower only in the sorghum cropping systems. In the cassava based systems, N balances were also lower in the second year though not significant. No robust explanation could be found other than the unfavourable climatic conditions that reduced BNF as well as reduced the amount of residues which were returned to the soil for decomposition (Ledgard and Steele, 1992; Rao and Mathuva 2000; Snapp *et al.,* 1998).

4.3.3.2 Phosphorus balances

P balances were negative in both cassava and sorghum based cropping systems. P losses were significantly higher in the cassava than sorghum based cropping systems (Table 29 and 30). More P losses under cassava based cropping systems was attributed to export of P through harvesting of tubers and stems.

Table 29: P balances as affected by cropping systems and organic inputs in sorghum based cropping systems (kg/ha/yr)

				KATANGI				
	YEAR 1 (SR 2010/LR 2011)			YEAR 2 (SR 2011/LR 2012)				MEAN
	FYM	COMP	CTRL	MEAN	FYM	COMP	CTRL	MEAN
Sorghum monocrop	-4.03	-4.77	-9.50	-6.10^{b}	-10.87	-8.67	-11.6	-10.38^{b}
Sorghum/Dolichos intercrop	-10.2	-11.2	-15.03	-12.14^{d}	-21.77	-21.17	-23.17	-22.04^{c}
Sorghum/Pigeon pea intercrop	-6.23	-8.67	-12.23	-9.04^{c}	-11.57	-10.63	-13.03	-11.74^{b}
Dolichos-Sorghum rotation	-3.47	-5.53	-8.17	-5.72^{b}	-2.73	-5.20	-8.67	-5.5.3^{ab}
Pigeon pea-Sorghum rotation	0.13	-1.57	-6.23	-2.56^{a}	-2.00	-3.00	-5.87	-3.62^{a}
MEAN	-4.76^{a}	-6.35^{b}	-10.23^{c}		-9.79^{a}	-9.73^{a}	-12.47^{b}	
LSD $^{0.05}$	Cropping systems (C)		0.78				6.41	
	Organic inputs (OI)		0.49				1.08	
	(C*OI)							
CV%			9				13.2	
				IKOMBE				
	FYM	COMP	CTRL		FYM	COMP	CTRL	MEAN
Sorghum monocrop	-4.67^{d}	-5.37^{e}	-9.53^{j}		-10.53	-9.10	-15.43	-6.52^{c}
Sorghum/Dolichos intercrop	-11.13^{k}	-12.10^{l}	-15.03^{m}		-14.10	-13.77	-18.00	-12.76^{e}
Sorghum/Pigeon pea intercrop	-7.30^{g}	-8.03^{i}	-10.70^{k}		-9.23	-11.03	-14.07	-8.68^{d}
Dolichos-Sorghum rotation	-3.63^{c}	-6.00^{f}	-7.77^{h}		-0.83	-2.73	-6.37	-5.80^{b}
Pigeon pea-Sorghum rotation	-0.07^{a}	-1.50^{b}	-5.37^{e}		-0.63	-3.33	-8.40	-2.31^{a}
MEAN					-7.07^{a}	7.99^{b}	-12.45^{b}	
LSD $^{0.05}$	Cropping systems (C)						2.62	
	Organic inputs (OI)						1.36	
	(C*OI)		0.5				3.4	
CV%			3.5				19.5	

Table 30: P balances as affected by cropping systems and organic inputs in cassava based cropping systems

	KATANGI							
	YEAR 1 (SR 2010/LR 2011)				YEAR 2 (SR 2011/LR 2012)			MEAN
	FYM	COMP	CTRL	MEAN	FYM	COMP	CTRL	MEAN
Cassava monocrop	-12.10^{abcd}	-12.90^{abcdef}	-9.30^{abc}		-17.83	-14	-9.7	-13.84^{b}
Cassava/Dolichos intercrop	-21.33^{i}	-19.57^{ghi}	-17.00^{efghi}		-10.70	-8.47	-7.93	-9.03^{a}
Cassava/Pigeon pea intercrop	-19.13^{fghi}	-16.90^{defgh}	-19.87^{hi}		-23.7	-19.9	-23.07	-22.22^{c}
Dolichos-Cassava rotation	-12.17^{abcd}	-13.7^{cdefg}	-13.30^{bcdefg}					
Pigeon pea-Cassava rotation	-8.40^{ab}	-7.50^{a}	-12.70^{abcde}					
MEAN					-17.41^{a}	-14.12^{a}	-13.57^{a}	
LSD $^{0.05}$	Cropping systems (C)						2.84	
	Organic inputs (OI)						3.43	
	(C*OI)		6.91					
CV%			13.3				22.2	
	IKOMBE							
	FYM	COMP	CTRL		FYM	COMP	CTRL	MEAN
Cassava monocrop	-21.60	-20.40	-18.20	4.14^{a}	-22.00	-18.40	-10.20	-16.86^{a}
Cassava/Dolichos intercrop	-30.00	-27.10	-24.50	-10.22^{a}	-35.80	-25.90	-18.00	-26.57^{b}
Cassava/Pigeon pea intercop	-23.50	-19.00	-14.70	-12.82^{a}	-32.60	-30.60	-26.50	-29.87^{b}
Dolichos-Cassava rotation	-24.90	-23.60	-19.80	-11.01^{a}				
Pigeon pea-Cassava rotation	-24.10	-18.20	-21.90	-7.93^{a}				
MEAN	-8.96^{a}	-8.88^{a}	-9.84^{a}		-30.19^{c}	-25.00^{b}	-18.2^{a}	
LSD $^{0.05}$	Cropping systems (C)						9.18	
	Organic inputs (OI)						5.83	
	(C*OI)		0.5				10.81	
CV%			3.5				23.2	

Only during the first year in Ikombe under sorghum based cropping systems and year 1 in Katangi under the cassava based cropping systems had significant interaction effects. Under the sorghum cropping systems, only pigeon-pea sorghum rotation had significantly higher P balances than monocropping (Table 29). In the cassava cropping systems at Ikombe, monocropping with cassava had significantly higher P balances than intercropping with pigeon pea and dolichos in the second year. In the first year, though not significant, monocropping also had the highest P balances (Table 30).

Higher P losses in the cropping systems involving legumes could be attributed to higher uptake of P by the legume crops which mostly depend on BNF for their N supply (Cassman *et al.*, 1981). Legumes have also been shown to increase the uptake of P for the subsequent crop in rotation or the associated crop in intercropping systems (Li *et al.,* 2004; Nuruzzaman *et al.*, 2005). Increased crop yields under legume rotation could also have played a part in increased mining of P (Onwonga *et al.*, 2008). Inclusion of pigeon pea into the cropping systems resulted in higher P balances compared to dolichos. The data revealed that more P was lost through crop uptake under dolichos based cropping system than pigeon pea and this could be attributed to differences in acquisition efficiency of these elements by various legumes (Hinsinger and Gilkes 1997; Pearse *et al.*, 2007; Pearse *et al.*, 2006). Another reason could have been that differing residual benefits between the two legumes might have resulted in increased cassava and sorghum yield hence differing levels of P. Differences in yields of the subsequent crop depending on the legume used was demonstrated by Cheruiyot *et al.,* (2001), who observed the greatest increase in biomass and grain yield of maize following dolichos compared to other legumes tested. Furthermore, rotation with pigeon pea resulted in higher P balances compared to intercropping. Dolichos use in rotation also had less P losses compared to intercropping. Intercropping resulted in stronger P losses than rotation in both cassava and sorghum based cropping systems mainly due to nutrient removal from the system through harvest of the intercrops.

Pigeon pea-sorghum rotation with FYM at Ikombe in year 2 resulted in significantly ($p \leq 0.05$) higher P balances than sorghum-pigeon pea rotation with compost (Table 29). At Katangi, FYM application also significantly reduced P losses relative to compost and control in the sorghum based cropping system. Similar observations were made at Ikombe in year 2 (Table 29). This was due to higher P input through FYM as well as the higher biomass production, which could have led to more P release upon decomposition. Mpairwe *et al.,* (2002) had also noted an increased biomass production due to application of manure. In cassava systems however, application of compost at Ikombe in season 1 and in season 2 at Katangi resulted in less P losses than FYM (Table 30). Further, combination of pigeon pea-cassava rotation with compost had higher P balances than pigeon pea-cassava with FYM though also not significant. It was observed that the main contributing factor was the uptake of P through biomass which was removed at harvest. Losses of P in second year were significantly ($p \leq 0.05$) higher under sorghum based cropping systems in the first year probably due to reduced productivity of the crops hence reduced amount of residue available for decomposition. Bauer and Black, (1994) observed that plant productivity is closely linked to organic matter available for decomposition hence affecting the quantity of P released.

4.3.3.3 Potassium balances

K balances were negative across organic inputs only except when monocropping or pigeon pea was used in rotation and/or intercrop and FYM applied. In cassava cropping systems very high K losses were observed across all the cropping systems and organic inputs (Table 31 and 32)

Table 31: K balance as affected by cropping systems and organic inputs in sorghum cropping systems

	KATANGI					
	YEAR 2 (SR 2010/LR 2011)			YEAR 2 (SR 2011/LR 2012)		
	FYM	COMP	CTRL	FYM	COMP	CTRL
Sorghum monocrop	16.63^{a}	-0.60^{d}	-6.40^{f}	12.07^{ab}	-3.20^{abcd}	-7.80^{abcd}
Sorghum/Dolichos intercrop	-26.63^{i}	-40.17^{k}	-38.20^{k}	-37.93^{efg}	-50.13^{g}	-49.60^{g}
Sorghum/Pigeon pea intercrop	4.67^{c}	-12.37^{g}	-15.00^{h}	-2.17^{abcd}	-15.27^{bcdef}	-17.67^{bcdef}
Dolichos-Sorghum rotation	-26.40^{i}	-40.13^{k}	-30.20^{j}	6.53^{abcd}	-10.8^{abcdef}	-10.77^{abcde}
Pigeon pea-Sorghum rotation	13.60^{b}	-3.37^{e}	-7.40^{f}	13.5^{a}	-3.40^{abcd}	-7.27^{abcd}
LSD $^{0.05}$	Cropping systems (C)					
	Organic inputs (OI)					
	(C*OI)		2.54			28.17
CV%			9.9			13.6
	IKOMBE					
	FYM	COMP	CTRL	FYM	COMP	CTRL
Sorghum monocrop	16.23^{a}	-1.00^{d}	-6.40^{f}	12.30^{a}	-3.50^{c}	-10.43^{ef}
Sorghum/Dolichos intercrop	13.37^{b}	-3.70^{e}	-7.63^{g}	-22.90^{h}	-29.10^{i}	-30.17^{i}
Sorghum/Pigeon pea intercrop	3.07^{c}	-12.20^{h}	-13.73^{i}	4.23^{b}	-12.1^{efg}	-16.03^{g}
Dolichos-Sorghum rotation	-27.17^{j}	-41.83^{m}	-30.13^{l}	11.17^{a}	-5.47^{cd}	-8.70^{cd}
Pigeon pea-Sorghum rotation	-28.20^{k}	-42.43^{m}	-41.83^{m}	14.53^{a}	-4.03^{c}	-9.63^{de}
LSD $^{0.05}$	Cropping systems (C)					
	Organic inputs (OI)					
	(C*OI)		2.21			4.96
CV%			6.2			35.6

Table 32: K balance as affected by cropping systems and organic inputs in sorghum cropping systems

				KATANGI				
	YEAR 2 (SR 2010/LR 2011)				YEAR 2 (SR 2011/LR 2012)			MEAN
	FYM	COMP	CTRL	MEAN	FYM	COMP	CTRL	MEAN
Cassava monocrop	-32.23^{abc}	-40.37^{abc}	-28.90^{abc}		-50.20	-41.1	-31.3	-40.90^{a}
Cassava/Dolichos intercrop	-111.40^{ef}	-107.67^{de}	-96.07^{de}		-47.70	-42.7	-38.8	-43.07^{b}
Cassava/Pigeon pea intercrop	-59.47^{abc}	-59.97^{abcd}	-61.57^{abcde}		-74.80	-64	-63.7	-67.49^{b}
Dolichos-Cassava rotation	-71.10^{abcde}	-79.97^{cde}	-70.07^{abcde}					
Pigeon pea-Cassava rotation	-27.53^{a}	-30.63^{abc}	-34.83^{abc}					
MEAN					57.60^{a}	-49.30^{ab}	-44.60^{cb}	
LSD $^{0.05}$	Cropping systems (C)						15.26	
	Organic inputs (OI)						9.82	
	(C*OI)		50.63					
CV%			9.2				18.9	
				IKOMBE				
	FYM	COMP	CTRL		FYM	COMP	CTRL	MEAN
Cassava monocrop	-31.7	-29.3	-22.4	-27.80^{a}	-71.3	-60.6	-31.7	-54.54^{a}
Cassava/Dolichos intercrop	-81.10	-76.6	-62.4	-73.34^{b}	-127.50	-97	-61.5	-93.31^{b}
Cassava/Pigeon pea intercop	-68.00	-72.8	-55.2	-65.34^{b}	-101.70	-95.9	-79.3	92.29^{b}
Dolichos-Cassava rotation	-80.00	-77.5	-68.3	-75.28^{b}				
Pigeon pea-Cassava rotation	-40.30	-44.5	-42.9	-42.54^{a}				
MEAN	60.20^{a}	60.10^{a}	50.20^{a}		100.20 a	-84.50 b	-57.50 c	
LSD $^{0.05}$	Cropping systems (C)		19.35				29.06	
	Organic inputs (OI)						16.26	
	(C*OI)							
CV%			24.2				19.6	

The high K losses in both cassava and sorghum based cropping systems occurred mainly through harvesting of crop products. This confirms observation by Murugappan *et al.,* (1999) that mining of soil K always occurred regardless of whether K is added or not due to luxury consumption of K by most crops. Comparison between the cassava based cropping systems and sorghum based cropping systems revealed K losses were significantly higher in cassava compared to sorghum based cropping systems. Increased losses in the cassava based cropping systems mainly occurred due to tuber and stover harvest. This observation concurs with Howeler (2002) who noted that cassava is highly responsive to K hence mines the soil of very high quantities of K when tubers are harvested. Increased K losses through biomass have also been reported by Smalling (1993) who found that most K losses occurred due to export of harvested residue. In Katangi, sorghum monocrop with FYM (16.63) had significantly lower K losses the either sorghum/pigeon pea intercrop with FYM (4.67) applied and sorghum/dolichos intercrop with FYM (-26.63). Monocropping with compost applied still yielded significantly lower K losses (-40.37) than pigeon pea-sorghum rotation with FYM sorghum/pigeon pea intercrop (-12.37) and sorghum/dolichos intercrop (-40.17). Although not significantly different, comparison between rotation and monocropping under a given organic input also resulted in lower K balances in the monocrop (Table 31). This observation was repeated in Ikombe. This observation indicates that monocropping depleted the soil off K compared to legume rotation mainly due increased yields of the subsequent crop which increased amount of K released through decomposition of residues. Similarly, cassava monocrop resulted in lower K losses compared to the legume-based systems though the difference was not significant under pigeon pea-sorghum rotation. Intercropping with a legume under a given organic inputs also resulted in lower K balances compared to the equivalent rotation. For example, sorghum/pigeon pea intercrop with FYM had significantly lower (4.67) K balances than pigeon pea-sorghum rotation with FYM (13.60). Similarly under the cassava plots, the main effects of cassava/pigeon pea intercrop resulted in significantly lower K balances than pigeon pea-cassava rotation. Inclusion of legumes into the cropping systems especially in rotation could have increased crop yields for the following cassava and sorghum crop which played a part in increased mining of K from the soil through harvested crop products (Onwonga *et al.,* 2008). Intercropping increased combined losses through harvest of the combined products at the same time (Fermont *et al.,* 2007). It was also observed that inclusion of dolichos under a given organic input yielded significantly lower K balances than pigeon pea inclusion probably due to increased losses through removal of harvested crop products.

Application of FYM resulted in reduced K losses than application of compost under a given cropping system (Table 31 and 32). For example, Sorghum monocrop with FYM (16.63) had significantly higher K balances compared to sorghum monocrop with compost (-0.6). This was attributed to increased losses in harvested tubers and stems due to increase in yield caused by FYM application. Salami and Sangoyomi (2013) also observed increasing levels of K mining with the increase adoption and increasing yield of cassava. Fermont *et al.,* (2009) also observed a triple fold increase in the amount of K mining per hectare as the amount of yield of tubers tripled.

4.3.4 Conclusion

The NPK balances varied according to the type of crop chosen, the cropping systems adopted, the type of legumes and the organic input used. Cassava plots had to relatively more losses of NPK from the soil compared to sorghum regardless of the legume, cropping system or organic input used. Stronger nutrient losses in cassava cropping systems were mainly due to removal of both stems and tubers from the soil as well as losses due to leaching. Consequently if cassava based cropping systems are to be chosen, then technologies such mulching which reduce leaching need to be explored. Increased application of residues could also compensate for the losses due to crop harvest. Inclusion of legumes in the cropping systems led to more P and K losses relative to the monocrop though N losses were reduced when legumes were included into the cropping systems. N losses were minimized when dolichos was used while with P and K, pigeon pea was the preferred legume. The study showed that rotation with either legume could be preferred to intercropping so as to reduce soil NPK losses. Application of compost also reduced soil N losses compared to FYM but PK losses were reduced under FYM. It is recommended that under N limited conditions, inclusion of dolichos in rotation with Compost application would be the method of choice. In P limited conditions however, pigeon pea rotation-sorghum with FYM applied and cassava monocropwith compost applied would be ideal. However, if legumes are to be incorporated into the farming system, rotating with pigeon pea with application of compost would applicable in the cassava based systems. The same goes for K limited conditions. Most of the nutrient losses in the recommended packages would occurred due to export of harvested products. Low cost technologies such as use of night soil, rock phosphates in addition to increasing amount of residue incorporation into the soil need to be explored.

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CHAPTER FIVE: GENERAL DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

5.1 DISCUSSION

Intercropping sorghum with dolichos and cassava with pigeon pea and FYM increased soil moisture compared to Monocropping while yields of sorghum and cassava also increased under sorghum/dolichos and cassava/pigeon pea intercrop with FYM added. Higher soil moisture under the respective intercrops could have been the main reason for the increased yields. Ghanbari *et al.,* (2010) and Choudhary *et al.,* (2012) gave observed that intercropping results in higher light interception and reduced evaporation hence increase in soil moisture. In dry environments where soil moisture is low and yields low, it has been opined by Natarajan and Willey (1986) that intercropping could ensure that the reduction in yield is not severe compared to Monocropping. Other factors other than soil moisture could also have contributed to enhanced yields under intercrops. Intercropping has been shown to be effective in suppression of weeds which reduce yields of crops either through allelopathy or competition (Girjesh and Patil, 1991). Reduced yields of crops under monocrops has also been attributed by Kouyat´e *et al*., (2000) to allelopathic effects, which caused poor germination and stand establishment. Though highest grain and tuber yields were under sorghum/dolichos and cassava/pigeon pea, it was however under sorghum/pigeon pea and cassava/dlcihos that the highest moisture was recorded. This observation appears to support the observation that other factors such as competition and suppression of weeds could have played a bigger role in yield increases rather than absolute levels of soil moisture (Girjesh and Patil, 1991).

Application of FYM increased soil moisture and yields of crops compared to other organic inputs probably due to its ability to improve soil physical structure. It has been proven that organic manure has the ability to improve organic matter status. This has the effect of improving soil physical properties such as aggregate stability with the end result of reducing runoff and increasing water holding capacity (Su *et al.,* 2006; Wortman and Shapiro, 2008; Adeyemo and Agele, 2010). Mando *et al.,* (2005) and Fening *et al.,* (2005) observed increased sorghum yield and cassava yield respectively under manure. Diangar *et al.,* 2004 also noted a 40% increase in millet yields under fertilization with compost compared to when no compost was applied.

Intercropping with either dolichos/pigeon pea did not however result in higher soil OC and NP content. Though the highest PK content was highest under intercropping with dolichos, intercropping with pigeon pea and FYM added still resulted in higher tissue NPK content compared to monocrop. Lack of increase in OC could be attributed to high levels of decomposition in the tropics which could have been enhanced by oxen plough tillage hence reducing the effectiveness of imposed treatments. Tiessen *et al.,* (2001) and Diallo *et al.,* (2008) have observed high decomposition which are enhanced by tillage in tropics. Soil N inclusion of legumes into the cropping systems probably due to loss of recently recently fixed/mineralized N through leaching as well as it being fixed beyond the root zone as observed by Myaka *et al.,* (2006). Gachimbi *et al.,* (2005) also documented that N losses through leaching could account for most of the N losses from the soil while Giller (2001) also observed that grain-pulse intercrop systems may not lead to more soil N as most of the N may be taken up by the crops. Soil P was also not enhanced by legumes due to high requirement of legumes for P nitrogen fixation (Cassman *et al.,* 1981) and ability of legumes to accelerated uptake of P by companion crops (Li *et al.,* 2004; Nuruzzaman *et al.,* 2005) . Soil K was increased only when cassava/sorghum was intercropped with dolichos and FYM added due to release of K from decomposition of residues which were in larger quantities as biomass production was higher. Zia *et al.,* (1992) similarly observed that use of manure and incorporation of plant residue could increase soil K by 27 kg ha^{1}.

Higher grain and tuber NPK under intercropping with pigeon pea could be attributed to N fixation by the legumes which improve available N, complementarity in root zone exploration hence reduced competition as well as the ability of pigeon pea to bring minerals deep down the soil profiles (Kumar Rao *et al.,* 1983; Skerman *et al.,* 1988). Myaka *et al.,* (2006) working with pigeon pea and maize also found that intercropping did not reduce N accumulated in the grain. Esakandari (2012) also observed greater P uptake for intercrops compared to monocrop attributing this to complementarity in exploration of root zone. Higher P could also be caused by the ability of legumes to facilitate uptake of P by companion crop due to their acidifying effect on the rhizosphere with mobilizes sparingly soluble P (Whitehead and Isaac 2012; Li *et al.,* 2008). FYM application resulted in higher NPK status due to slower release of these elements over time, which would reduce any losses. Improved physical characteristics of the soil due to application of FYM may also have led to enhanced availability of these nutrients (Elsheikh and Alzidany, 1997; Buerkert *et al.,* 2000; Adekayode and Ogunkoya, 2011).

Soil NPK balances differed depending on the legumes and organic inputs used. Use of legumes either in rotation or intercropped increased N balances compared to monocrop with the highest being observed under cassava/sorghum rotation with dolichos and compost applied compared to Monocropping with control. This could be as a result of BNF by the legumes which increased N input into the systems as well as decomposition of residues. Harawa *et al.,* (2009) found that BNF at one site in southern Malawi was the second highest source of N accounting for approximately 30% of the total N input at on site in southern Malawi. Higher N balances under rotations compared to intercrops could be attributed to export of N through combined harvest of the component crops in the intercrop. This observation is supported by Fermont *et al.,* (2007), Bagayoko *et al.,* (1996) and Rusinamhodzi *et al.,* (2006) who all observed more N losses under intercrops. Compost application had higher N balances compared to Control due to increased biomass production which increased residue for decomposition as well as direct input of N. FYM application had lower N balances due to increased yields which also led to higher N removal through harvested products. De Jager *et al.,* (1998) also observed higher productivity could lead to more N losses. Pigeon pea-sorghum/cassava pigeon pea rotation with FYM and compost added respectively led to higher P balances possibly due to P release from decomposition of residues in addition to P input from FYM. K balances were also higher under Pigeon pea-sorghum rotation with FYM. However, intercropping either crop had lower P balances Monocropping due to increased uptake of P by crops (Pearse *et al.,* 2007; Pearse *et al.,* 2006) and removal through harvested products. K balances under Monocropping cassava with compost applied were higher due to increased losses due to combined harvest of products at the same time (Fermont *et al.,* 2007) as well as increased yield of cassava under legume-incorporated systems which increases K losses through harvested products Onwonga *et al.,* (2008).These losses were further enhanced when FYM was applied. Salami and Sangoyomi (2013) and Fermont *et al.*, (2009) have also reported K losses with increasing yield of cassava.

5.2 CONCLUSIONS

Inetcropping sorghum and cassava with legumes increased soil moisture and yields of crops with dolichos and pigeon pea being the prefferd legume under sorghum and cassava respectively. Inclusion of legumes showed mixed results with soil nutrients except with regard to K where intercropping with dolichos improved its levels. Intercropping with dolichos however improved the grain and tuber NPK content. FYM application also increased soil moisture, yields and content of nutrients in the soil as well as the grain and tuber. Inclusion of legumes in either rotation or intercrop with compost applied resulted in higher N balances compared to monocrop though the highest N balances occurred under rotation with dolichos and compost applied. P balances were higher under pigeon pea-sorghum rotation with FYM applied. In cassava plots however, P balances were higher under cassava monocrop with compost applied although this was not significantly different to pigeon pea-cassava rotation with compost applied. K balances were highest under cassava monocrop and pigeon pea-sorghum rotation with FYM and compost applied respectively.

If the farmer is to improve yields it is recommended that sorghum is intercropped with dolichos and cassava with pigeon pea and FYM applied in both cases. To improve the NPK content of sorghum, then intercropping with dolichos is should be embraced. With tuber N content, rotation with cassava is recommended while in the case of PK intercropping with pigeon pea and FYM added is appropriate. However, if the farmer is interested in the long-term sustainability of the systems, rotation of sorghum/cassava and compost added is recommended in N limited environments. In P and K limited environments pigeon pea-sorghum with FYM added should be practised. If cassava is to be planted in PK limited environment, then Monocropping is recommended with compost added but if legumes need to be planted, then using pigeon pea in rotation with cassava and compost applied is recommended.

5.3 RECOMMENDATIONS

1. For increasing moisture and yields of sorghum and cassava, farmers can benefit from intercropping sorghum with dolichos and cassava with pigeon pea amid addition of FYM as this would provide an effective way of improving yields without resorting to inorganic fertilizers.
2. To improve soil nutrients and and tissue NPK status, intercropping with sorghum with dolichos and cassava with pigeon pea should be embraced as a uniform package.
3. For long-term sustainability of the farm, rotation with dolichos and compost should be practised in N limited environments. In P limited environments, rotation of pigeon pea with sorghum and cassava with FYM added is advisable while in K limited environments pigeon pea-sorghum rotation with FYM added and cassava monocrop with compost added would be appropriate.
4. Since leaching wasa main contributor to N losses, further studies should be undertaken to find out ways of minimizing these losses. Furthermore, since increase in yield due to intercropping and FYM enhances N P and K losses hence strategies to replace these losses should be explored.
5. Long-term studies intercropping and rotation studies should be done to find out the soil nutrients' response to these treatments would become more consistenst over time. especially with regard to OC. Since FYM appears to have a huge influence on soil properties such as moisture and nutrients, strategies to improve its management to ensure good quality are needed.
6. Further studies need to be done determine the economic implications of the technologies recommended.

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APPENDICES

APPENDICE 1: Sorghum based cropping systems

Soil Nutrients

Katangi season 1

Soil Organic C

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.00561	0.00280	3.25	
Rep.Crop_system stratum					
Crop_system	4	0.91448	0.22862	265.10	<.001
Residual	8	0.00690	0.00086	0.01	
Rep.Crop_system.Organics stratum					
Organics	2	7.30093	3.65046	63.00	<.001
Crop_system.Organics	8	0.47007	0.05876	1.01	0.457
Residual	20	1.15892	0.05795	0.88	
Rep.Crop_system.Organics.*Units* stratum					
	45	2.97843	0.06619		
Total	89	12.83534			

Soil N

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.0005303	0.0002651	1.23	
Rep.Crop_system stratum					
Crop_system	4	0.0064292	0.0016073	7.44	0.008
Residual	8	0.0017282	0.0002160	0.39	
Rep.Crop_system.Organics stratum					
Organics	2	0.0169680	0.0084840	15.49	<.001
Crop_system.Organics	8	0.0041458	0.0005182	0.95	0.502
Residual	20	0.0109536	0.0005477	0.67	
Rep.Crop_system.Organics.*Units* stratum					
	45	0.0366995	0.0008155		
Total	89	0.0774545			

Soil P

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	2.185	1.092	1.73	
Rep.Crop_system stratum					
Crop_system	4	3326.138	831.534	1314.58	<.001
Residual	8	5.060	0.633	0.23	
Rep.Crop_system.Organics stratum					
Organics	2	190.788	95.394	34.92	<.001
Crop_system.Organics	8	43.195	5.399	1.98	0.104
Residual	20	54.638	2.732	0.68	
Rep.Crop_system.Organics.*Units* stratum					
	45	179.544	3.990		

Total	89	3801.548

Soil K

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.00689	0.00345	2.06	
Rep.Crop_system stratum					
Crop_system	4	1.16952	0.29238	174.59	<.001
Residual	8	0.01340	0.00167	0.10	
Rep.Crop_system.Organics stratum					
Organics	2	0.23787	0.11893	7.01	0.005
Crop_system.Organics	8	1.20825	0.15103	8.90	<.001
Residual	20	0.33954	0.01698	0.24	
Rep.Crop_system.Organics.*Units* stratum					
	45	3.21960	0.07155		
Total	89	6.19507			

Ikombe season 2

Soil Organic C

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.01247	0.00623	7.36	
Rep.Crop_system stratum					
Crop_system	4	0.88045	0.22011	259.78	<.001
Residual	8	0.00678	0.00085	0.06	
Rep.Crop_system.Organics stratum					
Organics	2	10.44792	5.22396	396.74	<.001
Crop_system.Organics	8	0.51781	0.06473	4.92	0.002
Residual	20	0.26334	0.01317	0.52	
Rep.Crop_system.Organics.*Units* stratum					
	45	1.14958	0.02555		
Total	89	13.27834			

Soil N

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.0015548	0.0007774	2.08	
Rep.Crop_system stratum					
Crop_system	4	0.0055558	0.0013890	3.71	0.054
Residual	8	0.0029915	0.0003739	1.15	
Rep.Crop_system.Organics stratum					
Organics	2	0.0731890	0.0365945	112.82	<.001
Crop_system.Organics	8	0.0085540	0.0010693	3.30	0.014
Residual	20	0.0064873	0.0003244	0.36	
Rep.Crop_system.Organics.*Units* stratum					
	45	0.0404065	0.0008979		
Total	89	0.1387390			

Soil P

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.19	0.09	0.26	
Rep.Crop_system stratum					
Crop_system	4	998.19	249.55	706.54	<.001
Residual	8	2.83	0.35	0.62	
Rep.Crop_system.Organics stratum					
Organics	2	347.69	173.85	307.14	<.001
Crop_system.Organics	8	52.78	6.60	11.66	<.001
Residual	20	11.32	0.57	0.02	
Rep.Crop_system.Organics.*Units* stratum					
	45	1019.29	22.65		
Total	89	2432.28			

Soil K

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.00070	0.00035	0.41	
Rep.Crop_system stratum					
Crop_system	4	0.74283	0.18571	219.68	<.001
Residual	8	0.00676	0.00085	1.61	
Rep.Crop_system.Organics stratum					
Organics	2	0.30614	0.15307	291.94	<.001
Crop_system.Organics	8	1.17183	0.14648	279.37	<.001
Residual	20	0.01049	0.00052	0.01	
Rep.Crop_system.Organics.*Units* stratum					
	45	3.28867	0.07308		
Total	89	5.52741			

Ikombe season 3

Soil Organic C

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.29097	0.14549	5.44	
Rep.Crop_system stratum					
Crop_system	4	0.06638	0.01660	0.62	0.661
Residual	8	0.21402	0.02675	1.34	
Rep.Crop_system.Organics stratum					
Organics	2	2.96136	1.48068	74.18	<.001
Crop_system.Organics	8	0.89615	0.11202	5.61	<.001
Residual	20	0.39923	0.01996	0.50	
Rep.Crop_system.Organics.*Units* stratum					
	45	1.80916	0.04020		
Total	89	6.63728			

Soil N

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	32.16	16.08	1.00	
Rep.Crop_system stratum					
Crop_system	4	274.16	68.54	4.25	0.039
Residual	8	129.07	16.13	1.00	
Rep.Crop_system.Organics stratum					
Organics	2	165.68	82.84	5.15	0.016
Crop_system.Organics	8	550.20	68.77	4.28	0.004
Residual	20	321.64	16.08	0.47	
Rep.Crop_system.Organics.*Units* stratum					
	45	1549.72	34.44		
Total	89	3022.61			

Soil P

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	40.11	20.05	1.22	
Rep.Crop_system stratum					
Crop_system	4	2998.29	749.57	45.53	<.001
Residual	8	131.71	16.46	1.07	
Rep.Crop_system.Organics stratum					
Organics	2	244.82	122.41	7.97	0.003
Crop_system.Organics	8	564.59	70.57	4.59	0.003
Residual	20	307.20	15.36	0.47	
Rep.Crop_system.Organics.*Units* stratum					
	45	1482.14	32.94		
Total	89	5768.88			

Soil K

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.80148	0.40074	1.24	
Rep.Crop_system stratum					
Crop_system	4	2.43001	0.60750	1.88	0.208
Residual	8	2.58625	0.32328	38.55	
Rep.Crop_system.Organics stratum					
Organics	2	4.61068	2.30534	274.94	<.001
Crop_system.Organics	8	0.49480	0.06185	7.38	<.001
Residual	20	0.16770	0.00838	0.16	
Rep.Crop_system.Organics.*Units* stratum					
	45	2.36461	0.05255		
Total	89	13.45552			

Ikombe season 4

Soil Organic C

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.06752	0.03376	3.89	
Rep.Crop_system stratum					
Crop_system	4	3.25373	0.81343	93.64	<.001
Residual	8	0.06949	0.00869	1.74	
Rep.Crop_system.Organics stratum					
Organics	2	0.30659	0.15329	30.70	<.001
Crop_system.Organics	8	0.02626	0.00328	0.66	0.722
Residual	20	0.09986	0.00499	0.18	
Rep.Crop_system.Organics.*Units* stratum					
	45	1.24140	0.02759		
Total	89	5.06484			

Soil N

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.005369	0.002684	6.45	
Rep.Crop_system stratum					
Crop_system	4	0.063682	0.015921	38.23	<.001
Residual	8	0.003331	0.000416	0.65	
Rep.Crop_system.Organics stratum					
Organics	2	0.013502	0.006751	10.52	<.001
Crop_system.Organics	8	0.008898	0.001112	1.73	0.152
Residual	20	0.012833	0.000642	0.54	
Rep.Crop_system.Organics.*Units* stratum					
	45	0.053500	0.001189		
Total	89	0.161116			

Soil P

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	65.932	32.966	4.45	
Rep.Crop_system stratum					
Crop_system	4	2145.575	536.394	72.36	<.001
Residual	8	59.301	7.413	2.52	
Rep.Crop_system.Organics stratum					
Organics	2	222.351	111.175	37.75	<.001
Crop_system.Organics	8	24.372	3.047	1.03	0.444
Residual	20	58.908	2.945	0.53	
Rep.Crop_system.Organics.*Units* stratum					
	45	250.524	5.567		
Total	89	2826.963			

Soil K

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.4688	0.2344	0.44	
Rep.Crop_system stratum					
Crop_system	4	74.1164	18.5291	34.51	<.001
Residual	8	4.2948	0.5368	54.79	
Rep.Crop_system.Organics stratum					
Organics	2	0.7399	0.3700	37.76	<.001
Crop_system.Organics	8	0.2653	0.0332	3.38	0.013
Residual	20	0.1960	0.0098	0.05	
Rep.Crop_system.Organics.*Units* stratum					
	45	9.1460	0.2032		
Total	89	89.2272			

Ikombe season 1

Soil Organic C

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.003336	0.001668	1.40	
Rep.Crop_system stratum					
Crop_system	4	1.047462	0.261866	220.57	<.001
Residual	8	0.009498	0.001187	0.85	
Rep.Crop_system.Organics stratum					
Organics	2	5.581769	2.790884	1998.25	<.001
Crop_system.Organics	8	0.838898	0.104862	75.08	<.001
Residual	20	0.027933	0.001397	0.15	
Rep.Crop_system.Organics.*Units* stratum					
	45	0.429150	0.009537		
Total	89	7.938046			

Soil N

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.0024696	0.0012348	5.90	
Rep.Crop_system stratum					
Crop_system	4	0.0397301	0.0099325	47.49	<.001
Residual	8	0.0016733	0.0002092	0.73	
Rep.Crop_system.Organics stratum					
Organics	2	0.0254945	0.0127472	44.20	<.001
Crop_system.Organics	8	0.0141291	0.0017661	6.12	<.001
Residual	20	0.0057674	0.0002884	0.33	
Rep.Crop_system.Organics.*Units* stratum					
	45	0.0396725	0.0008816		
Total	89	0.1289365			

Soil P

```
Source of variation                 d.f.        s.s.        m.s.      v.r.    F pr.
Rep stratum                            2       1.802       0.901      0.78
Rep.Crop_system stratum
Crop_system                            4    3553.365     888.341    771.69    <.001
Residual                               8       9.209       1.151      0.89
Rep.Crop_system.Organics stratum
Organics                               2      86.224      43.112     33.45    <.001
Crop_system.Organics                   8      38.119       4.765      3.70    0.008
Residual                              20      25.781       1.289      0.86

Rep.Crop_system.Organics.*Units* stratum
                                      45      67.203       1.493

Total                                 89    3781.703
```

Soil K

```
Source of variation                 d.f.        s.s.        m.s.      v.r.    F pr.
Rep stratum                            2     0.00782     0.00391      0.97
Rep.Crop_system stratum
Crop_system                            4     1.01069     0.25267     62.51    <.001
Residual                               8     0.03234     0.00404      0.98
Rep.Crop_system.Organics stratum
Organics                               2     0.02153     0.01077      2.60    0.099
Crop_system.Organics                   8     2.16572     0.27071     65.46    <.001
Residual                              20     0.08271     0.00414      0.06

Rep.Crop_system.Organics.*Units* stratum
                                      45     3.03657     0.06748

Total                                 89     6.35739
```

Ikombe season 2

Soil organic C

```
 Source of variation       d.f.      s.s.      m.s.     v.r.      F pr.
 Rep stratum                           2    0.001493    0.000747      0.48
 Rep.Crop_system stratum
Crop_system                            4    1.195639    0.298910    190.21    <.001
Residual                               8    0.012572    0.001571      1.93
Rep.Crop_system.Organics stratum
Organics                               2    6.431655    3.215828   3953.78    <.001
Crop_system.Organics                   8    0.831223    0.103903    127.75    <.001
Residual                              20    0.016267    0.000813      0.11

Rep.Crop_system.Organics.*Units* stratum
                                      45    0.328631    0.007303

Total                                 89    8.817480
```

Soil N

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.00057	0.00028	0.39	
Rep.Crop_system stratum					
Crop_system	4	0.36329	0.09082	124.02	<.001
Residual	8	0.00586	0.00073	1.12	
Rep.Crop_system.Organics stratum					
Organics	2	0.49164	0.24582	376.63	<.001
Crop_system.Organics	8	0.80564	0.10070	154.29	<.001
Residual	20	0.01305	0.00065	0.02	
Rep.Crop_system.Organics.*Units* stratum					
	45	1.48199	0.03293		
Total	89	3.16204			

Soil P

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	1.124	0.562	1.20	
Rep.Crop_system stratum					
Crop_system	4	3366.865	841.716	1797.04	<.001
Residual	8	3.747	0.468	0.39	
Rep.Crop_system.Organics stratum					
Organics	2	82.322	41.161	34.25	<.001
Crop_system.Organics	8	21.771	2.721	2.26	0.066
Residual	20	24.036	1.202	1.01	
Rep.Crop_system.Organics.*Units* stratum					
	45	53.354	1.186		
Total	89	3553.220			

Soil K

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.00272	0.00136	0.70	
Rep.Crop_system stratum					
Crop_system	4	0.67834	0.16958	87.64	<.001
Residual	8	0.01548	0.00193	0.07	
Rep.Crop_system.Organics stratum					
Organics	2	0.44561	0.22281	7.65	0.003
Crop_system.Organics	8	0.57836	0.07230	2.48	0.047
Residual	20	0.58265	0.02913	1.15	
Rep.Crop_system.Organics.*Units* stratum					
	45	1.13774	0.02528		
Total	89	3.44091			

Ikombe season 3

Soil Organic C

```
Source of variation                  d.f.         s.s.         m.s.      v.r.    F pr.
Rep stratum                             2       0.2909       0.1454      3.87
Rep.Crop_system stratum
Crop_system                             4       3.4680       0.8670     23.06    <.001
Residual                                8       0.3007       0.0376      7.19
Rep.Crop_system.Organics stratum
Organics                                2       3.2860       1.6430    314.21    <.001
Crop_system.Organics                    8       0.5495       0.0687     13.14    <.001
Residual                               20       0.1046       0.0052      0.02

Rep.Crop_system.Organics.*Units* stratum
                                       45      12.0167       0.2670

Total                                  89      20.0163
```

Soil N

```
Source of variation                  d.f.        s.s.    m.s.         v.r.       F pr.
Rep stratum                             2     0.01266      0.00633      0.48
Rep.Crop_system stratum
Crop_system                             4     1.79304      0.44826     34.02    <.001
Residual                                8     0.10542      0.01318      1.76
Rep.Crop_system.Organics stratum
Organics                                2     1.71568      0.85784    114.69    <.001
Crop_system.Organics                    8     2.05855      0.25732     34.40    <.001
Residual                               20     0.14959      0.00748      0.27

Rep.Crop_system.Organics.*Units* stratum
                                       45     1.24297      0.02762

Total                                  89     7.07791
```

Soil P

```
Source of variation                  d.f.        s.s.    m.s.         v.r.       F pr.
Rep stratum                             2       6.669        3.335      1.64
Rep.Crop_system stratum
Crop_system                             4    2431.529      607.882    299.02    <.001
Residual                                8      16.263        2.033      1.61
Rep.Crop_system.Organics stratum
Organics                                2     390.643      195.321    154.27    <.001
Crop_system.Organics                    8      95.517       11.940      9.43    <.001
Residual                               20      25.322        1.266      0.44

Rep.Crop_system.Organics.*Units* stratum
                                       45     129.339        2.874

Total                                  89    3095.282
```

Soil K

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.1297	0.0649	0.38	
Rep.Crop_system stratum					
Crop_system	4	10.4704	2.6176	15.38	<.001
Residual	8	1.3613	0.1702	6.01	
Rep.Crop_system.Organics stratum					
Organics	2	1.0704	0.5352	18.90	<.001
Crop_system.Organics	8	0.6315	0.0789	2.79	0.030
Residual	20	0.5664	0.0283	0.10	
Rep.Crop_system.Organics.*Units* stratum					
	45	12.7937	0.2843		
Total	89	27.0236			

Ikombe season 4

Soil Organic C

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.01934	0.00967	0.52	
Rep.Crop_system stratum					
Crop_system	4	3.47140	0.86785	47.08	<.001
Residual	8	0.14746	0.01843	13.70	
Rep.Crop_system.Organics stratum					
Organics	2	0.14049	0.07024	52.23	<.001
Crop_system.Organics	8	0.00341	0.00043	0.32	0.950
Residual	20	0.02690	0.00135	0.08	
Rep.Crop_system.Organics.*Units* stratum					
	45	0.80120	0.01780		
Total	89	4.61020			

Soil N

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.00150	0.00075	0.58	
Rep.Crop_system stratum					
Crop_system	4	3.03254	0.75813	580.82	<.001
Residual	8	0.01044	0.00131	1.99	
Rep.Crop_system.Organics stratum					
Organics	2	0.01433	0.00716	10.95	<.001
Crop_system.Organics	8	0.00742	0.00093	1.42	0.250
Residual	20	0.01309	0.00065	0.01	
Rep.Crop_system.Organics.*Units* stratum					
	45	2.68685	0.05971		
Total	89	5.76617			

Soil P

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	81.959	40.979	2.53	
Rep.Crop_system stratum					
Crop_system	4	986.015	246.504	15.24	<.001
Residual	8	129.377	16.172	7.05	
Rep.Crop_system.Organics stratum					
Organics	2	313.304	156.652	68.32	<.001
Crop_system.Organics	8	39.164	4.895	2.13	0.081
Residual	20	45.860	2.293	0.33	
Rep.Crop_system.Organics.*Units* stratum	45	314.103	6.980		
Total	89	1909.782			

Soil K

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.120	0.060	3.98	
Rep.Crop_system stratum					
Crop_system	4	155.611	38.903	2582.33	<.001
Residual	8	0.121	0.015	0.14	
Rep.Crop_system.Organics stratum					
Organics	2	0.358	0.179	1.71	0.206
Crop_system.Organics	8	0.586	0.073	0.70	0.686
Residual	20	2.089	0.104	0.08	
Rep.Crop_system.Organics.*Units* stratum	45	56.606	1.258		
Total	89	215.491			

Grain nutrient content
Katangi season 1
Grain N

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	19.4578	9.7289	2.34	
Rep.Crop_system stratum					
Crop_system	2	2.0972	1.0486	0.25	0.789
Residual	4	16.6483	4.1621	5937.96	
Rep.Crop_system.Organics stratum					
Organics	2	0.0083	0.0042	5.95	0.016
Crop_system.Organics	4	0.0039	0.0010	1.39	0.297
Residual	12	0.0084	0.0007	0.00	
Rep.Crop_system.Organics.*Units* stratum	27	16.4142	0.6079		
Total	53	54.6382			

Grain P

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	1355051.	677526.	5.83	
Rep.Crop_system stratum					
Crop_system	2	226029.	113014.	0.97	0.453
Residual	4	464932.	116233.	29.50	
Rep.Crop_system.Organics stratum					
Organics	2	92660.	46330.	11.76	0.001
Crop_system.Organics	4	11388.	2847.	0.72	0.593
Residual	12	47289.	3941.	0.03	
Rep.Crop_system.Organics.*Units* stratum					
	27	4170922.	154479.		
Total	53	6368271.			

Grain K

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	4.52169	2.26084	3.03	
Rep.Crop_system stratum					
Crop_system	2	0.87253	0.43627	0.59	0.598
Residual	4	2.98173	0.74543	42.36	
Rep.Crop_system.Organics stratum					
Organics	2	0.00776	0.00388	0.22	0.805
Crop_system.Organics	4	0.05353	0.01338	0.76	0.571
Residual	12	0.21116	0.01760	0.19	
Rep.Crop_system.Organics.*Units* stratum					
	27	2.55408	0.09460		
Total	53	11.20248			

Katangi season 2

Grain N

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	23.3367	11.6683	2.41	
Rep.Crop_system stratum					
Crop_system	4	22.4878	5.6220	1.16	0.396
Residual	8	38.8090	4.8511	277.49	
Rep.Crop_system.Organics stratum					
Organics	2	0.0464	0.0232	1.33	0.288
Crop_system.Organics	8	0.0819	0.0102	0.59	0.778
Residual	20	0.3496	0.0175	0.03	
Rep.Crop_system.Organics.*Units* stratum					
	45	28.5621	0.6347		
Total	89	113.6736			

Grain P

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	36344.	18172.	0.10	
Rep.Crop_system stratum					
Crop_system	4	795828.	198957.	1.11	0.416
Residual	8	1434898.	179362.	48.36	
Rep.Crop_system.Organics stratum					
Organics	2	234297.	117149.	31.58	<.001
Crop_system.Organics	8	59539.	7442.	2.01	0.099
Residual	20	74181.	3709.	0.05	
Rep.Crop_system.Organics.*Units* stratum					
	45	3099376.	68875.		
Total	89	5734464.			

Grain K

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	3.5197	1.7599	1.71	
Rep.Crop_system stratum					
Crop_system	4	2.0233	0.5058	0.49	0.743
Residual	8	8.2378	1.0297	514.67	
Rep.Crop_system.Organics stratum					
Organics	2	0.0598	0.0299	14.94	<.001
Crop_system.Organics	8	0.0076	0.0010	0.48	0.858
Residual	20	0.0400	0.0020	0.02	
Rep.Crop_system.Organics.*Units* stratum					
	45	5.4221	0.1205		
Total	89	19.3103			

Katangi season 3

Grain N

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.07994	0.03997	5.16	
Rep.Crop_system stratum					
Crop_system	2	0.70202	0.35101	45.35	0.002
Residual	4	0.03096	0.00774	0.67	
Rep.Crop_system.Organics stratum					
Organics	2	0.32507	0.16254	14.01	<.001
Crop_system.Organics	4	0.29511	0.07378	6.36	0.005
Residual	12	0.13917	0.01160	0.52	
Rep.Crop_system.Organics.*Units* stratum					
	27	0.59873	0.02218		
Total	53	2.17100			

Grain P

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	133782.	66891.	2.94	
Rep.Crop_system stratum					
Crop_system	2	105642.	52821.	2.32	0.214
Residual	4	90918.	22729.	1.64	
Rep.Crop_system.Organics stratum					
Organics	2	426171.	213086.	15.40	<.001
Crop_system.Organics	4	40045.	10011.	0.72	0.592
Residual	12	166055.	13838.	1.91	
Rep.Crop_system.Organics.*Units* stratum					
	27	195930.	7257.		
Total	53	1158543.			

Grain K

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.011767	0.005884	1.44	
Rep.Crop_system stratum					
Crop_system	2	0.147847	0.073923	18.09	0.010
Residual	4	0.016346	0.004087	5.38	
Rep.Crop_system.Organics stratum					
Organics	2	0.039228	0.019614	25.80	<.001
Crop_system.Organics	4	0.005851	0.001463	1.92	0.171
Residual	12	0.009122	0.000760	0.28	
Rep.Crop_system.Organics.*Units* stratum					
	27	0.074623	0.002764		
Total	53	0.304784			

Katangi season 4

Grain N

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.04878	0.02439	1.12	
Rep.Crop_system stratum					
Crop_system	4	3.81459	0.95365	43.96	<.001
Residual	8	0.17355	0.02169	3.26	
Rep.Crop_system.Organics stratum					
Organics	2	0.96991	0.48495	72.87	<.001
Crop_system.Organics	8	0.70400	0.08800	13.22	<.001
Residual	20	0.13310	0.00666	0.37	
Rep.Crop_system.Organics.*Units* stratum					
	45	0.82037	0.01823		
Total	89	6.66430			

Grain P

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	65945.	32972.	5.07	
Rep.Crop_system stratum					
Crop_system	4	118667.	29667.	4.56	0.033
Residual	8	52007.	6501.	0.63	
Rep.Crop_system.Organics stratum					
Organics	2	1191011.	595505.	57.79	<.001
Crop_system.Organics	8	391162.	48895.	4.74	0.002
Residual	20	206109.	10305.	1.09	
Rep.Crop_system.Organics.*Units* stratum					
	45	425689.	9460.		
Total	89	2450590.			

Grain K

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.0056822	0.0028411	1.11	
Rep.Crop_system stratum					
Crop_system	4	0.1688044	0.0422011	16.53	<.001
Residual	8	0.0204289	0.0025536	1.73	
Rep.Crop_system.Organics stratum					
Organics	2	0.0760822	0.0380411	25.71	<.001
Crop_system.Organics	8	0.0130289	0.0016286	1.10	0.403
Residual	20	0.0295889	0.0014794	2.10	
Rep.Crop_system.Organics.*Units* stratum					
	45	0.0317000	0.0007044		
Total	89	0.3453156			

Ikombe Season 1

Grain N

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	5.1963	2.5982	1.01	
Rep.Crop_system stratum					
Crop_system	2	4.0908	2.0454	0.79	0.512
Residual	4	10.2938	2.5735	5938.74	
Rep.Crop_system.Organics stratum					
Organics	2	0.0627	0.0313	72.32	<.001
Crop_system.Organics	4	0.0023	0.0006	1.30	0.324
Residual	12	0.0052	0.0004	0.00	
Rep.Crop_system.Organics.*Units* stratum					
	27	26.6054	0.9854		
Total	53	46.2565			

Grain P

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	225915.	112958.	3.27	
Rep.Crop_system stratum					
Crop_system	2	103295.	51648.	1.50	0.327
Residual	4	137994.	34498.	34.99	
Rep.Crop_system.Organics stratum					
Organics	2	115250.	57625.	58.45	<.001
Crop_system.Organics	4	8030.	2007.	2.04	0.153
Residual	12	11831.	986.	0.13	
Rep.Crop_system.Organics.*Units* stratum					
	27	202861.	7513.		
Total	53	805176.			

Grain K

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	1.8250	0.9125	2.41	
Rep.Crop_system stratum					
Crop_system	2	0.1327	0.0664	0.18	0.845
Residual	4	1.5121	0.3780	1275.81	
Rep.Crop_system.Organics stratum					
Organics	2	0.0318	0.0159	53.67	<.001
Crop_system.Organics	4	0.0014	0.0003	1.16	0.374
Residual	12	0.0036	0.0003	0.00	
Rep.Crop_system.Organics.*Units* stratum					
	27	2.8222	0.1045		
Total	53	6.3288			

Ikombe Season 2

Grain N

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	7.7080	3.8540	1.05	
Rep.Crop_system stratum					
Crop_system	4	30.8290	7.7072	2.10	0.172
Residual	8	29.3045	3.6631	5279.04	
Rep.Crop_system.Organics stratum					
Organics	2	0.1501	0.0751	108.19	<.001
Crop_system.Organics	8	0.0171	0.0021	3.08	0.020
Residual	20	0.0139	0.0007	0.00	
Rep.Crop_system.Organics.*Units* stratum	45	43.8075	0.9735		
Total	89	111.8302			

Grain P

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	92492.	46246.	1.64	
Rep.Crop_system stratum					
Crop_system	4	202426.	50607.	1.80	0.223
Residual	8	225188.	28148.	21.10	
Rep.Crop_system.Organics stratum					
Organics	2	109169.	54585.	40.91	<.001
Crop_system.Organics	8	22496.	2812.	2.11	0.084
Residual	20	26687.	1334.	0.17	
Rep.Crop_system.Organics.*Units* stratum	45	353815.	7863.		
Total	89	1032273.			

Grain K

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	1.9226	0.9613	1.12	
Rep.Crop_system stratum					
Crop_system	4	1.3744	0.3436	0.40	0.804
Residual	8	6.8674	0.8584	129.91	
Rep.Crop_system.Organics stratum					
Organics	2	0.0241	0.0121	1.83	0.187
Crop_system.Organics	8	0.0641	0.0080	1.21	0.341
Residual	20	0.1322	0.0066	0.04	
Rep.Crop_system.Organics.*Units* stratum	45	6.6601	0.1480		
Total	89	17.0450			

Ikombe Season 3

Grain N

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.003837	0.001919	0.17	
Rep.Crop_system stratum					
Crop_system	2	6.331826	3.165913	283.61	<.001
Residual	4	0.044652	0.011163	7.98	
Rep.Crop_system.Organics stratum					
Organics	2	0.108381	0.054191	38.76	<.001
Crop_system.Organics	4	0.019007	0.004752	3.40	0.044
Residual	12	0.016778	0.001398	0.16	
Rep.Crop_system.Organics.*Units* stratum					
	27	0.242400	0.008978		
Total	53	6.766881			

Grain P

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	219066.	109533.	12.87	
Rep.Crop_system stratum					
Crop_system	2	6066.	3033.	0.36	0.720
Residual	4	34034.	8509.	3.10	
Rep.Crop_system.Organics stratum					
Organics	2	249379.	124690.	45.36	<.001
Crop_system.Organics	4	43142.	10785.	3.92	0.029
Residual	12	32986.	2749.	0.14	
Rep.Crop_system.Organics.*Units* stratum					
	27	521307.	19308.		
Total	53	1105979.			

Grain K

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.05454	0.02727	1.15	
Rep.Crop_system stratum					
Crop_system	2	0.25111	0.12556	5.29	0.075
Residual	4	0.09486	0.02372	3.64	
Rep.Crop_system.Organics stratum					
Organics	2	0.03496	0.01748	2.69	0.109
Crop_system.Organics	4	0.00437	0.00109	0.17	0.951
Residual	12	0.07810	0.00651	0.19	
Rep.Crop_system.Organics.*Units* stratum					
	27	0.90800	0.03363		
Total	53	1.42595			

Ikombe Season 4

Grain N

```
Source of variation              d.f.          s.s.        m.s.      v.r.   F pr.
 Rep stratum                        2      0.001167    0.000583      0.05
 Rep.Crop_system stratum
Crop_system                         4     14.054362    3.513591    307.39   <.001
Residual                            8      0.091444    0.011431      2.94
 Rep.Crop_system.Organics stratum
Organics                            2      0.398187    0.199093     51.19   <.001
Crop_system.Organics                8      0.061791    0.007724      1.99   0.102
Residual                           20      0.077789    0.003889      0.56

Rep.Crop_system.Organics.*Units* stratum
                                   45      0.312950    0.006954

Total                              89     14.997690
```

Grain P

```
Source of variation              d.f.          s.s.        m.s.      v.r.   F pr.
Rep stratum                         2       233560.     116780.      5.09
Rep.Crop_system stratum
Crop_system                         4       131611.      32903.      1.43   0.307
Residual                            8       183539.      22942.      1.57
Rep.Crop_system.Organics stratum
Organics                            2       529859.     264930.     18.11   <.001
Crop_system.Organics                8       100655.      12582.      0.86   0.564
Residual                           20       292548.      14627.      0.72

Rep.Crop_system.Organics.*Units* stratum
                                   45       910846.      20241.

Total                              89      2382618.
```

Grain K

```
Source of variation              d.f.          s.s.        m.s.      v.r.   F pr.
 Rep stratum                        2      0.021216    0.010608      0.65
 Rep.Crop_system stratum
Crop_system                         4      0.268082    0.067021      4.09   0.043
Residual                            8      0.131218    0.016402      2.24
 Rep.Crop_system.Organics stratum
Organics                            2      0.015849    0.007924      1.08   0.358
Crop_system.Organics                8      0.089151    0.011144      1.52   0.212
Residual                           20      0.146633    0.007332      0.75

Rep.Crop_system.Organics.*Units* stratum
                                   45      0.437100    0.009713

Total                              89      1.109249
```

Soil moisture

Katangi Season 1

```
Source of variation                  d.f.        s.s.        m.s.      v.r.    F pr.
 Rep stratum                            2     0.15272     0.07636      3.03
 Rep.Crop_system stratum
Crop_system                             4    15.86320     3.96580    157.21    <.001
Residual                                8     0.20181     0.02523      0.44
 Rep.Crop_system.Organics stratum
Organics                                2     3.58652     1.79326     31.18    <.001
Crop_system.Organics                    8     1.76402     0.22050      3.83    0.007
Residual                               20     1.15019     0.05751      1.26

Rep.Crop_system.Organics.*Units* stratum
                                       45     2.06053     0.04579

Total                                  89    24.77900
```

Katangi Season 2

```
Source of variation                  d.f.        s.s.        m.s.      v.r.    F pr.
Rep stratum                             2     0.09468     0.04734      6.90
Rep.Crop_system stratum
Crop_system                             4    15.54784     3.88696    566.74    <.001
Residual                                8     0.05487     0.00686      0.49
Rep.Crop_system.Organics stratum
Organics                                2    17.37548     8.68774    626.73    <.001
Crop_system.Organics                    8     1.03825     0.12978      9.36    <.001
Residual                               20     0.27724     0.01386      0.63

Rep.Crop_system.Organics.*Units* stratum
                                       45     0.99585     0.02213

Total                                  89    35.38421
```

KatangiSeason 3

```
Source of variation                  d.f.        s.s.        m.s.      v.r.    F pr.
 Rep stratum                            2       8.429       4.214      2.09
 Rep.Crop_system stratum
Crop_system                             4     186.785      46.696     23.18    <.001
Residual                                8      16.118       2.015     32.66
 Rep.Crop_system.Organics stratum
Organics                                2       6.182       3.091     50.11    <.001
Crop_system.Organics                    8       6.964       0.870     14.11    <.001
Residual                               20       1.234       0.062      0.03

Rep.Crop_system.Organics.*Units* stratum
                                       45     102.815       2.285

Total                                  89     328.527
```

KatangiSeason 4

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	1.103	0.551	2.57	
Rep.Crop_system stratum					
Crop_system	4	157.281	39.320	183.33	<.001
Residual	8	1.716	0.214	0.79	
Rep.Crop_system.Organics stratum					
Organics	2	12.534	6.267	23.08	<.001
Crop_system.Organics	8	0.577	0.072	0.27	0.970
Residual	20	5.430	0.272	0.16	
Rep.Crop_system.Organics.*Units* stratum					
	45	78.243	1.739		
Total	89	256.885			

Ikombe season 1

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.27983	0.13991	9.51	
Rep.Crop_system stratum					
Crop_system	4	0.68997	0.17249	11.73	0.002
Residual	8	0.11765	0.01471	0.57	
Rep.Crop_system.Organics stratum					
Organics	2	25.91396	12.95698	504.83	<.001
Crop_system.Organics	8	1.01272	0.12659	4.93	0.002
Residual	20	0.51332	0.02567	0.87	
Rep.Crop_system.Organics.*Units* stratum					
	45	1.33000	0.02956		
Total	89	29.85745			

Ikombe season 2

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.06353	0.03176	1.64	
Rep.Crop_system stratum					
Crop_system	4	1.88892	0.47223	24.41	<.001
Residual	8	0.15475	0.01934	1.21	
Rep.Crop_system.Organics stratum					
Organics	2	24.92974	12.46487	780.95	<.001
Crop_system.Organics	8	3.98864	0.49858	31.24	<.001
Residual	20	0.31922	0.01596	0.31	
Rep.Crop_system.Organics.*Units* stratum					
	45	2.31100	0.05136		
Total	89	33.65580			

IkombeSeason 3

```
Source of variation                  d.f.        s.s.        m.s.      v.r.    F pr.
 Rep stratum                            2       4.593       2.297      8.06
 Rep.Crop_system stratum
Crop_system                             4      34.522       8.630     30.27    <.001
Residual                                8       2.281       0.285     21.00
 Rep.Crop_system.Organics stratum
Organics                                2       1.917       0.958     70.60    <.001
Crop_system.Organics                    8       0.602       0.075      5.54    <.001
Residual                               20       0.271       0.014      0.00

Rep.Crop_system.Organics.*Units* stratum
                                       45     256.228       5.694

Total                                  89     300.414
```

IkombeSeason 4

```
Source of variation                  d.f.        s.s.        m.s.      v.r.    F pr.
Rep stratum                             2       1.451       0.725      6.25
Rep.Crop_system stratum
Crop_system                             4      22.991       5.748     49.50    <.001
Residual                                8       0.929       0.116      0.73
Rep.Crop_system.Organics stratum
Organics                                2       3.605       1.802     11.27    <.001
Crop_system.Organics                    8       0.762       0.095      0.60    0.770
Residual                               20       3.197       0.160      0.04

Rep.Crop_system.Organics.*Units* stratum
                                       45     161.805       3.596

Total                                  89     194.740
```

Sorghum yield
Katangi season 1

```
Source of variation                  d.f.        s.s.        m.s.      v.r.    F pr.
 Rep stratum                            2     0.00034     0.00017      0.36
 Rep.Crop_system stratum
Crop_system                             2     0.26673     0.13336    284.65    <.001
Residual                                4     0.00187     0.00047      0.09
 Rep.Crop_system.Organics stratum
Organics                                2     0.42538     0.21269     39.48    <.001
Crop_system.Organics                    4     0.07406     0.01852      3.44    0.043
Residual                               12     0.06466     0.00539      0.51

Rep.Crop_system.Organics.*Units* stratum
                                       27     0.28415     0.01052

Total                                  53     1.11719
```

Katangi season 2

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.000943	0.000472	0.20	
Rep.Crop_system stratum					
Crop_system	4	0.329743	0.082436	34.78	<.001
Residual	8	0.018964	0.002371	2.42	
Rep.Crop_system.Organics stratum					
Organics	2	0.926354	0.463177	473.77	<.001
Crop_system.Organics	8	0.045983	0.005748	5.88	<.001
Residual	20	0.019553	0.000978	0.14	
Rep.Crop_system.Organics.*Units* stratum					
	45	0.313234	0.006961		
Total	89	1.654775			

Katangi season 3

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.8765	0.4383	13.66	
Rep.Crop_system stratum					
Crop_system	2	2.7066	1.3533	42.17	0.002
Residual	4	0.1284	0.0321	0.51	
Rep.Crop_system.Organics stratum					
Organics	2	1.7934	0.8967	14.37	<.001
Crop_system.Organics	4	0.0739	0.0185	0.30	0.875
Residual	12	0.7487	0.0624	0.09	
Rep.Crop_system.Organics.*Units* stratum					
	27	17.8687	0.6618		
Total	53	24.1962			

Katangi season 4

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	3.0450	1.5225	1.14	
Rep.Crop_system stratum					
Crop_system	4	5.4333	1.3583	1.02	0.452
Residual	8	10.6429	1.3304	11.04	
Rep.Crop_system.Organics stratum					
Organics	2	6.8642	3.4321	28.47	<.001
Crop_system.Organics	8	1.3684	0.1710	1.42	0.249
Residual	20	2.4109	0.1205	0.13	
Rep.Crop_system.Organics.*Units* stratum					
	45	41.0914	0.9131		
Total	89	70.8561			

Ikombe season 1

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.001457	0.000729	0.70	
Rep.Crop_system stratum					
Crop_system	2	0.227500	0.113750	108.85	<.001
Residual	4	0.004180	0.001045	0.52	
Rep.Crop_system.Organics stratum					
Organics	2	0.958300	0.479150	238.13	<.001
Crop_system.Organics	4	0.032200	0.008050	4.00	0.027
Residual	12	0.024145	0.002012	0.37	
Rep.Crop_system.Organics.*Units* stratum					
	27	0.148393	0.005496		
Total	53	1.396176			

Ikombe season 2

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.012932	0.006466	2.24	
Rep.Crop_system stratum					
Crop_system	4	0.342207	0.085552	29.68	<.001
Residual	8	0.023062	0.002883	1.52	
Rep.Crop_system.Organics stratum					
Organics	2	2.337407	1.168703	617.88	<.001
Crop_system.Organics	8	0.149727	0.018716	9.89	<.001
Residual	20	0.037829	0.001891	0.30	
Rep.Crop_system.Organics.*Units* stratum					
	45	0.283684	0.006304		
Total	89	3.186848			

Ikombe season 3

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	14.1317	7.0659	14.68	
Rep.Crop_system stratum					
Crop_system	2	0.4257	0.2128	0.44	0.671
Residual	4	1.9247	0.4812	79.11	
Rep.Crop_system.Organics stratum					
Organics	2	0.7179	0.3589	59.01	<.001
Crop_system.Organics	4	0.0470	0.0117	1.93	0.170
Residual	12	0.0730	0.0061	0.01	
Rep.Crop_system.Organics.*Units* stratum					
	27	13.7745	0.5102		
Total	53	31.0944			

Ikombe season 4

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.5987	0.2994	0.91	
Rep.Crop_system stratum					
Crop_system	4	5.2626	1.3156	3.98	0.046
Residual	8	2.6421	0.3303	1.38	
Rep.Crop_system.Organics stratum					
Organics	2	2.2868	1.1434	4.78	0.020
Crop_system.Organics	8	1.5548	0.1944	0.81	0.600
Residual	20	4.7797	0.2390	0.62	
Rep.Crop_system.Organics.*Units* stratum					
	45	17.3902	0.3864		
Total	89	34.5148			

Nutrient balances

Katangi N balances year 1

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	18.265	9.133	3.19	
REP.TREATMENT stratum					
TREATMENT	4	19423.970	4855.992	1694.18	<.001
Residual	8	22.930	2.866	1.11	
REP.TREATMENT.INPUTS stratum					
INPUTS	2	13993.801	6996.901	2712.44	<.001
TREATMENT.INPUTS	8	679.574	84.947	32.93	<.001
Residual	20	51.591	2.580		
Total	44	34190.132			

Katangi P balances year 1

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	0.9853	0.4927	0.96	
REP.TREATMENT stratum					
TREATMENT	4	474.9898	118.7474	232.26	<.001
Residual	8	4.0902	0.5113	1.24	
REP.TREATMENT.INPUTS stratum					
INPUTS	2	237.9053	118.9527	289.27	<.001
TREATMENT.INPUTS	8	7.1169	0.8896	2.16	0.077
Residual	20	8.2244	0.4112		
Total	44	733.3120			

Katangi K balances year 1

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	11.792	5.896	1.98	
REP.TREATMENT stratum					
TREATMENT	4	12012.483	3003.121	1009.70	<.001
Residual	8	23.794	2.974	1.52	
REP.TREATMENT.INPUTS stratum					
INPUTS	2	2482.822	1241.411	636.29	<.001
TREATMENT.INPUTS	8	429.845	53.731	27.54	<.001
Residual	20	39.020	1.951		
Total	44	14999.756			

Katangi N balances year 2

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	2580.46	1290.23	1.13	
REP.TREATMENT stratum					
TREATMENT	4	6237.15	1559.29	1.37	0.326
Residual	8	9099.95	1137.49	55.62	
REP.TREATMENT.INPUTS stratum					
INPUTS	2	11917.58	5958.79	291.37	<.001
TREATMENT.INPUTS	8	463.10	57.89	2.83	0.028
Residual	20	409.01	20.45		
Total	44	30707.25			

Katangi P balances year 2

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	128.646	64.323	1.85	
REP.TREATMENT stratum					
TREATMENT	4	1857.792	464.448	13.36	0.001
Residual	8	278.054	34.757	17.42	
REP.TREATMENT.INPUTS stratum					
INPUTS	2	73.282	36.641	18.36	<.001
TREATMENT.INPUTS	8	33.278	4.160	2.08	0.087
Residual	20	39.913	1.996		
Total	44	2410.966			

Katangi K balances year 2

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	1208.785	604.393	0.90	
REP.TREATMENT stratum					
TREATMENT	4	13655.446	3413.861	5.10	0.024
Residual	8	5359.210	669.901	240.17	
REP.TREATMENT.INPUTS stratum					
INPUTS	2	2588.628	1294.314	464.04	<.001
TREATMENT.INPUTS	8	94.694	11.837	4.24	0.004
Residual	20	55.784	2.789		
Total	44	22962.548			

Ikombe N balances year 1

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	64.549	32.275	1.73	
REP.CROPPING_SYSTEMS stratum					
CROPPING_SYSTEMS	4	20804.558	5201.139	279.29	<.001
Residual	8	148.980	18.622	2.84	
REP.CROPPING_SYSTEMS.INPUTS stratum					
ORGANIC	2	11623.785	5811.893	886.92	<.001
CROPPING_SYSTEMS.ORGANIC	8	804.310	100.539	15.34	<.001
Residual	20	131.058	6.553		
Total	44	33577.240			

Ikombe P balances year 1

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	0.17200	0.08600	0.66	
REP.CROPPING_SYSTEMS stratum					
CROPPING_SYSTEMS	4	534.30978	133.57744	1017.52	<.001
Residual	8	1.05022	0.13128	2.01	
REP.CROPPING_SYSTEMS.ORGANIC stratum					
ORGANIC	2	148.43200	74.21600	1137.89	<.001
CROPPING_SYSTEMS.ORGANIC	8	7.96356	0.99544	15.26	<.001
Residual	20	1.30444	0.06522		
Total	44	693.23200			

Ikombe K balances year 1

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	11.4813	5.7407	1.79	
REP.CROPPING_SYSTEMS stratum					
CROPPING_SYSTEMS	4	13081.8236	3270.4559	1018.97	<.001
Residual	8	25.6764	3.2096	3.77	
REP.CROPPING_SYSTEMS.ORGANIC stratum					
ORGANIC	2	2418.6413	1209.3207	1418.65	<.001
CROPPING_SYSTEMS.ORGANIC	8	434.7964	54.3496	63.76	<.001
Residual	20	17.0489	0.8524		
Total	44	15989.4680			

Ikombe N balances year 2

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	1460.96	730.48	7.02	
REP.CROPPING_SYSTEMS stratum					
CROPPING_SYSTEMS	4	7054.22	1763.55	16.94	<.001
Residual	8	832.87	104.11	3.66	
REP.CROPPING_SYSTEMS.INPUTS stratum					
ORGANIC	2	12713.53	6356.77	223.59	<.001
CROPPING_SYSTEMS.ORGANIC	8	484.25	60.53	2.13	0.082
Residual	20	568.60	28.43		
Total	44	23114.43			

Ikombe P balances year 2

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	227.870	113.935	19.56	
REP.CROPPING_SYSTEMS stratum					
CROPPING_SYSTEMS	4	978.888	244.722	42.02	<.001
Residual	8	46.595	5.824	1.82	
REP.CROPPING_SYSTEMS.ORGANIC stratum					
ORGANIC	2	248.832	124.416	38.89	<.001
CROPPING_SYSTEMS.ORGANIC	8	27.099	3.387	1.06	0.428
Residual	20	63.989	3.199		
Total	44	1593.272			

Ikombe K balances year 2

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	116.150	58.075	4.70	
REP.CROPPING_SYSTEMS stratum					
CROPPING_SYSTEMS	4	4922.318	1230.579	99.67	<.001
Residual	8	98.777	12.347	1.82	
REP.CROPPING_SYSTEMS.ORGANIC stratum					
ORGANIC	2	2946.179	1473.090	216.61	<.001
CROPPING_SYSTEMS.ORGANIC	8	295.621	36.953	5.43	0.001
Residual	20	136.013	6.801		
Total	44	8515.058			

APPENDIX 2: Cassava cropping systems

Soil nutrients
Katangi season 1
Soil Organic C

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.00051	0.00026	0.18	
Rep.Crop_system stratum					
Crop_system	4	0.15571	0.03893	26.94	<.001
Residual	8	0.01156	0.00144	0.02	
Rep.Crop_system.Organics stratum					
Organics	2	5.62671	2.81336	33.47	<.001
Crop_system.Organics	8	0.72627	0.09078	1.08	0.415
Residual	20	1.68125	0.08406	6.86	
Rep.Crop_system.Organics.*Units* stratum					
	45	0.55107	0.01225		
Total	89	8.75309			

Soil N

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.0001539	0.0000770	0.19	
Rep.Crop_system stratum					
Crop_system	4	0.0210041	0.0052510	13.27	0.001
Residual	8	0.0031667	0.0003958	0.42	
Rep.Crop_system.Organics stratum					
Organics	2	0.0174311	0.0087156	9.21	0.001
Crop_system.Organics	8	0.0175466	0.0021933	2.32	0.061
Residual	20	0.0189307	0.0009465	1.80	
Rep.Crop_system.Organics.*Units* stratum					
	45	0.0237124	0.0005269		
Total	89	0.1019456			

Soil P

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	5.674	2.837	1.66	
Rep.Crop_system stratum					
Crop_system	4	2489.266	622.317	364.79	<.001
Residual	8	13.648	1.706	0.26	
Rep.Crop_system.Organics stratum					
Organics	2	253.703	126.852	19.46	<.001
Crop_system.Organics	8	46.778	5.847	0.90	0.537
Residual	20	130.387	6.519	3.18	
Rep.Crop_system.Organics.*Units* stratum					
	45	92.262	2.050		
Total	89	3031.718			

Soil K

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.00849	0.00424	3.27	
Rep.Crop_system stratum					
Crop_system	4	1.17137	0.29284	225.87	<.001
Residual	8	0.01037	0.00130	0.14	
Rep.Crop_system.Organics stratum					
Organics	2	0.19132	0.09566	10.16	<.001
Crop_system.Organics	8	0.05338	0.00667	0.71	0.681
Residual	20	0.18824	0.00941	0.86	
Rep.Crop_system.Organics.*Units* stratum					
	45	0.49123	0.01092		
Total	89	2.11440			

Katangi season 2

Soil Organic C

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.00151	0.00076	0.32	
Rep.Crop_system stratum					
Crop_system	4	0.34437	0.08609	35.96	<.001
Residual	8	0.01916	0.00239	0.62	
Rep.Crop_system.Organics stratum					
Organics	2	8.31710	4.15855	1072.05	<.001
Crop_system.Organics	8	0.47536	0.05942	15.32	<.001
Residual	20	0.07758	0.00388	0.30	
Rep.Crop_system.Organics.*Units* stratum					
	45	0.57879	0.01286		
Total	89	9.81386			

Soil N

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.0002415	0.0001207	0.26	
Rep.Crop_system stratum					
Crop_system	4	0.0260165	0.0065041	14.13	0.001
Residual	8	0.0036813	0.0004602	0.64	
Rep.Crop_system.Organics stratum					
Organics	2	0.0487776	0.0243888	34.12	<.001
Crop_system.Organics	8	0.0080975	0.0010122	1.42	0.250
Residual	20	0.0142949	0.0007147	0.92	
Rep.Crop_system.Organics.*Units* stratum					
	45	0.0349180	0.0007760		
Total	89	0.1360273			

Soil P

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	79.679	39.840	1.61	
Rep.Crop_system stratum					
Crop_system	4	1779.012	444.753	17.92	<.001
Residual	8	198.554	24.819	1.33	
Rep.Crop_system.Organics stratum					
Organics	2	327.753	163.876	8.81	0.002
Crop_system.Organics	8	265.373	33.172	1.78	0.140
Residual	20	372.038	18.602	2.84	
Rep.Crop_system.Organics.*Units* stratum					
	45	294.699	6.549		
Total	89	3317.107			

Soil K

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.00175	0.00087	0.42	
Rep.Crop_system stratum					
Crop_system	4	0.87466	0.21867	103.99	<.001
Residual	8	0.01682	0.00210	0.52	
Rep.Crop_system.Organics stratum					
Organics	2	0.49594	0.24797	61.74	<.001
Crop_system.Organics	8	0.10941	0.01368	3.40	0.012
Residual	20	0.08033	0.00402	0.30	
Rep.Crop_system.Organics.*Units* stratum					
	45	0.60184	0.01337		
Total	89	2.18075			

Katangi season 3

Soil Organic C

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.04184	0.02092	3.14	
Rep.Crop_system stratum					
Crop_system	4	0.33094	0.08273	12.43	0.002
Residual	8	0.05325	0.00666	1.31	
Rep.Crop_system.Organics stratum					
Organics	2	3.84455	1.92228	378.86	<.001
Crop_system.Organics	8	0.92931	0.11616	22.89	<.001
Residual	20	0.10148	0.00507	0.25	
Rep.Crop_system.Organics.*Units* stratum					
	45	0.90441	0.02010		
Total	89	6.20579			

Soil N

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.071793	0.035897	0.85	
Rep.Crop_system stratum					
Crop_system	4	0.226415	0.056604	1.34	0.334
Residual	8	0.337169	0.042146	1.38	
Rep.Crop_system.Organics stratum					
Organics	2	0.089167	0.044584	1.46	0.257
Crop_system.Organics	8	0.239693	0.029962	0.98	0.481
Residual	20	0.612801	0.030640	17.03	
Rep.Crop_system.Organics.*Units* stratum					
	45	0.080984	0.001800		
Total	89	1.658022			

Soil K

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.03181	0.01590	0.43	
Rep.Crop_system stratum					
Crop_system	4	2.26040	0.56510	15.28	<.001
Residual	8	0.29592	0.03699	5.27	
Rep.Crop_system.Organics stratum					
Organics	2	0.86286	0.43143	61.52	<.001
Crop_system.Organics	8	0.80230	0.10029	14.30	<.001
Residual	20	0.14025	0.00701	0.22	
Rep.Crop_system.Organics.*Units* stratum					
	45	1.44896	0.03220		
Total	89	5.84249			

Soil P

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	35.030	17.515	20.72	
Rep.Crop_system stratum					
Crop_system	4	2267.517	566.879	670.68	<.001
Residual	8	6.762	0.845	0.30	
Rep.Crop_system.Organics stratum					
Organics	2	135.498	67.749	23.85	<.001
Crop_system.Organics	8	58.572	7.321	2.58	0.041
Residual	20	56.802	2.840	0.69	
Rep.Crop_system.Organics.*Units* stratum					
	45	185.400	4.120		
Total	89	2745.580			

Katangi season 4

Soil Organic C

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.00482	0.00241	0.11	
Rep.Crop_system stratum					
Crop_system	4	31.01823	7.75456	347.42	<.001
Residual	8	0.17856	0.02232	1.35	
Rep.Crop_system.Organics stratum					
Organics	2	1.74796	0.87398	52.98	<.001
Crop_system.Organics	8	0.85326	0.10666	6.46	<.001
Residual	20	0.32996	0.01650	0.52	
Rep.Crop_system.Organics.*Units* stratum					
	45	1.43096	0.03180		
Total	89	35.56376			

Soil N

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.0044262	0.0022131	4.07	
Rep.Crop_system stratum					
Crop_system	4	0.0061867	0.0015467	2.85	0.097
Residual	8	0.0043471	0.0005434	0.45	
Rep.Crop_system.Organics stratum					
Organics	2	0.0276097	0.0138048	11.35	<.001
Crop_system.Organics	8	0.0044533	0.0005567	0.46	0.871
Residual	20	0.0243265	0.0012163	1.63	
Rep.Crop_system.Organics.*Units* stratum					
	45	0.0336733	0.0007483		
Total	89	0.1050228			

Soil P

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	41.401	20.700	3.03	
Rep.Crop_system stratum					
Crop_system	4	253.039	63.260	9.25	0.004
Residual	8	54.699	6.837	2.01	
Rep.Crop_system.Organics stratum					
Organics	2	261.639	130.819	38.43	<.001
Crop_system.Organics	8	45.740	5.717	1.68	0.165
Residual	20	68.089	3.404	0.56	
Rep.Crop_system.Organics.*Units* stratum					
	45	273.259	6.072		
Total	89	997.866			

Soil K

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.20816	0.10408	5.94	
Rep.Crop_system stratum					
Crop_system	4	6.17003	1.54251	88.08	<.001
Residual	8	0.14010	0.01751	0.75	
Rep.Crop_system.Organics stratum					
Organics	2	0.04938	0.02469	1.06	0.364
Crop_system.Organics	8	0.21437	0.02680	1.15	0.373
Residual	20	0.46475	0.02324	0.64	
Rep.Crop_system.Organics.*Units* stratum					
	45	1.64300	0.03651		
Total	89	8.88979			

Ikombe season 1

Soil Organic C

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.00385	0.00192	1.17	
Rep.Crop_system stratum					
Crop_system	4	0.87061	0.21765	132.79	<.001
Residual	8	0.01311	0.00164	0.02	
Rep.Crop_system.Organics stratum					
Organics	2	4.17798	2.08899	31.52	<.001
Crop_system.Organics	8	1.04721	0.13090	1.98	0.104
Residual	20	1.32556	0.06628	5.62	
Rep.Crop_system.Organics.*Units* stratum					
	45	0.53051	0.01179		
Total	89	7.96883			

Soil N

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.0000014	0.0000007	0.00	
Rep.Crop_system stratum					
Crop_system	4	0.0243281	0.0060820	12.14	0.002
Residual	8	0.0040071	0.0005009	0.55	
Rep.Crop_system.Organics stratum					
Organics	2	0.0118566	0.0059283	6.48	0.007
Crop_system.Organics	8	0.0057792	0.0007224	0.79	0.618
Residual	20	0.0183037	0.0009152	1.10	
Rep.Crop_system.Organics.*Units* stratum					
	45	0.0372980	0.0008288		
Total	89	0.1015741			

Soil P

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	7.731	3.865	2.78	
Rep.Crop_system stratum					
Crop_system	4	2245.755	561.439	404.44	<.001
Residual	8	11.105	1.388	0.26	
Rep.Crop_system.Organics stratum					
Organics	2	310.927	155.463	28.95	<.001
Crop_system.Organics	8	53.721	6.715	1.25	0.322
Residual	20	107.409	5.370	2.06	
Rep.Crop_system.Organics.*Units* stratum					
	45	117.057	2.601		
Total	89	2853.706			

Soil K

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.00039	0.00020	0.07	
Rep.Crop_system stratum					
Crop_system	4	0.50337	0.12584	42.00	<.001
Residual	8	0.02397	0.00300	0.40	
Rep.Crop_system.Organics stratum					
Organics	2	0.20726	0.10363	13.92	<.001
Crop_system.Organics	8	0.21280	0.02660	3.57	0.010
Residual	20	0.14894	0.00745	0.36	
Rep.Crop_system.Organics.*Units* stratum					
	45	0.93471	0.02077		
Total	89	2.03144			

Ikombe season 2
Soil Organic C

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.00951	0.00475	4.97	
Rep.Crop_system stratum					
Crop_system	4	0.78185	0.19546	204.51	<.001
Residual	8	0.00765	0.00096	0.53	
Rep.Crop_system.Organics stratum					
Organics	2	5.80647	2.90324	1613.90	<.001
Crop_system.Organics	8	0.51849	0.06481	36.03	<.001
Residual	20	0.03598	0.00180	0.16	
Rep.Crop_system.Organics.*Units* stratum					
	45	0.49322	0.01096		
Total	89	7.65316			

Soil N

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.0008248	0.0004124	0.83	
Rep.Crop_system stratum					
Crop_system	4	0.0315649	0.0078912	15.81	<.001
Residual	8	0.0039920	0.0004990	0.51	
Rep.Crop_system.Organics stratum					
Organics	2	0.0448217	0.0224108	23.11	<.001
Crop_system.Organics	8	0.0076062	0.0009508	0.98	0.479
Residual	20	0.0193987	0.0009699	1.74	
Rep.Crop_system.Organics.*Units* stratum					
	45	0.0250926	0.0005576		
Total	89	0.1333008			

Soil P

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.433	0.217	0.21	
Rep.Crop_system stratum					
Crop_system	4	1685.073	421.268	401.22	<.001
Residual	8	8.400	1.050	0.97	
Rep.Crop_system.Organics stratum					
Organics	2	410.042	205.021	190.17	<.001
Crop_system.Organics	8	60.228	7.528	6.98	<.001
Residual	20	21.562	1.078	0.45	
Rep.Crop_system.Organics.*Units* stratum					
	45	108.979	2.422		
Total	89	2294.717			

Soil K

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.01793	0.00897	2.64	
Rep.Crop_system stratum					
Crop_system	4	0.53322	0.13331	39.31	<.001
Residual	8	0.02713	0.00339	0.56	
Rep.Crop_system.Organics stratum					
Organics	2	0.21731	0.10865	17.87	<.001
Crop_system.Organics	8	0.08962	0.01120	1.84	0.128
Residual	20	0.12159	0.00608	0.28	
Rep.Crop_system.Organics.*Units* stratum					
	45	0.96839	0.02152		
Total	89	1.97519			

Ikombe season 3

Soil Organic C

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.01374	0.00687	0.86	
Rep.Crop_system stratum					
Crop_system	4	10.89359	2.72340	341.83	<.001
Residual	8	0.06374	0.00797	2.33	
Rep.Crop_system.Organics stratum					
Organics	2	3.18513	1.59256	464.83	<.001
Crop_system.Organics	8	0.60748	0.07594	22.16	<.001
Residual	20	0.06852	0.00343	0.13	
Rep.Crop_system.Organics.*Units* stratum					
	45	1.17385	0.02609		
Total	89	16.00605			

Soil N

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.000294	0.000147	0.03	
Rep.Crop_system stratum					
Crop_system	4	0.038388	0.009597	1.92	0.201
Residual	8	0.040057	0.005007	9.76	
Rep.Crop_system.Organics stratum					
Organics	2	0.009712	0.004856	9.47	0.001
Crop_system.Organics	8	0.006040	0.000755	1.47	0.229
Residual	20	0.010258	0.000513	0.47	
Rep.Crop_system.Organics.*Units* stratum					
	45	0.049635	0.001103		
Total	89	0.154383			

Soil P

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	14.555	7.277	6.70	
Rep.Crop_system stratum					
Crop_system	4	25.484	6.371	5.87	0.017
Residual	8	8.688	1.086	0.77	
Rep.Crop_system.Organics stratum					
Organics	2	201.649	100.824	71.84	<.001
Crop_system.Organics	8	14.151	1.769	1.26	0.317
Residual	20	28.070	1.404	0.30	
Rep.Crop_system.Organics.*Units* stratum					
	45	213.941	4.754		
Total	89	506.538			

Soil K

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.078040	0.039020	1.39	
Rep.Crop_system stratum					
Crop_system	4	0.580839	0.145210	5.17	0.023
Residual	8	0.224609	0.028076	1.11	
Rep.Crop_system.Organics stratum					
Organics	2	0.204174	0.102087	4.02	0.034
Crop_system.Organics	8	0.516971	0.064621	2.55	0.043
Residual	20	0.507700	0.025385	2.73	
Rep.Crop_system.Organics.*Units* stratum					
	45	0.418960	0.009310		
Total	89	2.531294			

Ikombe season 4

Soil Organic C

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.091829	0.045914	3.00	
Rep.Crop_system stratum					
Crop_system	4	20.908251	5.227063	341.32	<.001
Residual	8	0.122516	0.015314	7.39	
Rep.Crop_system.Organics stratum					
Organics	2	1.055416	0.527708	254.79	<.001
Crop_system.Organics	8	0.375696	0.046962	22.67	<.001
Residual	20	0.041422	0.002071	0.34	
Rep.Crop_system.Organics.*Units* stratum					
	45	0.277000	0.006156		
Total	89	22.872129			

Soil N

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.0045062	0.0022531	3.95	
Rep.Crop_system stratum					
Crop_system	4	0.0210038	0.0052510	9.20	0.004
Residual	8	0.0045668	0.0005709	1.14	
Rep.Crop_system.Organics stratum					
Organics	2	0.0072470	0.0036235	7.22	0.004
Crop_system.Organics	8	0.0041636	0.0005205	1.04	0.442
Residual	20	0.0100367	0.0005018	0.68	
Rep.Crop_system.Organics.*Units* stratum					
	45	0.0333990	0.0007422		
Total	89	0.0849232			

Soil P

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	50.726	25.363	4.33	
Rep.Crop_system stratum					
Crop_system	4	444.536	111.134	18.97	<.001
Residual	8	46.874	5.859	3.85	
Rep.Crop_system.Organics stratum					
Organics	2	423.320	211.660	139.25	<.001
Crop_system.Organics	8	72.923	9.115	6.00	<.001
Residual	20	30.400	1.520	0.25	
Rep.Crop_system.Organics.*Units* stratum					
	45	278.007	6.178		
Total	89	1346.785			

Soil K

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.22251	0.11126	0.50	
Rep.Crop_system stratum					
Crop_system	4	10.00465	2.50116	11.23	0.002
Residual	8	1.78141	0.22268	5.68	
Rep.Crop_system.Organics stratum					
Organics	2	0.09036	0.04518	1.15	0.336
Crop_system.Organics	8	1.00241	0.12530	3.19	0.017
Residual	20	0.78470	0.03923	0.71	
Rep.Crop_system.Organics.*Units* stratum					
	45	2.47361	0.05497		
Total	89	16.35966			

Tuber nutrient content
Katangi Year 1
Tuber N

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.01564	0.00782	0.63	
Rep.Crop_system stratum					
Crop_system	4	1.66533	0.41633	33.67	<.001
Residual	8	0.09892	0.01236	6.30	
Rep.Crop_system.Organics stratum					
Organics	2	0.16535	0.08267	42.10	<.001
Crop_system.Organics	8	0.00487	0.00061	0.31	0.953
Residual	20	0.03928	0.00196	0.06	
Rep.Crop_system.Organics.*Units* stratum					
	45	1.42180	0.03160		
Total	89	3.41118			

Tuber P

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	56168.	28084.	5.07	
Rep.Crop_system stratum					
Crop_system	4	2345035.	586259.	105.81	<.001
Residual	8	44323.	5540.	3.69	
Rep.Crop_system.Organics stratum					
Organics	2	226081.	113040.	75.23	<.001
Crop_system.Organics	8	38413.	4802.	3.20	0.017
Residual	20	30052.	1503.	0.08	
Rep.Crop_system.Organics.*Units* stratum					
	45	877465.	19499.		
Total	89	3617536.			

Tuber K

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.026587	0.013293	2.14	
Rep.Crop_system stratum					
Crop_system	4	3.825338	0.956334	153.93	<.001
Residual	8	0.049702	0.006213	1.25	
Rep.Crop_system.Organics stratum					
Organics	2	0.243227	0.121613	24.47	<.001
Crop_system.Organics	8	0.028996	0.003624	0.73	0.665
Residual	20	0.099411	0.004971	1.41	
Rep.Crop_system.Organics.*Units* stratum					
	45	0.158950	0.003532		
Total	89	4.432210			

Katangi Year 2

Tuber N

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.01143	0.00572	0.68	
Rep.Crop_system stratum					
Crop_system	2	1.79951	0.89976	106.41	<.001
Residual	4	0.03382	0.00846	23.72	
Rep.Crop_system.Organics stratum					
Organics	2	0.04381	0.02191	61.45	<.001
Crop_system.Organics	4	0.01038	0.00259	7.28	0.003
Residual	12	0.00428	0.00036	0.03	
Rep.Crop_system.Organics.*Units* stratum					
	27	0.36825	0.01364		
Total	53	2.27148			

Tuber P

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	37045.	18522.	2.79	
Rep.Crop_system stratum					
Crop_system	2	1416835.	708418.	106.54	<.001
Residual	4	26597.	6649.	7.63	
Rep.Crop_system.Organics stratum					
Organics	2	354345.	177172.	203.20	<.001
Crop_system.Organics	4	184800.	46200.	52.99	<.001
Residual	12	10463.	872.	0.05	
Rep.Crop_system.Organics.*Units* stratum					
	27	464109.	17189.		
Total	53	2494194.			

Tuber K

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.00298	0.00149	0.72	
Rep.Crop_system stratum					
Crop_system	2	2.58043	1.29022	622.62	<.001
Residual	4	0.00829	0.00207	1.97	
Rep.Crop_system.Organics stratum					
Organics	2	0.14921	0.07461	71.05	<.001
Crop_system.Organics	4	0.02582	0.00646	6.15	0.006
Residual	12	0.01260	0.00105	0.09	
Rep.Crop_system.Organics.*Units* stratum					
	27	0.32360	0.01199		
Total	53	3.10293			

Ikombe Year 1

Tuber N

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.094329	0.047164	4.43	
Rep.Crop_system stratum					
Crop_system	4	5.050004	1.262501	118.57	<.001
Residual	8	0.085182	0.010648	2.44	
Rep.Crop_system.Organics stratum					
Organics	2	0.130702	0.065351	14.97	<.001
Crop_system.Organics	8	0.015209	0.001901	0.44	0.886
Residual	20	0.087289	0.004364	1.01	
Rep.Crop_system.Organics.*Units* stratum					
	45	0.193850	0.004308		
Total	89	5.656566			

Tuber P

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	167488.	83744.	1.97	
Rep.Crop_system stratum					
Crop_system	4	1507375.	376844.	8.86	0.005
Residual	8	340253.	42532.	11.75	
Rep.Crop_system.Organics stratum					
Organics	2	204741.	102370.	28.29	<.001
Crop_system.Organics	8	79750.	9969.	2.76	0.032
Residual	20	72367.	3618.	0.97	
Rep.Crop_system.Organics.*Units* stratum					
	45	167379.	3720.		
Total	89	2539352.			

Tuber K

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.022962	0.011481	1.30	
Rep.Crop_system stratum					
Crop_system	4	1.111462	0.277866	31.42	<.001
Residual	8	0.070738	0.008842	3.36	
Rep.Crop_system.Organics stratum					
Organics	2	0.227002	0.113501	43.07	<.001
Crop_system.Organics	8	0.009898	0.001237	0.47	0.863
Residual	20	0.052700	0.002635	0.46	
Rep.Crop_system.Organics.*Units* stratum					
	45	0.258100	0.005736		
Total	89	1.752862			

Ikombe Year 2

Tuber N

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.043478	0.021739	0.96	
Rep.Crop_system stratum					
Crop_system	2	4.184478	2.092239	92.84	<.001
Residual	4	0.090144	0.022536	10.02	
Rep.Crop_system.Organics stratum					
Organics	2	0.044633	0.022317	9.93	0.003
Crop_system.Organics	4	0.003189	0.000797	0.35	0.836
Residual	12	0.026978	0.002248	0.58	
Rep.Crop_system.Organics.*Units* stratum					
	27	0.105050	0.003891		
Total	53	4.497950			

Tuber P

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	31673.	15837.	1.42	
Rep.Crop_system stratum					
Crop_system	2	746659.	373329.	33.43	0.003
Residual	4	44666.	11167.	1.55	
Rep.Crop_system.Organics stratum					
Organics	2	122382.	61191.	8.47	0.005
Crop_system.Organics	4	40331.	10083.	1.40	0.294
Residual	12	86717.	7226.	1.44	
Rep.Crop_system.Organics.*Units* stratum					
	27	135192.	5007.		
Total	53	1207619.			

Tuber K

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.039137	0.019569	0.80	
Rep.Crop_system stratum					
Crop_system	2	0.712459	0.356230	14.51	0.015
Residual	4	0.098230	0.024557	20.18	
Rep.Crop_system.Organics stratum					
Organics	2	0.052470	0.026235	21.56	<.001
Crop_system.Organics	4	0.004696	0.001174	0.96	0.462
Residual	12	0.014600	0.001217	0.22	
Rep.Crop_system.Organics.*Units* stratum					
	27	0.147200	0.005452		
Total	53	1.068793			

Soil moisture

Katangi season 1

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.4809	0.2404	2.73	
Rep.Crop_system stratum					
Crop_system	4	53.7080	13.4270	152.51	<.001
Residual	8	0.7043	0.0880	0.82	
Rep.Crop_system.Organics stratum					
Organics	2	9.6135	4.8067	44.65	<.001
Crop_system.Organics	8	1.0891	0.1361	1.26	0.315
Residual	20	2.1532	0.1077	0.18	
Rep.Crop_system.Organics.*Units* stratum					
	45	27.0074	0.6002		
Total	89	94.7564			

Katangi season 2

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.3301	0.1650	8.23	
Rep.Crop_system stratum					
Crop_system	4	52.9241	13.2310	659.72	<.001
Residual	8	0.1604	0.0201	0.55	
Rep.Crop_system.Organics stratum					
Organics	2	12.5764	6.2882	171.97	<.001
Crop_system.Organics	8	0.2487	0.0311	0.85	0.572
Residual	20	0.7313	0.0366	0.12	
Rep.Crop_system.Organics.*Units* stratum					
	45	14.0155	0.3115		
Total	89	80.9865			

Katangi season 2

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	8.939	4.469	1.69	
Rep.Crop_system stratum					
Crop_system	4	11.014	2.753	1.04	0.442
Residual	8	21.116	2.639	17.23	
Rep.Crop_system.Organics stratum					
Organics	2	13.424	6.712	43.81	<.001
Crop_system.Organics	8	4.236	0.530	3.46	0.012
Residual	20	3.064	0.153	0.05	
Rep.Crop_system.Organics.*Units* stratum					
	45	130.354	2.897		
Total	89	192.147			

Katangi season 3

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	6.306	3.153	2.36	
Rep.Crop_system stratum					
Crop_system	4	32.675	8.169	6.10	0.015
Residual	8	10.706	1.338	6.81	
Rep.Crop_system.Organics stratum					
Organics	2	11.527	5.763	29.33	<.001
Crop_system.Organics	8	1.988	0.248	1.26	0.315
Residual	20	3.929	0.196	0.07	
Rep.Crop_system.Organics.*Units* stratum					
	45	121.901	2.709		
Total	89	189.031			

Ikombe season 1

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.3503	0.1752	1.98	
Rep.Crop_system stratum					
Crop_system	4	5.4714	1.3679	15.48	<.001
Residual	8	0.7071	0.0884	0.86	
Rep.Crop_system.Organics stratum					
Organics	2	8.7332	4.3666	42.32	<.001
Crop_system.Organics	8	0.5907	0.0738	0.72	0.676
Residual	20	2.0636	0.1032	0.22	
Rep.Crop_system.Organics.*Units* stratum	45	21.1288	0.4695		
Total	89	39.0450			

Ikombe season 2

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.3730	0.1865	0.80	
Rep.Crop_system stratum					
Crop_system	4	42.4459	10.6115	45.28	<.001
Residual	8	1.8750	0.2344	3.12	
Rep.Crop_system.Organics stratum					
Organics	2	28.4689	14.2345	189.38	<.001
Crop_system.Organics	8	0.5977	0.0747	0.99	0.470
Residual	20	1.5032	0.0752	0.42	
Rep.Crop_system.Organics.*Units* stratum	45	8.0695	0.1793		
Total	89	83.3333			

Ikombe season 3

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.803	0.401	0.94	
Rep.Crop_system stratum					
Crop_system	4	1.933	0.483	1.13	0.408
Residual	8	3.427	0.428	5.26	
Rep.Crop_system.Organics stratum					
Organics	2	7.616	3.808	46.73	<.001
Crop_system.Organics	8	1.055	0.132	1.62	0.182
Residual	20	1.630	0.081	0.01	
Rep.Crop_system.Organics.*Units* stratum	45	331.795	7.373		
Total	89	348.257			

Ikombe season 4

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	1.105	0.553	2.13	
Rep.Crop_system stratum					
Crop_system	4	8.463	2.116	8.15	0.006
Residual	8	2.076	0.260	0.07	
Rep.Crop_system.*Units* stratum					
Organics	2	4.290	2.145	0.61	0.548
Crop_system.Organics	8	0.127	0.016	0.00	1.000
Residual	65	229.301	3.528		
Total	89	245.362			

Tuber yield

Katangi Year 1

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	336.71	168.35	11.21	
Rep.Crop_system stratum					
Crop_system	4	442.77	110.69	7.37	0.009
Residual	8	120.13	15.02	1.44	
Rep.Crop_system.Organics stratum					
Organics	2	345.46	172.73	16.54	<.001
Crop_system.Organics	8	106.60	13.33	1.28	0.310
Residual	20	208.82	10.44	0.31	
Rep.Crop_system.Organics.*Units* stratum					
	45	1514.79	33.66		
Total	89	3075.29			

Katangi Year 2

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	131.21	65.61	2.34	
Rep.Crop_system stratum					
Crop_system	2	1787.73	893.87	31.86	0.003
Residual	4	112.21	28.05	2.13	
Rep.Crop_system.Organics stratum					
Organics	2	217.50	108.75	8.25	0.006
Crop_system.Organics	4	25.18	6.30	0.48	0.752
Residual	12	158.09	13.17	0.32	
Rep.Crop_system.Organics.*Units* stratum					
	27	1095.02	40.56		
Total	53	3526.96			

Ikombe Year 1

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	220.05	110.03	1.83	
Rep.Crop_system stratum					
Crop_system	4	1945.06	486.26	8.10	0.006
Residual	8	480.07	60.01	1.02	
Rep.Crop_system.Organics stratum					
Organics	2	1695.36	847.68	14.47	<.001
Crop_system.Organics	8	211.17	26.40	0.45	0.876
Residual	20	1171.71	58.59	1.06	
Rep.Crop_system.Organics.*Units* stratum					
	45	2487.81	55.28		
Total	89	8211.23			

Ikombe Year 2

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	404.6	202.3	1.35	
Rep.Crop_system stratum					
Crop_system	2	1198.4	599.2	4.00	0.111
Residual	4	599.8	150.0	2.27	
Rep.Crop_system.Organics stratum					
Organics	2	2672.9	1336.5	20.26	<.001
Crop_system.Organics	4	230.5	57.6	0.87	0.508
Residual	12	791.5	66.0	0.36	
Rep.Crop_system.Organics.*Units* stratum					
	27	4926.3	182.5		
Total	53	10824.0			

Nutrient balances
Katangi N balances year 1

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	5546.21	2773.11	2.34	
REP.CROPPING stratum					
CROPPING	4	35715.90	8928.97	7.52	0.008
Residual	8	9496.31	1187.04	19.34	
REP.CROPPING.ORGANICS stratum					
ORGANICS	2	3136.72	1568.36	25.55	<.001
CROPPING.ORGANICS	8	1857.83	232.23	3.78	0.007
Residual	20	1227.68	61.38		
Total	44	56980.64			

Katangi P balances year 1

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	30.146	15.073	0.40	
REP.CROPPING stratum					
CROPPING	4	686.014	171.504	4.60	0.032
Residual	8	298.483	37.310	10.21	
REP.CROPPING.ORGANICS stratum					
ORGANICS	2	2.016	1.008	0.28	0.762
CROPPING.ORGANICS	8	112.372	14.047	3.84	0.007
Residual	20	73.104	3.655		
Total	44	1202.136			

Katangi K balances year 1

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	5754.66	2877.33	1.34	
REP.CROPPING stratum					
CROPPING	4	33657.53	8414.38	3.91	0.048
Residual	8	17194.90	2149.36	69.40	
REP.CROPPING.ORGANICS stratum					
ORGANICS	2	225.72	112.86	3.64	0.045
CROPPING.ORGANICS	8	632.09	79.01	2.55	0.043
Residual	20	619.38	30.97		
Total	44	58084.28			

Katangi N balances year2

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	5655.9	2828.0	11.26	
REP.CROPPING stratum					
CROPPING	2	26788.4	13394.2	53.33	0.001
Residual	4	1004.6	251.2	1.51	
REP.CROPPING.ORGANIC stratum					
ORGANIC	2	1271.8	635.9	3.83	0.052
CROPPING.ORGANIC	4	1988.7	497.2	2.99	0.063
Residual	12	1992.5	166.0		
Total	26	38701.8			

Katangi P balances year 2

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	139.39	69.69	14.78	
REP.CROPPING stratum					
CROPPING	2	801.84	400.92	85.02	<.001
Residual	4	18.86	4.72	0.42	
REP.CROPPING.ORGANIC stratum					
ORGANIC	2	77.72	38.86	3.48	0.064
CROPPING.ORGANIC	4	59.42	14.85	1.33	0.314
Residual	12	133.82	11.15		
Total	26	1231.04			

Katangi K balances year 2

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	837.24	418.62	3.08	
REP.CROPPING stratum					
CROPPING	2	3924.33	1962.16	14.43	0.015
Residual	4	543.84	135.96	1.49	
REP.CROPPING.ORGANIC stratum					
ORGANIC	2	778.31	389.16	4.26	0.040
CROPPING.ORGANIC	4	119.26	29.82	0.33	0.855
Residual	12	1097.08	91.42		
Total	26	7300.05			

Ikombe N balances year 1

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	20444.2	10222.1	19.77	
REP.CROPPING stratum					
CROPPING	4	24047.5	6011.9	11.63	0.002
Residual	8	4135.5	516.9	2.32	
REP.CROPPING.ORGANICS stratum					
ORGANICS	2	4076.3	2038.2	9.16	0.001
CROPPING.ORGANICS	8	3575.8	447.0	2.01	0.098
Residual	20	4450.0	222.5		
Total	44	60729.3			

Ikombe P balances year 1

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	2746.37	1373.18	26.23	
REP.CROPPING stratum					
CROPPING	4	401.45	100.36	1.92	0.201
Residual	8	418.78	52.35	4.18	
REP.CROPPING.ORGANICS stratum					
ORGANICS	2	8.51	4.26	0.34	0.716
CROPPING.ORGANICS	8	67.83	8.48	0.68	0.707
Residual	20	250.75	12.54		
Total	44	3893.69			

Ikombe K balances year 1

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	6680.2	3340.1	10.54	
REP.CROPPING stratum					
CROPPING	4	15591.2	3897.8	12.30	0.002
Residual	8	2534.6	316.8	1.67	
REP.CROPPING.ORGANICS stratum					
ORGANICS	2	990.8	495.4	2.61	0.099
CROPPING.ORGANICS	8	474.9	59.4	0.31	0.952
Residual	20	3802.1	190.1		
Total	44	30073.8			

Ikombe N balances year 2

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	12248.6	6124.3	4.96	
REP.CROPPING stratum					
CROPPING	2	4809.3	2404.7	1.95	0.257
Residual	4	4935.3	1233.8	2.49	
REP.CROPPING.ORGANICS stratum					
ORGANICS	2	9099.6	4549.8	9.17	0.004
CROPPING.ORGANICS	4	1222.4	305.6	0.62	0.659
Residual	12	5952.7	496.1		
Total	26	38268.0			

Ikombe P balances year 2

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	529.53	264.77	5.38	
REP.CROPPING stratum					
CROPPING	2	823.45	411.73	8.36	0.037
Residual	4	196.93	49.23	1.53	
REP.CROPPING.ORGANICS stratum					
ORGANICS	2	643.52	321.76	9.99	0.003
CROPPING.ORGANICS	4	114.12	28.53	0.89	0.502
Residual	12	386.63	32.22		
Total	26	2694.20			

Ikombe K balances year 2

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	3915.7	1957.9	3.97	
REP.CROPPING stratum					
CROPPING	2	9287.1	4643.5	9.42	0.031
Residual	4	1972.1	493.0	1.97	
REP.CROPPING.ORGANICS stratum					
ORGANICS	2	8402.5	4201.2	16.76	<.001
CROPPING.ORGANICS	4	1486.1	371.5	1.48	0.268
Residual	12	3008.3	250.7		
Total	26	28071.8			