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The effect of push-pull management and different fertilization strategies on maize crop yield in central Kenya

Peterson Newton Muchiri Njeru

Supervisors

Professor: Joakim Hjältén

Dr. Stephen Kamande Kimani

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CBM Swedish Biodiversity Centre

Abstract

The high population pressure in central Kenya has lead to continuous cultivation with minimal application of nutrient, resulting in nutrient depletion. A study was conducted to determine the effect of 'Push-pull' (intercropping maize with desmodium and napier grass) strategy management and nitrogen application on maize grain yield and soil fertility on smallholder farmer's fields in three districts of central Kenya highlands. The experiment design was a split plot design with two factors ('Push-pull' vs monoculture and manure (5 t/ha) only vs manure and fertilizer (40 kg/ha) replicated in three areas with a total of 24 farms in central Kenya. Soil and plant samples were analyzed for macro-nutrients and micro-nutrient at the beginning and end of the season. The quality of fodders and manures was tested by measuring crude protein and fibre content, ash content and dry matter content. I found an increase in maize yield in 'Push-pull' fields compared with monocultures with only manure added (5t/ha) and the yield increased even more with modest application of fertilizer (40 Kg N/ha) combined with manure (5 t/ha). The average maize grain yield in "good" farms (i.e. both manure and fertilizer added) with 'Push-pull' cropping system was 186.4, 86.46 and 49.79 percent above the yield in, monocultures and 'Push-pull' in field with only manure, and monoculture in "good" farms respectively. There was strong significant difference ($p<0.001$) on maize grain yield between 'Push-pull' (5.52 t/ha) and monoculture (1.93 t/ha) cropping systems in the three districts of central Kenya. However, there was significant difference ($p<0.05$) on major soil and manure nutrients between good and poor farmer's categories. The reduced maize yield (between 5.52 t/ha-1.93 t/ha) was due low rainfall distribution and different fertilization strategies between farmer's categories during short rains of 2008. From management perspective, the different fertilization regimes had strongest positive effect on maize yield in well managed 'Push-pull' cropping systems.

Key words: Soil fertility, central Kenya highlands, manure, fodders, fertilizer, smallholder farmers, 'push-pull', monoculture

Content

Introduction

Crop-livestock combination in agriculture

Agriculture is the main sector of Kenya's economy and its performance greatly influences the overall economic performance of the country. The report by Government of Kenya (2002) indicated that in 2003, the gross domestic product (GDP) was US dollar 13.8 billion (current dollar) with an annual growth rate of 1 percentage. The government report further reported that approximately 74 percent and 80 percent of the active population is employed in agriculture and the people working in agriculture are smallholder farmers respectively. Although, about 80 percent of Kenyans derive their livelihoods from Agricultural activities, it contributed to 26 percent to Gross Domestic Product (GDP) in (2004) and indirectly to about 53 percent when linked to other economic sectors such as agricultural products exports, industries, etc. as suggested in World Resources Institute (2007). In addition, most people in Kenya settle in the most productive agricultural lands or live along the coast of Lake Victoria and the Indian Ocean and areas around Nairobi as well as in the central highlands. These areas support the highest population densities of more than 600 people per square kilometre. According to Lekasi *et al.* (2000) and Kimani *et al.* (2004) farmers in central Kenya are predominantly smallholders who own small farms with an average range of 0.9 ha to 1.9 ha of land for agriculture. However, a mixed farming system is the most common cropping system where farmers grow crops and keep livestock together.

A crop-livestock combination is the major agricultural system in central Kenya. Although agriculture landscapes are often associated with reduced levels of biodiversity, this is not always the case because farmers can manage their land by conserving native plants and animal species. Cropping systems contributes to agricultural biodiversity by growing multiple crop species either simultaneously or sequentially over the course of a single season. In addition, farmers in central Kenya usually grow up to eight different crop species at one time in their farms as reported by Kimani *et al* (1999). Maize (*Zea mays* L.) is the countries staple food and also important fodder crop for livestock. Maize crop is mainly grown as an intercrop with legumes such as beans (*Phaseolus vulgaris*) in Kenya. The most commonly practiced cropping system in central Kenya is either growing maize alone, intercrop of maize-bean, Beans, keeping livestock and Banana (*Musa spp*) production. Since smallholder farmer's crops and livestock remains the main system of intensive farming in central Kenya, there is a need for developing technologies that will enhance the productivity of this basic system.

The award of 2002 world food programs (WFP) to Padro Sanchez one of the pioneer in the field of soil science illustrates that soil fertility management practices is regarded as a major problem and a process of poverty alleviation in Sub-Sahara Africa (SSA). Soil fertility has affected farmers practice in general in term of food security and household income generation from their farming practices. Therefore, there is need for development of best bet to be adopted in smallholder farmer's fields in central Kenya. A mix of dairy cattle, food, and cash crops dominates high-potential agricultural lands in central and western Kenya as suggested by World Resources Institute (2007). Therefore, there has been a lot of land for competition for livestock and growing crops. Due to this fact, farmers in central Kenya have opted to adopt different cropping systems as their rescue strategy towards the need for food and livestock fodder. A quantitative and predictive scientific understanding on integrated soil fertility management in Agro-ecosystems remains insufficient as far as famers cropping systems are concerned in central Kenya. Therefore, accelerated and sustainable agriculture requires intensification, increased agricultural productivity and improved rural livelihood by investing on integrated soil fertility management as suggested by Okalebo *et al* (2006) and Kimani *et al.* (2007) in central Kenya.

Integrated soil fertility management practices are thriving in agricultural research and development of projects with increased use of organic inputs rising, both on application of manure alone and in combination with mineral fertilizers. Most of these initiatives are due to farmers' innovation and adoption in central Kenya. On contrary, a biophysical research in integrated soil fertility management (ISFM) is progressing rapidly in central Kenya (Mairura *et al.* 2007). Kimani *et al.* (2004) and Okalebo *et al.* (2006) reported increasing human population, continuous decline in soil fertility and associated low maize yield over a period of continuous cultivation due to predominantly consisting of acidic nitisols soil classes (abiotic constraints) in central Kenya. In addition, they found that nitrogen (N) and phosphorus (P) and to some extend potassium (K), are the major limiting nutrients for maize crop production in central Kenya. This was a result of nutrients removed from the soil by harvest, runoff, erosion, leaching and other pathways. Place *et al.* (2003) reported that soil fertility improvement can be achieved by use of organically based soil mineral sources from livestock manure, compost, inter-crop of legumes (dual purpose legumes) and biomass transfer techniques rather than use of commercial fertilizers. Therefore, more research is needed to evaluate farmer's practices, including farmer's innovations and integration of individual components in existing cropping systems.

Manure is the most widely used organic fertilizer by approximately 80-90 percent of the smallholder households in central Kenya (Lekasi *et al.* 2000). In addition, they reported that smallholder farmers' manure is usually of poor quality. In this regard, ten percent of the famers usually purchase manure or receive it without cost from their friends in central Kenya. On the other hand, the quality and quantity of manure depends on so many parameters such farmers' routine mode of manure management (Lekasi *et al.* (2000, 2003).

Smallholder farmers applies inadequate amount of nutrients to the soil and inappropriate and insufficient combination of organic and inorganic mineral sources leads to low crop yield (Kimani *et al.* 2001, Mafongoya *et al.* 2003). Therefore, the practice of integrating organic and inorganic nutrient sources holds a key to effective soil fertility management in the central Kenya. However, there is limited information available on the quantities of organic sources of nutrients that should be applied to the cropping systems in Central Kenya. Therefore, this study undertakes to bring more insights on existing different soil fertility management strategies in different cropping systems of central Kenya. All these sources when put together with give a clear recommendations on rates of application that would assist smallholder farmers to increase their maize production and hence poverty alleviation in central Kenya.

Central Kenya region faces huge food supply challenges due to increasing human population, limited opportunities to increase arable land and declining crop yields associated with continuous decline of soil fertility (Lekasi *et al.* 2000 and Kimani *et al.* 2007). Therefore, there is also a newly introduced cropping system known as 'Push-pull' technology. This involves intercropping maize with desmodium (*Desmodium uncinatum*) and napier grass (*Pennisetum purpureum*) in the same cropping system.

'Push-pull' technology is a simple cropping system, where desmodium legume (silverleaf and green leaf desmodium) is usually planted between the rows of the maize. Desmodium produces a smell which scares away stemborer (*Lepidopteran spp*) moths from the main maize crop Khan *et al.* (1997, 2006b). Studies by Berner *et al.* (1996) and Khan *et al.* (2000, 2002) reported that mechanism of control of stemborers by the 'Push-pull' cropping system is facilitated by the volatile chemicals produced by desmodium species *(E)*-ß-ocimene and *(E)*-4-8-dimethyl-1, 3, 7-nonatriene together with large amounts of ἀ-ocimene which repels (push) the female stemborers leading to reduced levels of infestation in the main maize crop. At the same time, napier grass produces volatile chemicals such as octanal, nonanal, naphthalene, 4-allylanisole, eugenol and linalool which attract (Pull) stemborer moths away from the main crop. In addition, studies by Khan *et al.* (2002) and Midega *et al.* (2006) have shown that African witch weeds (*Striga hermonthica*.) and maize stemborers are two major biotic constraints to efficient maize production in Sub-Saharan Africa (SSA). Maize stemborer is the most common constraint to maize production in central Kenya. Studies by Showemimo *et al.* (2002) and Oswald (2005) have reported that smallholder famers are reluctance to accept the use of herbicide spraying and resistant/tolerant crop varieties as they are limited to them due to biological and socioeconomic reasons. Therefore, 'Push-pull' cropping system promotes biodiversity by supporting a variety of plant and animal species on-farm as reported by Khan *et al.* (2000). Therefore, to ensure that 'Push-pull' continues to enjoy a strong scientific base, there is need to study soil nutrient dynamics and understand its long-term effect on soil fertility management strategies. However, this study undertakes to bring more insight on long-term effect of 'Push-pull' cropping system on soil fertility management strategies and fodder quality in different smallholder farmer's fields in central Kenya.

Since the smallholder farmers' crop and livestock remain the main system of intensive farming in this area, there is a need for developing technologies that will enhance the productivity of this basic system. Lekasi *et al.* (2000) reported smallholder farmers in central Kenya should utilize the benefits already demonstrated by Kenya Agricultural Research Institute (KARI), Tropical Soil Biology and Fertility Institute (TSBF) and International Livestock Research Institute (ILRI) projects on crop, soil and livestock combinations. Studies by Henao & Baanante (2001) and Lekasi *et al.* (2003) have reported that livestock makes an important integral contribution to the sustainability of intensive smallholder farming through contribution to soil fertility. Therefore, there is need to evaluate the cropping systems in central Kenya and understand the quality and quantity of the fodder farmers feed to their livestock. In addition, desmodium is a nutritious and perennial fodder crop which farmers can obtain quality animal feed throughout the year in situations where household human population pressures is high especially in central Kenya as reported by Khan *et al.* (2004) . Therefore, intercropping of forage legumes with cereal crops can improve livestock fodder quality and quantity on smallholder farms and meets the district milk shortfall of 40percent in central Kenya as reported by Khan *et al.* (2000) & Lekasi *et al.* (2001). On the other hand, 'Push-pull' provides other benefits such as providing reduced run-off and soil erosion, enhanced soil fertility, minimized use of agrochemicals, improved food security and increased household income to smallholder farmers (Khan *et al.* 2001).

Aim of the study

The aim of the study was to evaluate the long-term effect of 'Push-pull' cropping system management and nitrogen application on maize grain yield and soil fertility on smallholder farmer's fields in the three districts of central Kenya highlands.

Main objectives

(i) To investigate if maize grain yields can be increased by intercropping maize with desmodium and napier grass on smallholder farms in central Kenya.

(ii) To determine the long-term effect of different cropping system on soil fertility on smallholder farms in central Kenya

Hypothesis

(i) Maize, desmodium and napier grass intercrop will increase maize grain yield and the yield can be increased further with addition of fertilizer.
(ii) The use of push-pull technology will increase the level of soil nutrients on-farms.

Limitations/constraints

(i) There was low rainfall distribution during the season which lead to low maize grain yield in the three districts of central Kenya.
(ii) Fodder samples were not sufficient for carrying out statistical test.

Materials and methods

Description of central Kenya

The study was conducted in three agricultural districts of central Kenya highlands of same Agro-ecological zones (AEZs) in Murang'a south, Murang'a north and Kirinyaga districts. Central Kenya covers an area of 13,176 km^2 (1 376 600 ha) of which 965 000 ha are suitable for agriculture representing 73 percent of the total area as reported by Institute of economic affairs (2002). The currently exploited land in the province is 79 000 ha and 116 000 ha not exploited representing 83 percent and 17 percent respectively. In addition, the province comprises of smallholder farmers with their families standing at 644 000 in an average farm size of 1.5 ha as reported by Institute of economic affairs (2002). Central Kenya has the highest life expectancy of 63.7 years compared to the national average of 54.7 years but with 8.7percent home for country population leaving in central province. Most population density resides in central Kenya province in central Kenya with a population density of 282 people per km^2 of which 40 percent are below 15 years of age as reported by Government of Kenya (2002). The province has 31.4 percent incidences of poverty which is much lower than the national average of 52 percent for the period of 1997 as found by Institute of economic affairs (2002). Fig. 1 shows the study area in the three districts of central Kenya.

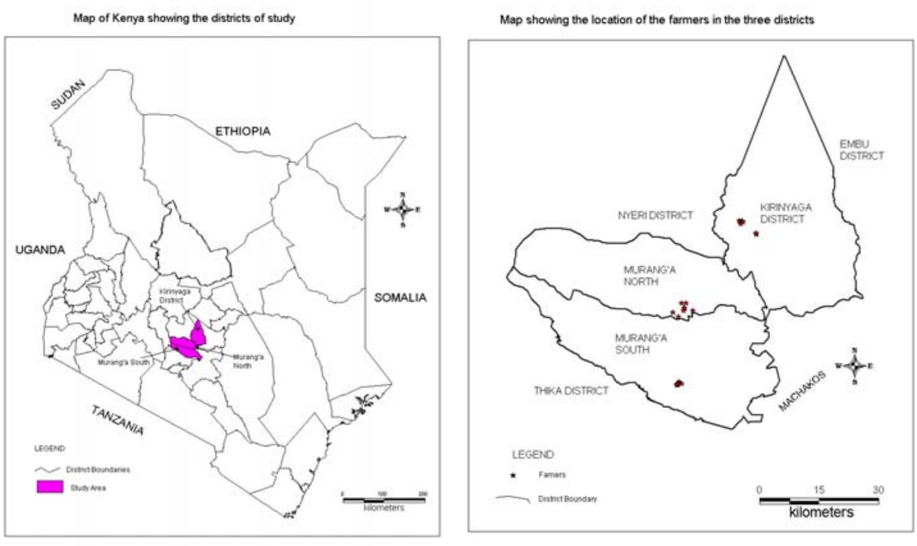


Figure 1 Map of Kenya showing study sites in the three districts of central Kenya.

Description of the three study sites in central Kenya

The study was carried out in the three districts of central Kenya highland. Murang'a south, Muranga north and Kirinyaga district occupies an area of 1 065 km^2, 930 km^2 and 1437 km^2 with Muruka, Mogoiri and Mukuure locations as the focal areas as reported by Government of Kenya (2002) respectively. On addition, Murang'a south lies between latitudes 0°45' south and 1°07' south and longitudes 36°east and 37°27' east at an altitude of 1 100 metres in the east to 2 950 metres above the sea level. Murang'a north lies between latitudes 0°34' South and 1°07' South and longitudes 36° East and 37° 27' East at an altitude of 914 metres to 3 354 metres above the sea level. On the other hand, Kirinyaga lies between latitudes 0° 1°and 0°40° south and longitudes 37° and 38° east at an altitude of 1 480 metres to 6 800 metres above the sea level. The population density of Murang'a south, Murang'a north and Kirinyaga districts is 447 375 and 309 people per km^2 in central Kenya respectively. Murang'a south, Murang'a north and Kirinyaga districts have about 91 010, 243 000 and 97 970 farm families working in agriculture sector occupying about 48 137, 16 980 and 96 938 farm holdings with an average farm size of 0.93 ha, 0.7 ha and 1.25 ha per family as reported by Government of Kenya (2002)respectively. In addition, the three districts lies within four major Agro-ecological zones (AEZs) LH1, UM1, UM2 and UM3 with major enterprises such as maize-beans, horticulture, French beans, dairy, coffee and Banana production being the major crops. However, they receives a mean rainfall between 900-2 700 mm per annum and temperatures between 14^{o}C and 30^{o}C. The soils in these districts are volcanic origin and compose of Nitisols favourable for maize crop production. In addition, the districts have two seasons long and short rains between March-June and July-December as reported by Government of Kenya (2002) respectively. The three study sites Muruka, Mugoiri and Mukuure location focal areas lies in a medium potential area of UM3 Agro-ecological zone characterized by marginal coffee zone as suggested by Government of Kenya (2002).

Questionnaire administration (Baseline survey)

A structured questionnaire with specific sections addressing the relevant subject's matters as per the project objectives was administered in the three districts of central Kenya Household interviews were carried out in the three district of central Kenya by administering structured questionnaire (Appendix 1) for identification of farmers in the project. The interview established number of farmers fields indentified for the project in the three districts. The classification results (Table 1) shows how farmers were categorized into good and poor farms fields. The survey had a task of trying to understand the current prevailing conditions that had lead to visual observed soil degradation and decreased crop yield in different farms management strategies. The classification criteria were based on respondent results on maize grain yield and mode of soil fertility management practiced previous seasons. In addition, the treatments were decided on the mode of soil fertility management regimes practiced from the year 2004 when 'Push-pull' cropping system was adopted by farmers. The study purely evaluated farmer's practices by monitoring long-term effect of different cropping systems on maize grain yield in central Kenya. A number of 52 farmers were interviewed and a minimum of four good and poorly managed farms were selected from each districts making a total of 24 farmers selected in three districts of central Kenya. Studies by Mairura *et al.* (2007) indicated that the farmer's sites can be classified by interviewing farmers based on soil fertility management regimes in their farms.

Table 1. The farm fields were categorized (Classified) from the interview results.

Number of treatments	Treatment	Fertilizer*	Manure	Status	Main plots
1	Maize	0	5 t ha-1	Control	Poor farms
2	'Push-pull'	0	5 t ha-1	Control	
3	Maize	40 kg N ha-1	5 t ha-1		Good farms
4	'Push-pull'	40 kg N ha-1	5 t ha-1		

*17, 17, 17 (NPK) fertilizer was used as the test fertilizer (17:Nitrogen, 17:Phosphorous, 17:Nitrogen)

Project experimental design (split-plot design)

Plot layout design

The experiment was a split-plot design with plots replicated three times in each farmer's sites with 0.5 m spacing between each plots. The block dimensions were approximately 11mx11m in size while the sample plot was 3mx3m where plots for each treatment was measured and marked. Similar sample plot size was used by Kimetu *et al.* (2004). There were three varieties of maize (*Zea mays* L.) Hybrids 513, 403 and Nduma 43 used as test maize crops planted in Murang'a south, Murang'a north and Kirinyaga districts respectively. On the other hand, fertilizer type (17: nitrogen, 17: phosphorous, 17: potassium) was used as test fertilizer in all the three districts of central Kenya. According to the plot layout design maize was planted row-to-row distance of 75 cm and a plant to plant distance of 30 cm within the rows. Studies by Khan *et al.* (2006b) have reported similar maize spacing during planting period in the field. In addition, the sample plot of 3mx3m gave an ideal plant population of 55 plants per plot. Therefore, the fertilizer application rate in one hole of plant was calculated at application rate of (40 Kg N/ha) by use of methods in Okalebo *et al.* (2002). The number of maize crops in the plot was used as a guideline to calculate the amount of fertilizer applied by the farmers since this study was purely farmers practice. Two maize seeds were planted per hole but later thinned to one plant per hill after 4 weeks. Desmodium in push-pull cropping system established in year (2004) through drilling system in furrows of 0.5m buffer strips between maize rows was used in the main plots and surrounded by 5m border of napier grass as reported by Khan *et al.* (2000) and Midega *et al.* (2006). In addition, the main plots for the monoculture (pure-stand) cropping system were selected from the farmer's fields where maize was grown alone from the year (2004). The maize grain was harvested at maturity from a net plot size of $9m^2$ at the end of the short rain (2008). The plot size was designed in such a way that one row on each side was left and first and the last maize plants on each row to minimize the edge effect with a similar plot set-up by Mugwe *et al.* (2007). Maize grains were manually threshed out of the cobs and the weight recorded in Kg in each plot and converted to tonnes per hectare (t/ha).

There were two farmers categories fields which were tested on-farm from the three districts if central Kenya (Table 1). The farmers who applied a combination of compost manure and fertilizer were categorized as 'good' category (Fig. 2) farms under good soil fertility management. On the other hand, farmers who applied Farm Yard Manure (FYM) directly from the cattle shed in their farms were categorized as 'poor' category (Fig. 3) farms under poor soil fertility management.

Figure 2. Good managed farmer's fields under good soil fertility management in 'Push-pull' (left) and monoculture (pure-stand) (right) cropping systems. (Photo: Njeru)


Figure 3. Poorly managed farmer's fields under poor soil fertility management in 'Push-pull cropping system. (Photo: Njeru)

The field experimental design on the ground represented farmer's categories as the main plots and push-pull arrangement and maize monoculture as the sub-plots. Each split sub-plot was treated with 5 t/ha manure (Fig. 4 & 5) as a blanket application and combination of fertilizer 40 kg N/ha and manure 5 t/ha (Fig. 6 &. 7) was applied on selected 'good' farms to test maize grain yield and soil fertility for increased nitrogen application in all the districts of central Kenya.

Figure 4. Manure application rates alone in poorly managed farmer's fields under monoculture (pure-stand) cropping system. (Photo: Njeru)

Figure 5. Manure application rates alone in poorly managed farmer's fields under 'Push-pull' cropping system. (Photo: Njeru)

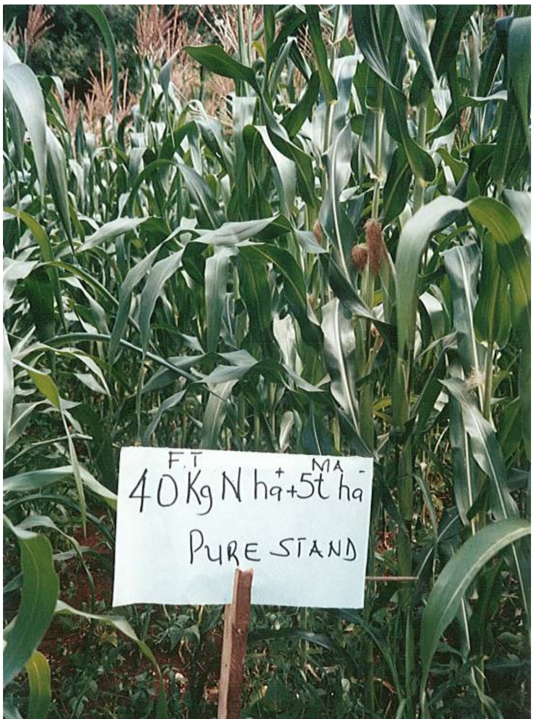


Figure 6. Combined fertilizer plus manure application rates in good managed farmer's fields under monoculture (pure-stand) cropping system. (Photo: Njeru)

Figure 7. Combined fertilizer plus manure application rates in good managed farmer's fields under 'push-pull' cropping system. (Photo: Njeru)

A total of four farms under 'good' management versus four farms under 'poor' management (Fig. 8) were selected giving a total of eight farmers in each district and three districts were studied. Therefore, there were four treatments (Fig. 8) as controls representing farmers split sub-plots in 'poorly' managed farms in all the districts. The farmer's categories were categorized based on farmers practices from their previous soil fertility management strategies on both 'Push-pull' and monoculture (pure-stand) cropping systems in the three districts of central Kenya. The experimental layout design (Fig. 8) represents field layout design in one of the study site and was replicated three times in each three districts of central Kenya.

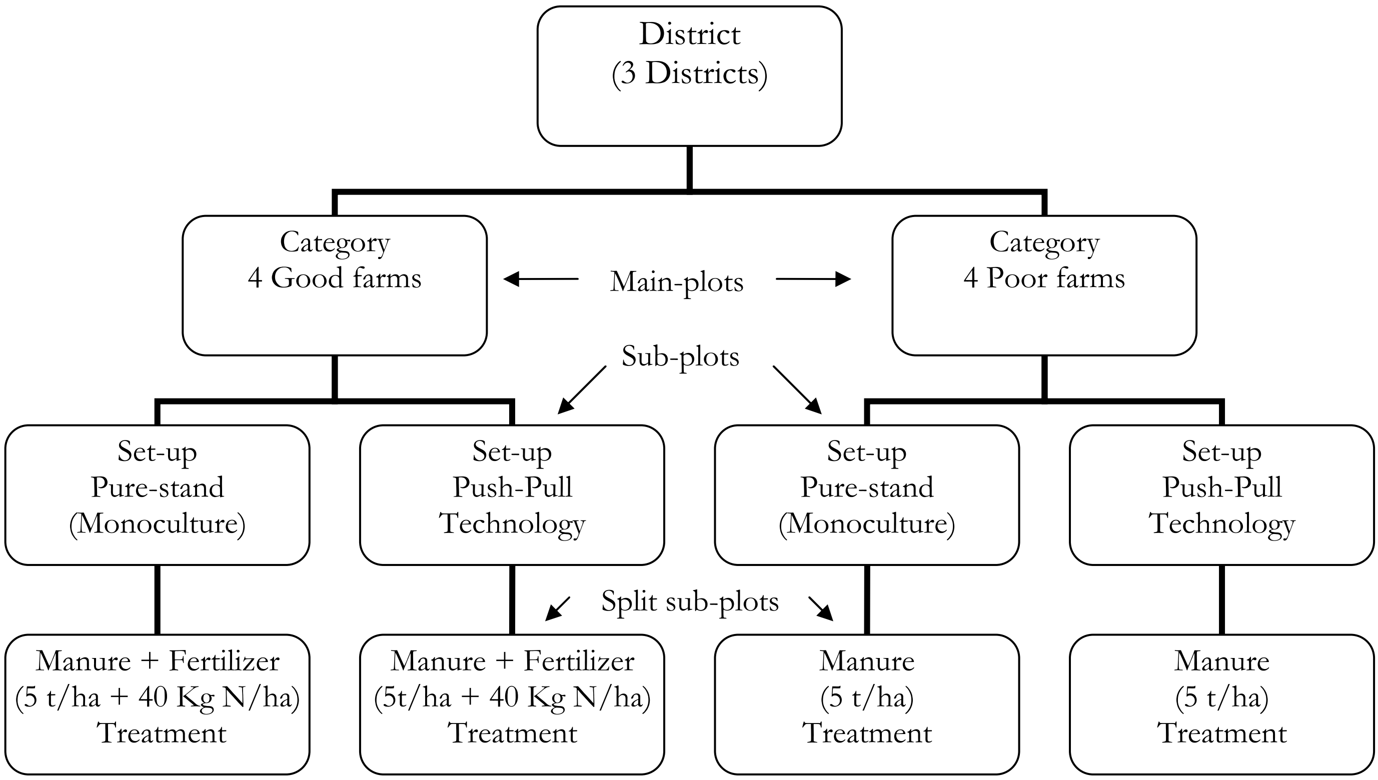


Figure 8. The experimental plot design in one of the three districts of central Kenya.

Soil and plant sampling

Soil and plant samples from this study were analyzed for micro-nutrients and macro-nutrients by the use of methods in Okalebo *et al.* (2002) which was available in the laboratories at the moment. The procedures outlined in this study is in summarized form from Okalebo *et al.* (2002), laboratory methods of soil and plant analysis for more details (see Anderson & Ingram (1993) and Okalebo *et al.* (2002). Soil was sampled in the short rain of (2008) at the beginning and the end of the season. The farmer's sites were geo-referenced after which top soil of depth 0-20 cm was sampled in replicates from the indentified farmer's categories plots. The plant samples (manure) was sampled also in replicate from each selected farmer homestead where the hip of the manure (FYM) or the compost manure was sampled in each farmers site in all the districts studied as suggested by Lekasi *et al.* (2003). However, a sub-sample (5 g) of fodder was collected at a random from one good and one poor farmer in each district from desmodium, napier grass, maize stovers and from the combination of the three fodders species (desmodium + napier grass + maize stovers) already harvested by the farmers to feed their cattle. In this regard, soil samples were composited by mixing where a sub-sample of (500 g) was sealed and transported in a cooler box at 4ºC for soil fertility attributes analyses in the laboratory. The soil were carried at 4ºC for the maintenance of the flesh soils at or near moisture holding capacity because the microbial biomass usually fluctuate greatly within a single sample due to litter input, moisture availability and temperatures as indicated in Anderson & Ingram (1993), Brooks *et al.* (1985) & Vance *et al.* (1987). The soils were first measured for percentage moisture content in the soil and then air dried and sieved through 2mm screen for macro-nutrients and micro-nutrients. The 12 soil attributes that were analyzed included PH, nitrogen, phosphorous (Available phosphorous for soil samples and total phosphorous for the plant samples), potassium, carbon, exchangeable bases calcium, magnesium, manganese, iron, copper and carbon: nitrogen (C:N) ratio was later calculated. In addition, plant samples were analyzed for extra attributes such as lignin, ash, dry matter, fibre contents. The soil and plant samples attributes were analyzed using methods in Anderson & Ingram (1993) and Okalebo *et al.* (2002). A summarized procedure on how each soil and plant samples was analyzed is outlined in (Appendix 3) and for more details instructions (see Anderson & Ingram (1993) and Okalebo *et al.* (2002).

Statistical analysis

Plot experiments were arranged in a split plot design. Statistical analysis was conducted using analysis of variance ANOVA a statistical package for social science (SPSS) software, version 11.5. The seasonal data was averaged for each treatment in all the districts studied and subjected to 3-way ANOVA where farmer's categories and cropping systems (set-up) were the grouping variables as indicated by Mairura *et al.* (2007) and Mugwe *et al.* (2007). A generalized linear model was employed to test for any significant differences among the districts, categories, cropping systems (set-up) and treatments effect on maize grain yield, soil fertility and manure quality in the soil. Because of the high variability observed for the actual maize grain yield, soil fertility attributes and manure chemical attributes both within and among the district, categories, cropping systems (set-up) and treatment, log10 (n+1) transformations of the original data was performed, which stabilized the variance for the analyses. Similarly, the data on maize grain yield, soil chemical attributes and manure chemical attributes were subjected to square root transformation and confirmed to the assumption of ANOVA as indicated by test of normality in the multivariate procedure and modified Levene's test of homogeneity of variance as suggested by Khan *et al.* (2006b). The significance level was set at $p<0.05$ for all analysis. Untransformed means are presented in tables and figures. This model was used to separate the means and estimate the main effect of different soil fertility replenishment technologies on maize grain yield in different districts, farmer's categories, cropping systems (set-up) and treatments in the experiment. The analysis model was chosen based on similar analyses by and Khan *et al.* (2006a, 2006b) and Mairura *et al.* (2007) to test treatment effect on maize grain yield results.

Results

Characterizations of the farms categories

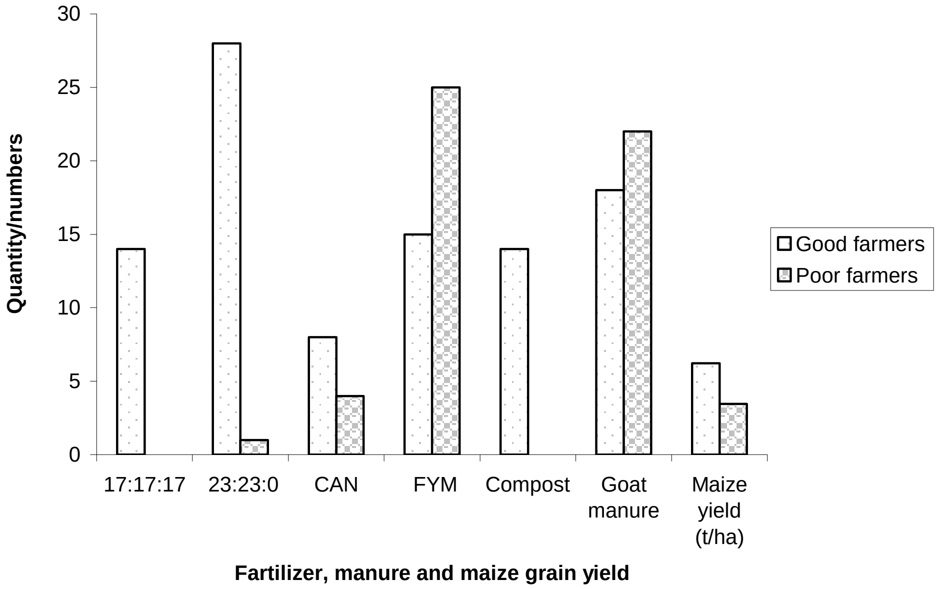
The results from the interviews were analyzed to determine the differences between the farmer's categories classified based on maize grain yield, fertilizer use and manure applications. The farms selected for the project were poor farms with manure application of (5 t/ha) (two hand full) and good farms with modest application of fertilizer (40 Kg N/ha) combined with manure (5 t/ha) from the year (2004) when they adopted 'Push-pull' technology was adopted. In addition, the results further indicated that both farmers categories interviewed benefited from 'Push-pull' cropping system on fodder quality, stemborer control, soil erosion control and nitrogen-fixed in the soil. The results (Table 2) shows that good farmers derived more benefits from maize grain yield (6.23 t/ha) as compared to poor farmers (3.46 t/ha) from the previous season.

Table 2. Differences and similarities of farmers categories interviewed from the three district of central Kenya (Mann-Whitney U-test).

Variables	Sample size (n)	Categories	Mean value	Std Deviation	U-value	P-value
Maize yield in push-pull (t/ha)	28	1	6.23	1.05	10.5	0.000
	25	2	3.46	0.58		
Use of fertilizers among farmers	28	1	1.0	0.0	14.0	0.000
	25	2	0.04	0.20		
Use of manure among farmers	28	1	1	0.0	350.0	1.0
	25	2	1	0.0		
Use of CAN fertilizer among farmers	28	1	0.29	0.46	306.0	0.28
	25	2	0.16	0.37		

*Category: 1=Good farm, 2=Poor farm

The results (Table 2) show that there was a strong significant difference ($p<0.001$) between good and poorly managed farms based on maize grain yield and the use of fertilizers at (40 Kg N/ha) in 'Push pull' cropping system. There was no significant difference ($p=1.0$) in manure use between the farmer's categories as a result of blanket application of manure in both categories in the three district. In addition, there was no significant difference in calcium-ammonium nitrate (CAN) and goat manure use between the two farmer's categories. The results were used to design project treatments from farmer's respondent. The results (Table 2) are clearly illustrated in (Fig. 9) showing how different farmer's categories used manure, fertilizers and the maize grain yield from the farmer's respondent from the three districts of central Kenya.



*17:17:17 represents fertilizer type of 17: Nitrogen, 17: Phosphorous, 17: Potassium
*23:23:0 represents fertilizer type of 23: Nitrogen, 23: Phosphorous, 0: Potassium
*CAN represents fertilizer type of Calcium-ammonium nitrate
*FYM represents manure type Farm yard manure

Figure 9. Farmer's responses on how they used manures, fertilizers and maize grain yield (t/ha) from previous season in three districts of central Kenya.

Maize grain yield (t/ha) in three districts of central Kenya

Mean (± SD) maize grain yield (t/ha) harvested in three districts

The results (Table 3) shows that the highest yield was recorded in Murang'a south in good managed farms with a mean maize grain yield of 6.27 t/ha in the 'Push-pull' strategy while the lowest maize grain yield was recorded in Murang'a North in the poorly managed farms with a mean maize grain yield of 1.13 t/ha in the pure-stand/monoculture (control). The maize grain yield was higher in both good and poorly managed farms in 'Push-pull' cropping system compared to the pure-stand (monoculture) cropping system in all the districts. In addition, there was an average increase of maize grain yield in good managed farms with 'Push-pull managements with 186.4, 86.46 and 49.79 percent compared to the controls 'poorly managed farms in monoculture, 'Push-pull' cropping system' and good managed farms in monoculture cropping system at the end of season respectively. The results (Table 3) are clearly illustrated in Fig. 10 in terms of mean values of maize grain yield in each farmer's categories in the three districts of central Kenya.

Table 3. The mean (± SD) seasonal results for the maize grain yield in 'Push-pull' and monoculture (Pure-stand). Sample size (N=12)

Districts	Categories	Set-up	End of season Maize yield (t/ha)
Murang'a South	Good	Push-pull	6.27 (0.62)
		Pure-stand	4.31 (0.59)
	Poor	Push-pull	3.19 (0.67)
		Pure-stand	2.18 (0.65)
Murang'a North	Good	Push-pull	4.63 (0.67)
		Pure-stand	3.06 (0.72)
	Poor	Push-pull	2.15 (0.49)
		Pure-stand	1.13 (0.40)
Kirinyaga	Good	Push-pull	5.67 (0.65)
		Pure-stand	3.70 (0.52)
	Poor	Push-pull	3.54 (0.46)
		Pure-stand	2.48 (0.62)

*Number in parenthesis is standard deviation
*Categories: 1=Good farms, 2=Poor farms
*Set-up: 1=Push-pull, 2=Pure stand (monoculture)

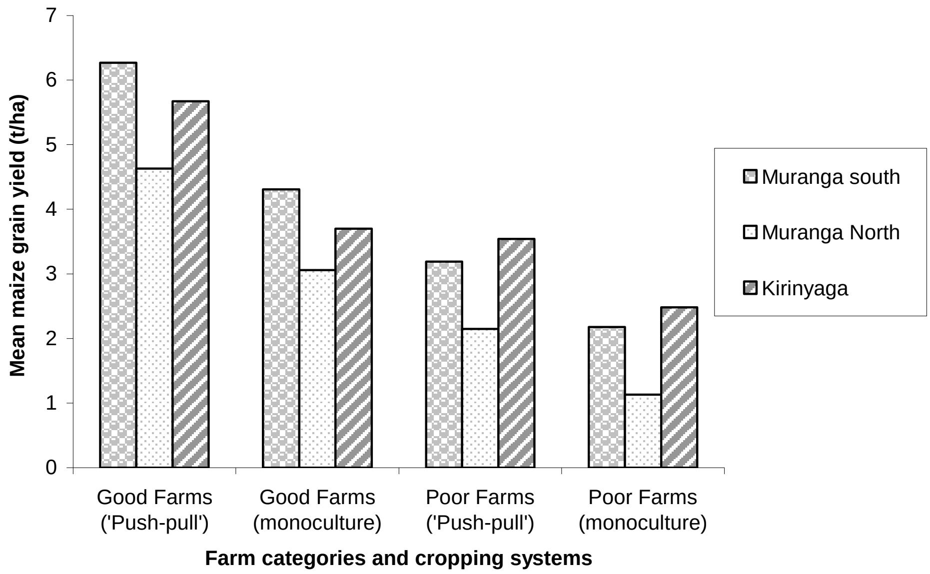


Figure 10. Maize grain yield (t/ha) in good and poorly managed farmer's under 'Push-pull' and monoculture cropping systems in three districts of central Kenya.

Maize grain yield tested between the districts, categories and cropping systems.

The results (Table 4) gives the Treatment effect tested on maize grain yield among the districts, categories and cropping systems in the three districts of central Kenya.

Table 4. treatment effect on maize grain yield among the districts, categories and cropping systems in the three districts of central Kenya.

Factors	Hypothesis df	End of the season Maize grain yield (t/ha)	
District (N=48)	2	62.46	0.000
Category (N=72)	1	470.36	0.000
Set-up (N=72)	1	207.56	0.000
District*category	2	7.24	0.001
District*set-up	2	20.49	0.61
Category*set-up	1	16.22	0.000
District*category*set-up	2	0.39	0.68

*Sample size = N

The results (Table 4) shows that there was a strong significant difference ($p<0.001$) in maize grain yield between the districts, farmer's categories, and set-up (cropping systems). In addition, there was also a significant difference ($p<0.001$) for the interactions between district*category and category*set-up (cropping systems). There were no significant difference interactions between the districts*set-up (cropping systems) and District*category*set-up. The significant differences was as result of maize grain yield being higher in 'Push-pull' cropping system compared to monoculture cropping system in both farmer's categories in all the districts. At the same time there was a higher maize grain yields in good managed farms compared to poorly managed farms in both cropping systems.

Soil chemical attributes analyzed in three districts of central Kenya

Mean (± SD) soil chemical attributes analyzed in three districts

The results are presented in Table 5, 6 &7 giving the means and standard deviation of soil chemical attributes analyzed in Murang'a south, Murang'a north and Kirinyaga districts in the beginning and at end of the season respectively (Appendix 2).

Table 5. mean (± SD) soil chemical attributes analyzed in different farmer's categories and cropping systems (set-ups) in Muruka focal area at the Beginning and end of the season in Murang'a south district. Sample size (N=12)

Seasons	Category	Set-up	PH	% N	% C	% Moist	(ppm) P	(ppm) K	(ppm) Ca	(ppm) Mg	(ppm) Cu	(ppm) Zn	(ppm) Fe	(ppm) Mn	C/N
B	1	1	5.3	0.17	1.9	19.1	49.34	934.61	1458.3	403.37	11.45	56.5	49.82	2902.1	10.7
			(0.1)	(0.01)	(0.2)	(7.2)	(5.88)	(179.2)	(1458)	(31.43)	(4.66)	(20.3)	(14.62)	(644.6)	(1.0)
E	1	1	6.6	0.15	2.27	15.3	59.73	1071.4	1380.0	475.12	0.19	1.43	2.06	2968.6	15.6
			(0.1)	(0.01)	(0.3)	(1.7)	(17.9)	(136.5)	(127.9)	(35.13)	(0.09)	(0.96)	(0.30)	(598.5)	(1.9)
B	1	2	5.3	0.17	1.9	19.2	42.10	885.26	1339.6	393.39	11.12	53.5	51.48	2920.1	11.1
			(0.2)	(0.01)	(0.1)	(7.1)	(21.1)	(426.7)	(208.8)	(21.29)	(6.47)	(26.3)	(14.62)	(716.4)	(0.6)
E	1	2	6.2	0.13	1.80	30.7	46.34	970.52	1055.0	432.99	0.19	1.25	2.26	3019.6	13.6
			(0.3)	(0.01)	(0.4)	(27)	(21.9)	(370.2)	(226.1)	(37.79)	(0.16)	(1.02)	(0.43)	(692.1)	(3.0)
B	2	1	5.7	0.19	2.5	25.2	69.31	918.16	2255.3	412.54	9.58	70.4	68.10	3539.9	13.2
			(0.5)	(0.03)	(0.4)	(2.5)	(43.3)	(389.1)	(626.4)	(93.52)	(2.18)	(19.6)	(11.26)	(152.7)	(3.4)
E	2	1	6.6	0.15	2.36	15.2	72.76	1273.7	2055.0	482.95	0.14	1.12	3.03	4251.5	16.5
			(0.3)	(0.02)	(0.3)	(1.3)	(43.2)	(388.5)	(856.1)	(127.2)	(0.06)	(0.82)	(0.62)	(839.9)	(2.8)
B	2	2	5.7	0.19	1.9	25.1	55.42	901.71	2221.4	421.16	9.25	69.5	62.42	3518.8	9.86
			(0.3)	(0.01)	(0.7)	(2.9)	(22.7)	(212.4)	(465.5)	(72.68)	(2.34)	(22.3)	(5.41)	(295.9)	(3.3)
E	2	2	6.4	0.13	2.18	17.1	62.26	957.89	1630.0	435.16	0.15	1.14	3.36	4786.8	17.2
			(0.3)	(0.01)	(0.3)	(3.3)	(21.2)	(192.1)	(492.6)	(91.94)	(0.08)	(0.72)	(0.68)	(506.7)	(2.0)

*Number in parenthesis is standard deviation
* Season: B=represent values in rows at the beginning of the season
* Season: E=represent values in rows at the end of the season
*Category: 1=Good farms, 2=Poor farms
*Set-up: 1=Push-pull, 2=Pure stand (monoculture)
*(ppm): parts per million (mg/kg)
*SD : standard deviation

Table 6. the mean (± SD) soil chemical attributes analyzed in different farmer's categories and cropping systems (set-ups) in Mugoiri focal area at the Beginning and end of the season in Murang'a North district. Sample size (N=12)

Seasons	Category	Set-up	PH	% N	% C	% Moist	(ppm) P	(ppm) K	(ppm) Ca	(ppm) Mg	(ppm) Cu	(ppm) Zn	(ppm) Fe	(ppm) Mn	C/N
B	1	1	5.57	0.18	2.5	11.9	56.02	737.19	1729.6	441.93	21.32	13.36	39.58	1499.8	14.2
			(0.3)	(0.03)	(0.8)	(2.0)	(29.71)	(78.27)	(763.9)	(78.21)	(10.72)	(7.54)	(10.06)	(690.8)	(4.0)
E	1	1	6.3	0.16	2.61	16.1	58.48	1286.4	1505.0	555.45	0.33	0.64	5.24	1239.2	16.3
			(0.2)	(0.04)	(1.0)	(3.2)	(41.17)	(620.0)	(564.2)	(115.2)	(0.18)	(0.45)	(6.21)	(863.6)	(5.0)
B	1	2	5.34	0.18	1.78	12.6	31.48	556.22	1153.1	398.51	23.32	9.91	35.27	1473.1	10.2
			(0.3)	(0.02)	(0.2)	(1.4)	(25.79)	(342.3)	(180.6)	(37.24)	(4.71)	(7.06)	(9.89)	(684.2)	(1.1)
E	1	2	6.2	0.13	1.99	18.4	54.44	970.5	1055.0	531.94	0.44	0.69	4.31	1158.7	15.7
			(0.2)	(0.04)	(0.4)	(8.2)	(29.36)	(651.1)	(298.8)	(111.7)	(0.12)	(0.48)	(4.95)	(526.8)	(1.7)
B	2	1	5.53	0.14	1.65	13.4	39.04	646.70	1627.9	597.54	11.85	11.87	34.10	1337.8	11.6
			(0.3)	(0.01)	(0.1)	(2.7)	(19.49)	(85.91)	(982.9)	(477.9)	(1.12)	(9.74)	(7.05)	(868.7)	(1.1)
E	2	1	6.2	0.15	1.81	12.3	40.21	932.6	1305.0	798.39	0.20	0.89	13.00	1254.6	12.5
			(0.4)	(0.01)	(0.4)	(1.2)	(22.68)	(352.0)	(849.7)	(604.9)	(0.03)	(0.49)	(7.35)	(825.0)	(2.7)
B	2	2	5.57	0.18	2.5	11.9	56.02	737.19	1729.6	441.93	21.32	13.36	39.58	1499.8	14.2
			(0.3)	(0.03)	(0.8)	(1.9)	(29.71)	(78.27)	(763.9)	(78.21)	(10.72)	(7.54)	(10.06)	(690.8)	(4.0)
E	2	2	6.3	0.13	1.58	11.8	31.05	654.7	1280.0	681.82	0.19	0.10	14.40	1430.9	12.5
			(0.3)	(0.02)	(0.3)	(1.7)	(15.06)	(199.2)	(767.5)	(589.3)	(0.06)	(0.98)	(5.41)	(984.7)	(2.6)

*Number in parenthesis is the standard deviation
* Season: B=represent values in rows at the beginning of the season
* Season: E=represent values in rows at the end of the season
*Category: 1=Good farms, 2=Poor farms
*Set-up: 1=Push-pull, 2=Pure stand (monoculture)
*(ppm): parts per million (mg/kg)
*SD : standard deviation

Table 7. the mean (± SD) soil chemical attributes analyzed in different farmer's categories and cropping systems (set-ups) in Mukuure focal area at the Beginning and end of the season in Kirinyaga district. Sample size (N=12)

Seasons	Category	Set-up	PH	% N	% C	% Moist	(ppm) P	(ppm) K	(ppm) Ca	(ppm) Mg	(ppm) Cu	(ppm) Zn	(ppm) Fe	(ppm) Mn	C/N
B	1	1	5.5	0.19	2.25	13.2	82.88	728.96	1610.9	441.3	14.25	20.38	56.74	1959.1	12.9
			(0.2)	(0.04)	(0.2)	(1.5)	(46.3)	(116.5)	(501.9)	(177.9)	(12.36)	(9.73)	(5.46)	(130.8)	(3.6)
E	1	1	5.7	0.15	1.9	11.1	83.66	869.46	1155.0	384.01	0.15	1.04	2.5	1703.2	13.1
			(0.4)	(0.02)	(0.4)	(3.1)	(44.9)	(270.1)	(413.7)	(108.2)	(0.17)	(0.39)	(0.4)	(229.8)	(3.0)
B	1	2	5.4	0.19	1.93	11.9	69.03	556.22	1271.8	740.35	14.85	15.94	56.19	1960.7	10.6
			(0.3)	(0.05)	(0.7)	(2.8)	(38.9)	(259.9)	(523.9)	(811.4)	(12.36)	(9.41)	(11.69)	(247.3)	(1.4)
E	1	2	5.63	0.14	1.8	11.0	92.0	755.76	1305.0	384.99	0.48	0.98	2.8	1703.2	13.7
			(0.5)	(0.02)	(0.5)	(2.7)	(58.4)	(262.6)	(674.4)	(57.25)	(0.75)	(0.69)	(0.8)	(365.5)	(3.4)
B	2	1	5.9	0.17	1.94	11.9	77.82	616.80	1899.2	419.55	8.32	23.22	59.93	1935.7	11.9
			(0.2)	(0.02)	(0.2)	(3.1)	(31.8)	(337.2)	(132.5)	(108.8)	(1.90)	(4.66)	(3.40)	(155.9)	(2.7)
E	2	1	5.96	0.15	2.1	12.2	105.8	1311.6	1530.0	502.55	0.11	1.22	3.1	1611.2	14.1
			(0.5)	(0.02)	(0.4)	(1.8)	(41.8)	(451.7)	(593.1)	(136.5)	(0.08)	(0.41)	(0.7)	(296.1)	(3.6)
B	2	2	5.5	0.19	2.51	12.7	57.6	334.19	1220.9	309.25	8.58	12.18	52.17	2026.4	15.2
			(0.2)	(0.09)	(0.8)	(1.5)	(24.5)	(64.29)	(260.3)	(48.02)	(3.76)	(9.11)	(10.19)	(554.6)	(6.7)
E	2	2	5.72	0.13	1.5	12.2	75.72	705.23	930.00	379.11	0.10	0.74	2.7	1419.5	12.1
			(0.4)	(0.00)	(0.2)	(0.8)	(34.7)	(206.1)	(458.3)	(100.9)	(0.10)	(0.59)	(0.7)	(308.6)	(1.6)

*Number in parenthesis is the standard deviation
* Season: B=represent values in rows at the beginning of the season
* Season: E=represent values in rows at the end of the season
*Category: 1=Good farms, 2=Poor farms
*Set-up: 1=Push-pull, 2=Pure stand (monoculture)
*(ppm): parts per million (mg/kg)
*SD : standard deviation

The results presented inTable 5, 6 & 7 give a summary of the macro-nutrients and micro-nutrients sources for the three in the three districts of central Kenya. Generally, the main macro-nutrients nitrogen, phosphorous and potassium had similar trend with high levels in 'Push-push' compared to monoculture cropping systems. But phosphorous mineral content was higher in Kirinyaga district compared to the other two sites. Similarly, the micro-nutrients, PH, moisture, carbon, iron and carbon: nitrogen (C/N) ratio had similar trend in 'Push-pull' and monoculture cropping systems in the beginning and at the end of the season in all the districts. Generally, the presence of high levels of calcium and magnesium in both cropping system slightly raised soil phosphorous (P) and lowered PH probably as a result of increased solubility of irons in all the districts. This was a result of high iron mineral source at the beginning of the season in both cropping systems. However, percentage carbon content was slightly higher in 'Push-pull' compared to monoculture cropping system but within the levels of (1.5-3.0 percent carbon) in three districts. The carbon: nitrogen (C/N) ratio was within acceptable levels (less than 20 percent) indicating that in the beginning of the season there was slightly high rates of decomposition of organic materials in the season simply increasing release of nitrogen mineral in the soil. The exchangeable bases in good and poorly managed farms under 'Push-pull' were generally high compared to monoculture cropping systems with an exception of Manganese and Copper in all three districts. On the other hand, potassium mineral was very high (>300 ppm K) in both farmer's categories with high increase in 'Push-pull' compared to monoculture cropping system in all the districts. In addition, the results (Table 5, 6 & 7) further indicate that 'Push-pull' had higher nutrient mineralization in nitrogen, phosphorous, calcium, magnesium and carbon content compared to monoculture cropping in three districts. Consequently, there were high mineral contents in both cropping systems at the beginning of the season compared to the end the season in the three districts. In all the sites, there was a stability of the macro-nutrients and micro-nutrients in all the farmer's categories at the beginning of the season as was expected probably due to crop harvest.

Soil chemical attributes tested between districts, categories and cropping systems.

The results (Table 8 & 9) shows the soil chemical attributes tested in the beginning and at the end of the season in good and poorly managed farms in three districts of central Kenya. Table 8 gives the soil chemical attributes differences tested in the beginning of the season between the districts, farmer's categories and cropping systems in the three districts of central Kenya.

Table 8. soils chemical attributes tested among the districts, categories and cropping systems at the beginning of the season in the three districts of central Kenya.

Factors	Df	PH		% N		(ppm) P		(ppm) K		% C		(ppm)Ca		(ppm) Fe		C/N	
		F	P	F	P	F	P	F	P	F	P	F	P	F	P	F	P
1	2	0.90	0.37	7.66	0.0	13.9	0.0	28.5	0.0	6.12	0.01	5.24	0.01	61.16	0.0	2.50	0.08
2	1	20.9	0.0	5.14	0.05	0.01	0.91	4.45	0.0	0.31	0.58	17.32	0.0	7.50	0.0	1.14	0.28
3	1	5.04	0.03	0.24	0.63	8.22	0.01	12.7	0.0	7.74	0.01	11.17	0.0	1.47	2.23	4.03	0.04

Note: F: represents F-values , P: represents P-values, Df: represents degree of freedom, Factors: 1=District: Sample size (N=48), 2=Farmers categories: Sample size (N=72), 3= Cropping systems (Set-ups): Sample size (N=72), (ppm): parts per million

Table 9. soils chemical attributes tested among the districts, categories and cropping systems at the end of the season in the three districts of central Kenya.

Factors	Df	PH		% N		(ppm) P		(ppm) K		% C		(ppm)Ca		(ppm) Fe		C/N	
		F	P	F	P	F	P	F	P	F	P	F	P	F	P	F	P
1	2	0.90	0.37	7.66	0.0	13.9	0.0	28.5	0.0	6.12	0.01	5.24	0.01	61.16	0.0	2.50	0.08
2	1	20.9	0.0	5.14	0.05	0.01	0.91	4.45	0.0	0.31	0.58	17.32	0.0	7.50	0.0	1.14	0.28
3	1	5.04	0.03	0.24	0.63	8.22	0.01	12.7	0.0	7.74	0.01	11.17	0.0	1.47	2.23	4.03	0.04

Note: F: represents F-values, P: represents P-values, Df: represents degree of freedom, Factors: 1=District: Sample size (N=48), 2=Farmers categories: Sample size (N=72), 3= Cropping systems (Set-ups): Sample size (N=72), (ppm): parts per million

The results (Table 8) show that there was a significant difference ($p<0.05$) of nitrogen, phosphorous, potassium, carbon, calcium, iron and carbon: nitrogen (C/N) ratio between three districts studied at the beginning of the season. In addition, there was significant difference ($p<0.05$) of PH, nitrogen, potassium, calcium and iron between farmer's categories (good and poorly managed farms (fields)) in three districts. In this regard, there was a significant difference ($p<0.05$) of PH, phosphorous, potassium, carbon, calcium and carbon: nitrogen (C/N) ratio between cropping systems ('Push-pull' and monoculture) at the beginning of the season in three districts. Generally, the results (Table 9) show that at the end of the season the results were different compared at the beginning of the season. The results (Table 9) show that there was a significant difference ($p<0.05$) of PH, phosphorous, carbon, calcium, iron and carbon: nitrogen (C/N) ratio between three districts studied at the end of the season. However, there was significant difference ($p<0.05$) of PH, nitrogen, carbon, calcium and iron between farmer's categories (good and poorly managed farms (fields)) at the end of the season in three districts. The results (Table 9) further indicated that there was a significant difference ($p<0.05$) of PH, nitrogen, phosphorous, potassium, carbon, calcium and iron minerals contents between cropping systems ('Push-pull' and monoculture) at the end of the season in three districts. The differences and similarities was of the soil chemical attributes was probably due to different fertilization regimes in the three sites studied. Table 10 shows the correlations of soil chemical attributes and maize grain yield at the beginning and end of the season.

Table 10 show a summary of the correlation of soil chemical attributes and maize grain yield in the beginning and at the end of the season in the three districts of central Kenya. The results indicate that maize grain yield had a significant difference ($P<0.05$) correlation with available nitrogen, phosphorous, potassium and carbon content in the soil. The results further indicate that indicate that available nitrogen levels in the soil had a significant difference ($P<0.05$) correlation with maize grain yield, carbon, moisture, and most of the exchangeable bases except potassium, calcium and magnesium at the beginning of the season. This indicates that increased nitrogen mineral source from nitrogen-fixation and inorganic inputs played a major role in increased maize grain yield in 'Push-pull' cropping system at the end of the season. In addition, there was a significant difference ($p<0.05$) correlation of maize grain yield with soil chemical attributes such as nitrogen, phosphorous, carbon and potassium in the soil. Consequently, there was a significant difference ($p<0.05$) negative correlation on maize grain yield with iron and magnesium mineral source probably due to soil acidity. However, there was a significant difference ($p<0.05$) correlation of calcium and magnesium which influenced soil PH and phosphorous.

Table 10. correlations among soil chemical attributes and maize grain yield in three districts of central Kenya. Sample size (N=144) (Pearson correlation)

Soil Attributes	Maize Yield (t/ha)	PH	% N	% C	(ppm) P	(ppm) K	(ppm) Ca
Maize Yield (t/ha)						0.276** (B) 0.197* (A)	
PH						0.435** (B)	0.736** (B)
% N	0.213* (A)			0.504** (A)			
% C	0.273** (B) 0.184* (A)	0.344** (A)	0.279** (B)			0.346** (A)	0.394** (A)
(ppm) P	0.213* (B) 0.190* (A)	0.507** (B)		0.172* (B)		0.455** (B) 0.507** (A)	0.385** (B)
(ppm) Mg	-0.184* (A)	0.419** (A)					0.375** (B)
(ppm) Zn		0.178* (B)	0.281** (B) 0.167* (A)			0.555** (B)	0.371** (B) 0.254** (A)
(ppm) Fe	-0.388** (A)	-0.710** (A)	0.362** (B)	0.308** (B) -0.200* (A)	-0.170* (A)		0.356** (B)
C/N		0.418** (A)	-0.443** (B) -0.176* (A)	0.700** (B) 0.748** (A)			0.254** (A)

*Letters in parenthesis represents the attributes in the rows B= before the start of season and A= at the end of season
** Correlation is significant at the 0.01 level (2-tailed)
*Correlation is significant at the 0.05 level (2-tailed)
*(ppm): parts per million (mg/kg)

Manure and fodder quality analyses (Chemical attributes)

Mean (±SD) of manure chemical attributes analyzes

The results in this section shows the mean values and standard deviation (±SD) of manure attributes analyzed from the famer's fields in the three district of central Kenya. Table 11 presents a summary of the manure attributes analyzed in farmer's fields in three district of central Kenya.

Table 11. mean (±SD) manures chemical attributes analyzed in different fields of farmer's categories in the three districts of central Kenya. Sample size (N=24)

District	Category	% N	% P	(ppm) K	% C	(ppm) Ca	(ppm) Mg	C/N	% ASH	% Fibre	% Lignin	% CP
1	1	0.93 (0.26)	0.26 (0.10)	1.40 (0.44)	8.10 (5.21)	0.67 (0.15)	0.09 (0.02)	8.71 (3.50)	70.59 (6.76)	75.40 (0.84)	12.44 (0.64)	5.80 (1.62)
1	2	0.81 (0.22)	0.19 (0.04)	1.69 (0.46)	10.50 (4.12)	0.82 (0.20)	0.08 (0.01)	12.96 (2.87)	74.25 (4.49)	83.65 (3.98)	18.13 (1.07)	5.04 (1.38)
2	1	1.52 (0.17)	0.41 (0.08)	2.17 (0.35)	7.95 (4.91)	1.25 (0.26)	0.11 (0.02)	8.69 (3.51)	59.19 (2.74)	75.36 (2.76)	12.99 (0.38)	9.51 (1.05)
2	2	0.88 (0.35)	0.38 (0.18)	1.17 (0.68)	14.12 (3.60)	0.76 (0.33)	0.10 (0.02)	12.97 (2.88)	70.42 (7.93)	82.24 (3.84)	18.88 (1.00)	5.51 (2.18)
3	1	0.98 (0.33)	0.53 (0.09)	1.41 (0.58)	7.20 (1.30)	0.88 (0.17)	0.08 (0.01)	7.70 (1.20)	70.01 (6.50)	74.66 (3.09)	8.97 (4.66)	6.15 (2.05)
3	2	0.95 (0.24)	0.42 (0.12)	1.40 (0.55)	9.30 (5.03)	1.01 (0.10)	0.15 (0.14)	9.07 (3.25)	70.51 (4.00)	81.93 (2.26)	17.80 (0.87)	5.93 (1.51)

*Number in parenthesis is the standard deviation
* District: 1= Murang'a south, 2= Murang'a north, 3=Kirinyaga,
*Category: 1=Good farms, 2=Poor farms
*(ppm): parts per million (mg/kg)
*SD : standard deviation

The results shows manure chemical attributes analyzed to measure manure quality among different farmer's categories in the three districts of central Kenya. Farmer's categories used different manure type in their cropping system where good and poor farmers used compost and Farm yard manure respectively. The result (Table 11) shows that manure from good farm fields had high nitrogen and lower carbon as compared to the poorly managed farms in all the districts. The manure carbon:nitrogen (C/N) ratio was higher in poorly managed farms compared to good managed farms. However, the amount of phosphorous in the manure was slightly higher in good farms compared to poorly managed farms in all the districts. The results further indicate that manure fibre, lignin and ash content was higher in poorly managed farms compared to good managed farms. This was probably due to manures not fully decomposed (plant material in it) with higher biomass. This was indication that manure from good farms (compost) had higher nutrients mineralization in the soil compared to manure from poorly managed farms (farm yard manure).

Manure chemical attributes differences tested between the districts, categories and cropping systems.

The results (Table 12) shows that there was a significant difference ($p<0.05$) of nitrogen, phosphorous, potassium, carbon, calcium, magnesium and carbon: nitrogen (C/N) ratio between the three districts studied. In addition, there was significant difference ($p<0.05$) of nitrogen, phosphorous, potassium, calcium and carbon:nitrogen (C/N) ratio between farmer's categories in the three districts. On the other hand, the results (Table 13) show that there was a stronger significant difference ($p<0.001$) of ash, fibre, lignin and crude protein content between the three districts. However, there was a similar trend for ash, fibre, lignin and lrude protein content between farmer's categories indicating stronger significant difference ($p<0.005$). This indicated different manure quality utilized by different farmer's categories in three districts of central Kenya.

Table 12. Manure chemical attributes tested among farmer's categories and districts in central Kenya.

Factors	Df	% N		% P		(ppm) K		% C		(ppm) Ca		(ppm) Mg		C/N	
		F	P	F	P	F	P	F	P	F	P	F	P	F	P
District	**2**	**19.68**	**0.0**	**62.92**	**0.0**	**2.99**	**0.05**	**5.27**	**0.006**	**19.6**	**0.0**	**3.75**	**0.03**	**4.59**	**0.01**
Category	**1**	**16.98**	**0.0**	**8.04**	**0.005**	**7.69**	**0.006**	**0.62**	**0.43**	**4.0**	**0.05**	**1.97**	**0.16**	**6.86**	**0.006**

*Factors: District-N=48, Categories-N=72
*F: represents F-values
*P: represents P-values
*Df: represents degree of freedom
*Factors: 1=District: Sample size (N=48), 2=Farmers categories: Sample size (N=72)
*(ppm): parts per million

Table 13. Extra manure chemical attributes tested among farmer's categories and districts in central Kenya.

Factors	Df	% Ash		% Fibre		% Lignin		% CP	
		F	P	F	P	F	P	F	P
District (N=48)	2	22.82	0.0	20.15	0.001	20.15	0.0	19.68	0.0
Categories (N=72)	1	8.05	0.005	224.39	0.0	398.09	0.0	16.98	0.0

*F: represents F-values
*P: represents P-values
*Df: represents degree of freedom
*Factors: 1=District: Sample size (N=48), 2=Farmers categories: Sample size (N=72)

There was a significant difference ($p<0.05$) in correlations of maize grain yield with manure nitrogen mineral content applied in the farmer's fields (table 14). On the other hand, there was a significant difference ($p<0.05$) negative correlations of maize grain yield with manure phosphorous, fibre and lignin content. However, there was a significant difference ($p<0.05$) correlations of nitrogen with phosphorous, potassium, calcium, carbon and carbon:nitrogen (C/N) ratio but with a negative correlation with Ash, Fibre and Lignin content in manure. In addition, there was a significant correlation of phosphorous with calcium, potassium, and carbon but with significant negative correlation with lignin and fibre content in the manure chemical attributes. The results indicate that manure quality played an important role in terms of maize grain yield in the three districts of central Kenya.

Table 14. Correlations among manure chemical attributes and maize grain yield in three districts of central Kenya. Sample size (N=144) (Pearson correlation)

Manure Attributes	Maize Yield	% N	% P
% N	0.286**		
% P	-0.183*	0.444**	
(ppm) K		0.784**	0.305**
(ppm) Ca		0.838**	0.518**
(ppm) Mg			
% Ash		-0.942**	-0.498**
% Fibre (ADF)	-0.539**	-0.274**	
% Lignin	-0.626**	-0,278**	-0.215**
% C		0.746**	0.335**
C/N		0.242**	

*Letters in parenthesis represents the attributes in the rows B=before the season and A=after the season.
ADF = Acid detergent fibre
** Correlation is significant at the 0.01 level (2-tailed)
*Correlation is significant at the 0.05 level (2-tailed)
*(ppm): parts per million (mg/kg)

Fodder quality analyses

The results in this section are presented as mean values and standard deviation (±SD) of fodder chemical attributes analyzed from randomly selected famer's fields in three district of central Kenya.

In general, the result (Table 15) shows that fodder species chemical attributes from different farmer's categories had a very slight difference (variation) between each fodder species in nutritional value in all the districts. The results further shows that fodder species from good managed farms had slightly higher nitrogen, phosphorous, potassium, dry matter content. On the other hand they had lower carbon:nitrogen ratio (C/N), lignin, ash and fibre content in all the fodders species analyzed. However, probably fodders species from good managed farms were of high nutritional value compared with fodder species in poorly managed farms. The lower lignin content in desmodium (species 1) and napier grass (species 3) shows that they were of high digestibility compared to the maize stovers (species 2) with high lignin content showing low digestibility. Similarly, desmodium (species 1) and combination of desmodium, napier grass and maize stovers (species 4) shows that they had lower fibre content with increased fodder quality as far as fibre content was concerned. On the other hand, slightly high levels of Ash contents were recorded in almost all the species greater than six percent in both categories but with slightly lower values in good managed farms. This was probably due to farmers' harvesting processes of fodder species in wet soils or due to wind which contaminated fodders with unwanted soil. This was probably due to contamination of exogenous minerals from the soil such as silica during harvesting and loading process leading to slightly high values as was expected. On the other hand, organic C was lower in good managed farms in all the species as compared to species from poorly managed farms. The higher carbon:nitrogen (C/N) of fodder species ratio from poorly managed farms compared to good farms shows that fodders species from good farms had high manure mineralization in all the three districts. However, the amount of phosphorous and nitrogen mineral sources from fodder species was slightly higher in good compared to poorly managed farms. The livestock fodder feed could be improved further by combining desmodium, maize stovers and napier grass together.

Table 15. mean (±SD) analytical data for fodders for all the three districts of central Kenya that were studied. Sample size (N=3)

Category	Fodder species	% N	% P	(ppm) K	(ppm) Ca	(ppm) Mg	% Ash	% C	C/N	% DM	% Fibre	% Lignin
1	1	2.37 (0.001)	0.22 (0.01)	0.49 (0.01)	1.50 (0.001)	0.43 (0.20)	6.34 (0.02)	42.67 (0.57)	18.03 (0.24)	58.94 (0.001)	54.57 (0.06)	2.31 (0.001)
2	1	2.12 (0.001)	0.21 (0.01)	0.48 (0.01)	1.48 (0.001)	0.46 (0.23)	7.25 (0.01)	43.90 (1.16)	20.69 (0.54)	50.33 (0.001)	55.37 (0.001)	2.95 (0.01)
1	2	1.10 (0.001)	0.18 (0.01)	2.48 (0.01)	0.21 (0.001)	0.18 (0.03)	7.78 (0.06)	36.60 (1.00)	33.39 (0.91)	70.65 (0.001)	58.30 (0.001)	15.20 (0.06)
2	2	0.96 (0.001)	0.17 (0.01)	2.47 (0.01)	0.22 (0.001)	0.21 (0.03)	8.56 (0.01)	38.30 (1.53)	39.77 (1.59)	65.03 (0.001)	60.30 (0.001)	17.48 (0.23)
1	3	2.76 (0.001)	0.19 (0.01)	4.10 (0.01)	0.64 (0.001)	0.23 (0.02)	13.88 (0.06)	36.87 (0.58)	13.36 (0.21)	53.68 (0.001)	60.69 (0.06)	5.07 (0.06)
2	3	2.68 (0.06)	0.18 (0.01)	4.80 (0.01)	0.61 (0.001)	0.23 (0.01)	15.23 (0.01)	38.36 (0.58)	14.34 (0.53)	51.33 (0.001)	62.28 (0.06)	5.96 (0.001)
1	4	1.71 (0.06)	0.18 (0.01)	2.42 (0.01)	0.64 (0.001)	0.31 (0.01)	8.55 (0.03)	36.67 (1.55)	21.44 (1.20)	59.68 (0.001)	57.57 (0.001)	8.65 (0.001)
2	4	1.38 (0.07)	0.18 (0.01)	2.37 (0.01)	0.62 (0.001)	0.28 (0.05)	8.97 (0.01)	37.31 (1.53)	27.07 (1.67)	57.33 (0.001)	59.24 (0.001)	9.06 (0.01)

*Category: 1=Good farms, 2=Poor farms
* Fodder species 1=Desmodium, 2=Maize, 3=Napier grass, 4= Combination of Desmodium + Maize stovers + Napier grass
*(ppm): parts per million (mg/kg)
*SD: standard deviation
*DM: Dry matter

Discussion

Maize grain yield and farm fertilization strategies

The results (Table 2) from the questionnaire analysis i found clear evidence that 'Push-pull' cropping system under good management had higher maize grain yield (6.23 t/ha) compared to poorly managed (3.46 t/ha) in all the three districts of central Kenya. The significant effect was due to different management strategies between the two classified farmer's categories good versus poor farms. On the other hand, similar results (Table 3) from the field experiment indicated that there was similar trend on maize grain yield between the two farmer's categories. The results from the famer's field experiments indicated that in good and poorly managed 'Push-pull' cropping system the maize grain yield was (5.52 t/ha) and (2.96 t/ha) respectively. The comparison of the two results shows that there was slightly lower maize grain yield in the fields experiment compared to the farmer's respondents from the interview. This was probably due to farmer's biasness (over estimation) from the interview or probably due low rainfall distribution during field experiments. In a similar study in central highland of Kenya, Mairura *et al.* (2007) found similar results that house hold interviews can be used to classify farmer's fields into low and high fertile soil farms as a result of crop yield and soil fertility management strategies. In this regard, similar results also by Goyale *et al.* (1992) and Murage *et al.* (2000) reported that higher maize grain was achieved in productive soils with a significant increase in soil PH, effective exchangeable bases, nitrogen and phosphorous than non-productive soils in central Kenya.

I found clear evidence that intercropping maize with desmodium and napier grass ('Push-pull') cropping system increased maize yield both in good and poorly managed farmer fields in central Kenya. The consistent higher maize grain yield (Table 3) in good managed farms under 'Push-pull' cropping system with modest application of fertilizer (40 Kg N/ha) plus manure (5t/ha) was most likely attributed by increased nitrogen application in good farms. The results (Table 4) from analysis indicated that there was significant effect on different fertilization strategies on maize grain yield in all the districts of central Kenya. The strong significant effect (Table 4 & Fig. 4) was as a result of an average maize grain yield of (5.52 t/ha) and (1.93 t/ha) in good and poorly managed farmer's fields respectively. In addition, the strong significant interactions effect was as a result of increase on average maize grain yield with (2.56 t/ha) and (1.76 t/ha) in good managed 'Push-pull' and monoculture above the controls in poorly managed 'Push-pull' and monoculture cropping systems respectively. The explanation for this might be due to different fertilization regimes between good and poorly managed farms in central Kenya. Although the lowest maize grain yield was (1.93 t/ha) obtained with the lowest input of manure (5 t/ha) from poorly managed farms under monoculture cropping system, it appears to be possible to reduce the levels of inorganic fertilizers application on-farm by smallholder farmers adopting 'Push-pull' as a whole package in central Kenya. But in most cases, smallholder farmers don't abandon their tradition monoculture cropping system which is not profitable. Similar observation was reported by Franzel *et al.* (2002) that smallholder farmers do not adopt technologies as a full package but they modify certain principles. . Therefore, decreasing soil fertility status remains the major biophysical cause of declining per capita in maize production in central Kenya highlands. Therefore, there is need to validate farmers cropping systems innovation and look for the ways of improving them on-farm in central Kenya.

The observed increase in maize grain yield (Figure 4) in good managed farms with modest application of fertilizer and manure in 'Push-pull' cropping systems demonstrated that legumes could make a significant contribution to crop production than monoculture cropping systems. Therefore, modest application of inorganic and organic mineral sources in 'Push-pull' cropping system could probably offer a sustainable solution for enhanced smallholders' food security in central Kenya. Similar findings were reported by Khan *et al.* (2006b) that 'Push-pull' cropping system had a significant effect of maize grain yield increase of 511.1 percent compared to maize monoculture cropping systems. On the other hand, similar results were reported by Kimani *et al.* (2007) that a combination of organic and inorganic mineral sources had a significant effect on maize grain yield with highest yield of (6.5 t/ha) and reduced yield was due to soil acidity in central Kenya highlands. Kimani *et al.* (2004) also found that there was 101, 111.9 and 196 percent increase with maize grain yield in central Kenya with an additional of fertilizers at 20 Kg N/ha, 40 Kg N/ha and 100 Kg N/ha respectively. Therefore, the reduced maize yield (Table 3) from (5.52 t/ha) and (1.93 t/ha) was probably attributed by poor rainfall distribution or soil acidity during the short rain season of (September-December 2008) in central Kenya.

The results (Table 10) further indicated that there was a significant increase (correlation) on maize grain yield with increase of nitrogen, phosphorous, potassium and carbon content in the soil in the three districts of central Kenya. Similar findings were also reported by Reganold *et al.* (1993), Khan *et al.* (2006b) and Mairura *et al.* (2007) that high fertile soils had a significant increase in maize grain yield compared to low fertile soils. On the other hand, there was a significant negative correlation on maize grain yield with iron content in the soil indicating that soil acidity had a negative effect to maize crop production in all the districts of central Kenya. Prasad and Power (1999), Kimani *et al.* (2007) and Mairura *et al.* (2007) found that acidic soils are commonly found in poorly managed acid soils rich in iron oxides in central Kenya. In contradiction to my expectations, there was no clear relationship between maize grain yield and carbon:nitrogen (C/N) ratio. Studies by Lekasi *et al.* (2003) and Kimani *et al.* (2004) have reported that maize grain yield increases with decreasing carbon:nitrogen (C/N) ratio in central Kenya.

The results (Table 3) indicated that manure alone never provided adequate nutrients in poorly managed farms on maize production in central Kenya. But there was a slight increase in maize grain yield in 'Push-pull' fields under poor management compared to monoculture cropping system. This was probably an indication that desmodium species maize intercrop played a major role in increased nitrogen-mineral (Table 5, 6, 7 & 11) through N-fixation on addition to manure application alone in poorly managed famer's fields. In addition, probably desmodium species also played a major role on reduced insect damage especially maize stemborer. Similar findings were reported by Midega *et al.* (2000) and Khan *et al.* (2002) that stemborers is a major biotic constraints to efficient maize production in central Kenya. Therefore, 'Push-pull' strategy is very efficient where desmodium can be used to control maize stemborer by reducing maize damage significantly by 74.7 percent than in monoculture cropping system. On the other hand, there was also significant difference between farmer's categories with regard to the manure chemical attributes tested such as ash, fibre and lignin content in the three districts as well as for the main manure chemical attributes tested such as nitrogen, phosphorous, potassium, calcium and carbon:nitrogen (C/N) ratio in all the districts of central Kenya. The reasons for this could be that compost and farm yard manures were used in good and poorly managed, farms respectively. Similar findings were reported by Lekasi *et al.* (2003), Okoko *et al.* (2003) and Esilaba *et al.* (2005), e.g. that there was higher maize grain yield with increased manure quality in terms of mineral content. They also reported that farm yard manure was of low quality compared to other compost manures in central Kenya. Another reason for the increased maize grain yield with manure nitrogen nutrient content could be a continuous application of manure in farmer's field in all the seasons resulting to accumulation of nutrients in the soil. Similar results were reported by Goyale *et al.* (1992) that nutrient accumulation on-farm can be as a result of applying organic manure over several season's in the previous seasons resulting to high soil nutrients and increased crop yield.

I found clear evidence that maize grain yield can be increased by application of high quality organic inputs (Compost) on-farm especially with modest application of fertilizers. Therefore, integration of inorganic and organic nutrients inputs could therefore be considered as better option of increasing fertilizer use efficiency and providing more balanced supply of nutrients on poorly managed farms in central Kenya. Studies by Vanlauwe *et al.* (2002), Nandwa (2003) and Okalebo *et al.* (2006) have also reported similar results, that high quality manure with high levels of nitrogen, phosphorous and potassium improves soil fertility status.

No concrete conclusion can be drawn from my study with regards to the quality of fodder species in relation to manure quality in central Kenya. One limitation was that fodder species samples were not sufficient in numbers to carry out statistical test. But the results demonstrated that the quality of fodders species was not different between each species among farmer's categories in central Kenya. However, the results demonstrated that there were slightly high levels of Ash contents in all farmers' categories. The results indicated that the Ash content was greater than six percent but with slightly lower values in good managed farms in all the species. Karin *et al.* (2007) reported similar findings, e.g. that the acceptable levels of Ash content was less than six percent and probably due to farmers fodder harvesting processes during the rain period or due to wind which contaminates it with unwanted soil minerals. Karin *et al.* (2007) further reported that contamination was probably from exogenous minerals sources from the soil such as silica during harvesting and loading processes leading to high values. The results also demonstrated that desmodium species and napier grass had lower lignin content levels, illustrating that they were of high digestibility which should increase their quality compared to the other fodder species. Tian & Kang (1998) also found that high lignin contents levels of fodder species slow down the decomposition process during the manure making process, thus affecting fodder species and manure quality. Similarly, the combination of desmodium, napier grass and maize stovers illustrated that they were of high quality as far as fibre content was concerned. In addition, the results indicated that desmodium and napier grass species were of high nutrition as compared to the other species but their nutritional value could be improved further by combining them together with maize stovers. Therefore, the results suggests that a combination of the three fodder species from 'Push-pull' cropping system could provide a high quality fodder feed for smallholder farmers livestock in central Kenya.

Fodder species from good managed farms also had slightly higher level of nitrogen, phosphorous and dry matter content and at the same time lower values in C/N ratio which also indicates they were of higher quality compared to poorly managed farms. Tian *et al.* (1998), Lekasi *et al.* (2003) and Karin *et al.* (2007) also reported that manure quality can be determined by quality of fodder species feed to livestock together and the mode of manure preparation. Therefore, there is need to validate farmers feeding regimes to their cattle and look for the ways of improving manure quality, especially for those farmers practicing 'Push-pull' cropping system for overall improvement on maize grain yield in central Kenya. .

'Push-pull' and nutrient levels on-farm

I found clear evidence that intercropping maize with desmodium and napier grass ('Push-pull) increased soil nutrients both in good and poorly managed farmer's fields at the beginning and end of the season in central Kenya. The significance difference on major soil nutrients between two cropping system provides an explanation for the higher maize grain yield in 'Push-pull' compared to monoculture cropping system. In addition to this benefit, Khan *et al.* (2006b) suggested that 'Push-pull' cropping system stands have a high potential for increasing maize grain yields by as much as 511.1 percent above monoculture cropping system due to its biological control on maize stemborers in western Kenya.

The increased maize grain in 'Push-pull' cropping system probably was as a result of increased nitrogen mineral fixation in the soil by desmodium or from inorganic mineral sources in all the districts. There was a significant increase (correlation) of nitrogen, phosphorous, potassium and carbon nutrients with the increase on maize grain yield in the three districts of central Kenya. This indicates that 'Push-pull' cropping system in both farmers' categories was playing a very important role in terms of soil fertility improvement. Reganold *et al.* (1993), Martina *et al.* (2004) and Khan *et al.* (2006a, 2006b) also suggested that the improved soil fertility could be as a result of nitrogen-fixed by legumes species in a crop intercrop. In addition, Kimani *et al.* (1999) reported that intercropping maize with legumes such as beans can increase the proportion of nitrogen mineral fixed in the soil with an average 55 to 69 percent. On the other hand, the is need for smallholder farmers to consider timely, split fertilization and intercropping fast growing tree species in their cropping systems to eliminate leaching nutrients as suggested by Gunner & Helena (2000) and Randall & Mulla (2001). However, the results (Table 5, 6 & 7) indicated that 'Push-pull' cropping system in good managed farmer's fields had higher soil nutrients compared to poorly managed fields. This was probably due to different soil fertility management strategies between the two famer's categories. The above discussion stress the need to evaluate farmers' manure preparation processes up to the final stage of application in the fields and look for the ways of improving them especially for the farmers using 'Push-pull' as their cropping system in central Kenya.

The nutrient levels were different between fields designated as 'Push-Pull' and controls fields before and end of the experiment (season). However, at the end of the experiment (season) the major nutrients levels in both cropping systems were lower compared to the beginning of the season as was expected. Similar findings have been reported by Van de Bosch *et al.* (1998). The results further indicated that nutrient levels were within acceptable levels as suggested by Murage *et al.* (2000) and Okalebo *et al.* (2000).

Soil nutrients were slightly higher in 'Push-pull' cropping system compared in monoculture cropping system in all the districts. The soil PH levels were slightly lower in monoculture cropping system and below acceptable levels, probably affecting maize crop production. This was probably due to increased solubility of irons oxides compared to 'Push-pull' cropping system. Studies by Prasad & power (1999) and Murage *et al*. (2000) reported similar finding that increased solubility of iron oxides results in decreased soil PH and lower availability phosphorous content to the growing crops. On the other hand, studies by Brejda *et al*. (2000) reported that soil PH levels never affects available soil phosphorous if is within the range of (5.5 - 7) and above or below this range, phosphorous is fixed and becomes unavailable to the growing crop. In addition, Murage *et al*. (2000) and Kimani *et al*. (2007) also found that continuous cultivations practiced by smallholder farmers is associated with acid soils in central Kenya. Therefore, this probably gives a reason why maize grain yield was lower in poorly managed farms especially in monoculture cropping system due soil acidity in the three districts of central Kenya.

The results (Table 5, 6, &7) shows that the percentage carbon content was slightly higher in both farmer's categories but slightly higher in 'Push-pull' compared to monoculture cropping system in the beginning and at the end of season, but they were within acceptable levels in all three districts of central Kenya. Nandwa & Bekunda (1998) and Lekasi *et al*. (2003) reported that a percentage organic carbon of two percent is recommended in soils under crop production. In addition, the average carbon:nitrogen (C/N) ratio was lower in the beginning compared to end of the season and was within acceptable levels but much lower in 'Push-pull cropping system in all the three districts. This could be explained by high mineralization in the beginning of the season compared to the end of the season. Lekasi *et al*. (2003), Kimani *et al*. (2004) and Probert *et al*. (2005) reported that the acceptable levels of carbon:nitrogen (C/N) ratio was below 20. But the smaller the ratio the more soil mineralization was recorded. Therefore, there was higher nutrient levels in 'Push-pull' compared to monoculture cropping system which contributed to significant maize grain yield increase in three districts of central Kenya highland.

Conclusion

From management perspective, the different fertilization regimes had the strongest effect on maize grain yield in central Kenya highland. However, 'Push-pull' cropping systems both in good and poorly managed farmer's fields also had a very strong effect on maize grain yield compared to monoculture cropping system in both farmers' categories. Thus, the observed significant increase on maize grain yield with modest application of fertilizer (40 Kg N/ha) and manure (5 t/ha) in 'Push-pull' cropping systems could be important information for smallholder farmers in central Kenya highland. Legumes could provide a significant improvement of maize crop production compared to monoculture cropping system in central Kenya. Even though, low input of manure (5 t/ha) in poorly managed farmer's fields had reduced overall maize grain yield, 'Push-pull' cropping system significant increase in maize grain yield also in these farms. Thus, it appears to be possible to reduce levels of inorganic fertilizers used in smallholder farmer's fields by adopting 'Push-pull' technology in central Kenya. Therefore, there is need for smallholder farmers to adopt 'Push-pull' technology since it is affordable and profitable to smallholder famers of central Kenya. I also suggest that there is need to minimize the use of inorganic mineral sources rich in phosphate mineral sources as they probably contributed to acidic soils in central Kenya. From environmental conservation aspect, there is need to encourage smallholder farmers in central Kenya to carry out timely application of fertilizers at different intervals of the season together with intercropping with fast growing tree species in their cropping systems to eliminate leaching nutrients. There is also a need to monitor the effect of excess nutrients in all the cropping systems with regard to environmental effects in central Kenya.

Compost manure used in well managed farmer's fields was of high quality compared to farmyard manure used in poorly managed farmer's fields in central Kenya highland. Therefore, livestock manure through composting processes in both good and poorly managed smallholder farmer's fields is an alternative option to mineral fertilizers in poorly managed farmer's fields in central Kenya highlands.

No concrete conclusion can be drawn from my study that fodder species influenced manure quality from different farmer's categories in central Kenya. This was due to sample limitation; there were no enough fodder species samples to carryout statistical analysis. There is still a need to evaluate the influence of livestock fodder species quality on manure quality as well as the effect of different mode of manure preparation on manure quality

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Appendix 1. Questionnaire

Farm No. -----
Farmers' name:
District:
Location:
Village:
Category:

What is your farm size?---
What size of the farm is occupied by the push pull?------------------------------
Number of dairy cattle do you have?----- other livestock-------------------------
Do you use monoculture cropping system in your farm------------------------
Do you use push pull in your farm?---
When was desmodium (push-pull) established (year)?---------------------
When was the Napier grass established (year)?-----------------------------------
What kind of maize varieties do you use?--
Do you use fertilizer in push-pull and in monoculture?---------------------------
Which type-------------------------------------
Amount--
Do you use the manure --------------------------------
Which type----------------------------------
Amount---
Which crops do you grow in push-pull?--
Has the push pull benefited you? If yes how?-----------------------------------
What is the approximate number of bags (90Kg) did you harvested last season? in Push-Pull--------------------
Do you use Desmodium as livestock fodder-------------------------------------
Has push pull benefited you in terms of fodder production.-------------------

Appendix 2. Mean Soil chemical properties of the three districts of central Kenya

Table 15. mean (±SE) soil chemical properties at the beginning for three districts of central Kenya. (N=36)

Category	Set-ups	PH	N	C	Moist	P	K	Ca	Mg	Cu	Zn	Fe	Mn	C/N
1	**1**	**5.5**	**0.18**	**2.2**	**14.8**	**62.75**	**800.3**	**1599.6**	**428.90**	**15.7**	**30.1**	**48.71**	**2120.3**	**12.6**
		(0.2)	**(0.03)**	**(0.56)**	**(5.3)**	**(34.33)**	**(159.9)**	**(530.9)**	**(111.8)**	**(10.0)**	**(23.3)**	**(12.63)**	**(797.8)**	**(13.4)**
1	**2**	**5.4**	**0.18**	**1.87**	**14.6**	**47.54**	**665.9**	**1254.8**	**510.75**	**16.4**	**26.44**	**47.65**	**2118.3**	**10.65**
		(0.4)	**(0,03)**	**(0.21)**	**(5.4)**	**(32.61)**	**(374.2)**	**(341.1)**	**(484.4)**	**(9.7)**	**(25.35)**	**(14.95)**	**(836.0)**	**(1.09)**
2	**1**	**5.7**	**0.17**	**2.02**	**16.8**	**62.06**	**726.2**	**1927.4**	**476.54**	**9.92**	**35.15**	**54.34**	**2271.1**	**12.24**
		(0.4)	**(0.03)**	**(0.45)**	**(6.6)**	**(36.25)**	**(323.7)**	**(707.4)**	**(292.8)**	**(2.3)**	**(28.59)**	**(16.22)**	**(1068)**	**(2.59)**
2	**2**	**5.6**	**0.17**	**1.96**	**16.6**	**49.32**	**564.45**	**1673.1**	**412.44**	**10.3**	**32.97**	**51.29**	**2392.9**	**12.12**
		(0.3)	**(0.06)**	**(0.70)**	**(6.5)**	**(23.12)**	**(281.2)**	**(674.8)**	**(198.9)**	**(3.4)**	**(30.62)**	**(13.18)**	**(1032)**	**(5.00)**

Table 17 mean (±SE) soil chemical properties at the end of the season for three districts of central Kenya. (N=36)

Category	Set-up	PH	N	C	Moisture	P	K	Ca	Mg	Cu	Zn	Fe	Mn	C/N
1	1	6.20	0.15	2.28	14.1	67.30	1075.8	1346.7	471.53	0.22	1.04	3.28	1970.4	15.00
		(0.5)	(0.25)	(0.68)	(3.5)	(37.53)	(423.6)	(424.9)	(115.3)	(0.2)	(0.71)	(3.77)	(955.5)	(3.74)
1	2	6.02	0.13	1.88	20.0	64.26	898.94	1138.3	449.97	0.37	0.97	3.12	1960.5	14.31
		(0.4)	(0.03)	(0.42)	(18)	(43.61)	(456.6)	(448.7)	(96.17)	(0.5)	(0.78)	(2.96)	(952.6)	(2.90)
2	1	6.27	0.15	2.08	13.3	72.93	1172.7	1630.0	594.63	0.15	1.07	6.37	2372.4	14.31
		(0.5)	(0.02)	(0.45)	(2.0)	(45.13)	(424.7)	(818.2)	(383.9)	(0.1)	(0.60)	(6.31)	(1516)	(3.42)
2	2	6.16	0.13	1.77	13.7	56.35	772.61	1280.0	498.96	0.14	0.96	6.77	2545.8	13.93
		(0.5)	(0.01)	(0.41)	(3.2)	(30.83)	(235.6)	(641.4)	(364.4)	(0.1)	(0.76)	(6.29)	(1731)	(3.08)

*Number in parenthesis is the standard deviation
*Category: 1=Good, 2=Poor
*Set-up: 1='Push-pull', 2=Pure stand (monoculture)

Appendix 3. Summarized analytical procedure for each chemical element in soil and plant samples as described in Anderson & Ingram (1993) and Okalebo et al. (2002).

Percentage moisture measurement

The percentage moisture content was calculated by measuring the flesh weight of the soil and then the soil was oven dried for 24 hours and measured after drying. Then the percentage moisture was calculated as follows as described in (Okalebo *et al.*2002) and calculated (Eq. 3) below.

Calculations.

$$\% Moisture = \frac{(W2 - W3)}{(W2 - W1)} * 100 \qquad (3)$$

Where W1= Weight of container
W2= Weight of container + wet soil
W3= Weight of container + oven dried soil

PH analyzes (1:2.5, soil: water)

Measurement of pH was expressed as the inverse log of the hydrogen ion concentration. Ten grams of the soil were weighed into a clean plastic container and 25 ml of distilled water was added. Then, the mixer was stirred for 10 minutes until is nearly saturated. The pH of the soil was finally measured by the glass electrode pH-meter to read and categorize the soils as saline or non-saline soils as described by (Okalebo *et al.* 2002).

Total Nitrogen and Crude protein in plant and soil

Principle: The content of total nitrogen was measured in a digest obtained by treating soils or plant samples with Hydrogen peroxide + sulphuric acid + Salicylic acid. The principal takes into account the possible omission of nitrates by coupling them with salicylic acid in an acid media to form 3-nitrosalicylic and or 4-nitrosalicylic. The compounds are reduced to their corresponding amino acid form by the soil organic matter. The hydrogen peroxide oxidizes the organic matter while the selenium compound acts as catalyst for the process and the H2S04 completes the digestion at elevated temperatures. The automated procedure for the determination of the ammonia is based on the modified Berthelot reaction where ammonia is chlorinated to monochloramine which reacts with salicylate to form 5- aminosalicylate. After oxidation and oxidative coupling a green coloured complex is formed. The absorption of the formed complex was measured at 660 nm as described by (Okalebo *et al.* 2002). The acid digestion was prepared by air-dry (<0.25,60 mesh) was weighed into a dry clean digestion tubes and 4.4 ml digestion mixture (prepared by adding 0.42g selenium powder as a catalyst) and 14 grams of lithium sulphate to 30 percent vol hydrogen peroxide and mixed well. Then 420 ml of concentrated sulphuric acid was added. The mixer was stored at 2°C to avoid further reaction. 4.4 ml of digestion mixer was added to tube with the soil and two reagent blanks. Digestion was made at 360°C for two hours until the solution remained clear and allowed to cool. The solution was made up to 75 ml mark by adding distilled water and mixed well. Acid wet digestion ensures availability of all nutrients and negligible volatilization of N. the n was analyzed as follows:

The supernatant clear solution from the well mixed solution was put in vials and arranged in labelled ranks. The automated machine was computer operated. The sampler needle was set at 75 mm base height from the bottom of the rank. The machine drew the sample on sequence as set from the computerized memory. The readings of both NH4-N and NHO3-N in parts per million (ppm) were recorded, the raw data was retrieved from the memory and necessary error collections and percentage N was calculated as described by (Okalebo *et al.* 2002). Calcuraton nitrogen (Eq. 4) and crude protein (Eq. 5) below.

Calculations:

$$\% N = \frac{Ppm * V * 100}{1{,}000 * W * 1{,}000} \qquad (4)$$

Where V= Final dilution
W = Weight of the sample digested

Calculation for the Crude protein (CP) in plant samples

$$\% CP = \% N * 6.25 \qquad (5)$$

Determination of available of available phosphorous (P) (Bray No. 2 Method)

The combination of hydrochloric acid (HCL) and ammonium fluoride (NH4F) was designed to remove easily acid-soluble forms of P, largely the calcium (Ca) phosphates and a portion of the aluminium (Al) and iron (Fe) phosphates. The NH4F dissolves Al and Fe phosphates by its complex formation with these metal ions in acid solution. In general the method has been reported widely to be useful on most acids as described in (Okalebo *et al.* 2002).
2.50g of air-dried soil (2mm) was weighed into a 250 ml plastic bottle. 50 ml of Bray P extracting solution (prepared by adding 300 ml of 1 N NH4F solution to 2000 ml of 0.5 N HCL to 7700 ml distilled water in a 10-litre container. This gave a solution, which had 0.03 N NH4F and 0.1N HCL) was added and shaken for 5 minutes. The suspension was filtered through Whatman filter paper No. 542. ten ml of each standard series solution and blanks were pippeted into 50 ml volumetric flasks. About 20 ml of distilled water was added and 5 ml of 0.8 M H3B03 (prepared by dissolving 49.4 g of Boric powder to one litre of distilled of distilled water). The Boric acid was added to react with any form of fluorides that could be present in the solution, which are likely to precipitate phosphates. Begging with the standards, 10 ml of ascorbic acid reagent (prepared by dissolving 2.108 g of ascorbic acid (C6H806) in 400 ml sulphuric acid/ammonium molybdate/antimony potassium tartrate solution and mixed well) was added into each flask and filled to the mark with distilled water. The flask were stoppered and shaken well and allowed to stand for one hour for full colour development. The solution is stable for about 24 hours. 1.0967 g of oven-dried KH2P04 was weighed and dissolved to make 250 ml with distilled water 1ml=1 mg P. this was the standard stock solution (1000 ppm P). Ten ml of the standard stock solution was diluted to 1 litre with diluted to 1 litre with distilled water (10 ppm P). This was used to prepare 0, 0.2, 0.4, 0.6, 0.8, 1.0 and 1.2 ppm P by adding pippeting 0, 1, 2, 3, 4, 5 and 6 ml of 10 ppm P solution respectively. The standards were used for calculating P in the soil. The intensity of the blue colour was read using a spectrophotometer at wavelength setting of 880 nm as described in (Okalebo *et al.* 2002).

Calculations:
The calibration curve was plotted, concentration agnaist the absorbance of the standard series (a regression curve). The intercept (C) from the curve was used to calculate the P concentration in the soil as described in (Okalebo *et al.* 2002) and calculated (Eq. 6) below.

Concentration of P mg per L in solution =Absorbance/ C-Intercept

$$Pmg\ /\ Kgor\,(ppm) = \frac{(a-b)*V*1{,}000}{1{,}000*W} \qquad (6)$$

Where a= concentration of P mg per litre in extract solution
b= concentration of P mg per litre in the blank sample
V=extract volume
W= weight of the air-dried sample

Determination of total phosphorous (P) (Ascorbic acid procedure)

The soil or plant sample digestion for the total phosphorous uses the same principle in total N (2.4.3). Ten ml of the supernatant clear wet-washed digested soil or plant tissue solution was pippeted into a 50 ml volumetric flask. About 20 ml of distilled water was added into each flask. About 10 ml of distilled water was added into each flask. Ten ml of ascorbic acid reducing agent was also added into each flask beginning with the standards. Then topped to 50 ml with distilled water, stoppered and shaken well. The solution was allowed to stand for 1 hour for full colour development. Phosphorous measurements and calculation were done as above (2.4.4 Bray No. 2) and (Eq. 6) as described by (Okalebo *et al.* 2002).

Calculations:
Concentration of P mg per L in solution =Absorbance/ C-Intercept

$$Pmg\ /\ Kgor\,(ppm) = \frac{(a-b)*V*1{,}000}{1{,}000*W} \qquad (7)$$

Where a= concentration of P mg per litre
b= concentration of P mg per litre in the blank sample
V=final volume dilution
W= weight of the oven dried sample

Organic carbon (C) content of soils

The organic carbon was determined by the wet combustion-titration method using $H2S04/K2Cr20_7^{2-}$ oxidation (Nelson and Sommers, 1975), the unused or residue K2CR207 (in oxidation is titrated against ferrous ammonium sulphate. The used K2CR207, the diffence between added and residual K2CR"07 gives the mesure of organic C content of the plant and soil sample. The method is very sentive and can be used in plant and soils with low levels organic carbon greater than five percent as described by (Anderson and ingram 1993; Okalebo *et al.* 2002).

Ground soil (0.3 of ground (60 mesh) soil was weighed into block digestion tubes, 5 ml potassium dichromate solution (prepared by dissolving 49.024 g of K2 CR207) and 7.5 ml conc. Sulphuric acid added. The tubes were placed in pre-heated block at 150 oC for expertly 30 minutes, removed and allowed to cool. The digest was quantitatively transferred to 100 ml conical flask and 0.3 ml (3 drops using a dropper) of the indicator solution (prepared by dissolving 1.485 g of 1, 10 ortho-phenanthroline monohydrate (C12H8N2.H20) in 100 ml of 0.025 M ferrous sulphate (0.695 g of ferrous sulphate, FeS04.7H20 in 100 ml of distilled water) was added. Using a magnet stirrer to ensure good mixing, the digest was titrated with ferrous ammonium sulphate solution, the end point was a colour change from greenish to brown. The titre was recorded and corrected for three reagent blanks (T). Percentage carbon calculated (Eq. 8) below.

Titration method calculation
Percent organic carbon = T x 0.2 x 0.3/Sample weight

$$\%C = \frac{T * 0.2 * 0.3}{W} \quad (8)$$

Where W= Sample weight
T= titration volume (titre)

Exchangeable Bases in soil and plant samples

A soil sample is extracted with excess of 1 M NH4 0Ac (ammonium acetate) solution such that the maximum exchange occurs between the NH4 and the cations originally occupy exchange sites on the surface. The amounts of exchangeable sodium, potassium, calcium and in the extract are determined in the extract are determined by the flame photometry (Na and K) and by atomic absorption spectrometry (Ca and Mg). Lanthanum or strontium is added as leasing agent to prevent formation of refractory compounds, which may interfere with the determinants (e.g. phosphate). Total nutrients cations of plants and other organic material may be measured by the complete oxidation of samples using Kjeldahl procedure followed by the same procedure as for soil analyzes. Either a flame photometer or atomic absorption spectrophotometer may be used for soil and plant samples in analyzing K and Ca but flame photometer for Mg. The standards solutions containing known mixtures of both sodium and the nutrient cations are used because of interference that may occur as a result of mutual excitation between elements.

All the bases uses different hollow cathode lamp at different wavelength in the atomic absorption spectrophotometer.

Below is a summarized Procedure for analyzing bases

Two point five of air dried soil (<2nm) was weighed into clean plastic bottles with stoppers. 50 ml of 1 M ammonium acetate (NH40Ac) solution ph 7 (prepared by dissolving 77.08 g of ammonium acetate in 1 litre of distilled water) was added, shaken for 30 minutes and filtered through No. 42 Whatman paper. This soil extract ''A'' was used for Na, K, Ca and Mg determination. An internal standard within each batch of test soil was included. The plant samples were first 0.3 g oven dried (70 oC), ground plant tissue into a lebelled, dry and clean. 4.4 ml digestion mixture (prepared by 0.42 g selenium powder plus 14 g lithium sulphate to 350 ml 30 percent hydrogen peroxide and mix well then added with care 420 ml concentrated H2S04 while cooling in an ice bath then store at 2 oC the mixer is stable for 4 weeks) to each tube and digest for 360 oC for 2 hours and make upto 50 ml with distilled water and mixed well. Then the extract ''B'' follows the same procedure with the soils.

Determination of K, Na and Ca

To fall within the measurable range of the flame photometer and the atomic absorption spectrophotometer, the soil extract solution A and plant solution B was diluted 10 times for K, Na, and Ca determination. Therefore 5 ml of the soil extract solution A and B was pippeted into 50 ml volumetric flasks, 1 ml of 26.8 percent Lanthanum chloride solution (prepared by dissolving 134 g of lanthanum chloride (LaCL3.7H20) in distilled water and made to 500 ml) was added and diluted to the mark with 1 M NH40Ac extraction solution. This solution was sprayed into the flame of the photometer for the determination of Na and K or into the atomic absorption spectrophotometer flame for Ca measurements and calcurated (Eq. 9) below.

Calculation:

$$Bmg \,/\, Kgor\,(ppm) = \frac{(a-b) * V * 1{,}000}{1{,}000 * W} \qquad (9)$$

Where B= Na, Ca or K mg/Kg or (ppm)
A= concentration of E mg per litre in extract solution
B= concentration of E mg per litre in the blank sample
V= Extract volume
W= weight of the air-dried sample.

Determination of Mg by atomic absorption spectrophotometer as described by (Okalebo et al. 2002)

The soil extracts solution A and plant solution B was diluted 17-fold for the determination of Mg. Therefore, 3 ml of the soil extract Solution A and B was pipetted into 50 ml volumetric flask, 5 ml of 5,000 ppm Sr as SrCl2 was added and filled to the mark with 1 M NH40Ac extracting solution. The solution was sprayed into flame atomic absorption spectrophotometer for Mg measurement calculated (Eq. 10) below.

Calculations

$$Mgmg \, / \, Kgor \, (ppm) = \frac{(a-b) * V * 1{,}000}{1{,}000 * W} \qquad (10)$$

Where a= Concentration of Mg per litre in extract solution
b= Concentration of Mg mg per litre in the blank sample
V= extractory volume
W= weight of the air dried sample (See Okalebo *et al.* 2002 (Laboratory working manual).

Determination of Cu, Zn, Mn and Fe

Weigh 0.3 g of finely ground and dried sample in a dry and clean digestion tubes. Add 2.5 ml of the digestion (Dissolve 7.2g salicylic acid prepared by (dissolving 3.5g selenium powder in 100ml concentrated sulphuric acid heated at 300 °C) and allow to react at room temperature for at east 2 hours. Heat the tubes in a block digestor at 110 °C for 1 hour. Allow to cool and add 1 ml of 30 percent of hydrogen peroxide and mix by swirling the tubes for each addition. Transfer the content into a 50ml volumetric with distilled water. Soils or plant are first digested in a mixture of sulphuric acid, hydrogen peroxide and selenium powder as outlined in principle (2.4.3). The standards were prepared by diluting 45 ml of concentrated sulphuric 96 percent in a litre of distilled water. Stock solution of 1000 ppm for Mn, Cu, Fe, and Zn dissolved into 1.483g of potassium permanganate, 3.929g copper II sulphate pentahydrate, 7.022g of iron II ferrous ammonium sulphate hexahydrate and 4.398g of zinc sulphate heptahydrate in about 1000 ml volumetric flask and Reduce the permanganate with a few drops of Hydrogen peroxide make up to the mark with distilled water. The standard solution 50 Mn, Cu, Fe, Zn ppm dilutes with 25 ml of the stock solution in a 500 volumetric flask and make the 500 ml mark with 0.8mol litre sulphuric acid for Mn and the rest with distilled water. Then in a clean set of 100 ml volumetric flask, pippeted 0, 2.0, 4.0 8.0, 12.0, 16.0 and 20.0 ml of the standards solution and these solutions standards series contains 0, 1.0, 2.0, 4.0, 6.0, 8.0 and 10.0 Mn, Cu, Fe, and Zn/L(ppm)

respectively. Aspirate the standard series and suitable samples and blank digest into the atomic absorption spectrophotometer calibrated for Mn, Cu, Fe and Zn at wave length of 279.5, 324.7, 248.3 and 213.9 nm respectively. The digest then follows the same procedure for the exchangeable bases where they are sprayed into the atomic absorption spectrophotometer flame for Cu, Zn, Mn and Fe measurements.
The calculation remains the same with the rest exchangeable base except that each uses it own standards (Eq. 10).

Determination of organic carbon and Ash content in plant samples

The sample is ignited in a muffle furnace to a final temperature of 550 °C. The loss in weight represents the moisture and organic matter content of the sample while the residue represents the Ash. 10g of well mixed air dry (<2mm) manure sample of a known moisture content in a dry porcelain or nickel crucible. Heat slowly in furnace by raising temperature setting in steps (10, 200 and 550 °C). The final temperature setting of 550 °C should be maintained for 8 hours. Remove the crucible containing a greyish white ash. Cool in a desiccator and weigh.

Calculation
The percentage Ash and organic matter are calculated by the differences in weight of the crucibles before and after combustion.

$$\%Ash = \frac{(W3 - W1)}{(W2 - W1)} * 100 \qquad (11)$$

$$\%C = 100 - \%Ash \qquad (12)$$

Where W1= the weight of the empty, dry crucible
W2= the weight of the dry crucible containing sample
W3= the weight of the dry crucible containing sample following ignition
Note the weight of the Ash=W3-W1.

Determination of Lignin content in Acid-detergent fibre for the plant samples

The acid detergent fibre is determined from the plant material by boiling with sulphuric acid. Acid solution of Cetrimethyl Ammonium Bromide (CTAB) under controlled temperatures. The CTAB dissolves nearly all the nitrogenous constituents. The acid hydrolyses the starch to leave a residue containing Lignin, Cellulose and the Ash. The lignin is removed by buffered permanganate solution and than cellulose is determined by weight loss upon ashing. Weigh 1.0g of the plant sample (W1) into 250 ml round bottom flask with a glass joint to later fix a reflux condenser. Add 100ml of the CTAB/sulphuric acid and add a few drops of anti-foam agent. Connect the condenser and reflux for one hour. Filter through a vitreosil crucible (No.1) of known weight (W2) under gentle suction. Wash the residue with three portions of 50ml boiling water then wash with acetone to remove all the colour and dry residue fibre. Place the crucible and the content in an oven at 105 ^{o}C for two hours, cool in a desiccator and re-weigh the crucible and the detergent fibre content (W3). Place the vitreosil containing the dried acid detergent fibre (ADF) in a shallow enamel pan containing cool water (1cm depth)and do not wet the fibre at this stage then add 25ml of the combined permanganate buffer solution (prepared by combining saturated potassium permanganate (by dissolving 50g potassium permanganate and silver sulphate diluted to 1,000ml with distilled water) and lignin buffer (by dissolving 5g potassium acetate, 400ml methanol diluted to 1,000ml with distilled water). Adjust the water in the pan to 2 to 3cm in order to reduce the flow of solution from the crucible and allowed to stand for 90 minutes at 20 to 25 ^{o}C. Place the crucible in a clean pan and fill with oxalic acid demineralising solution (prepared by dissolving 100g oxalic dehydrate in 1,400ml of 95 percent ethanol plus 100ml of concentrated sulphuric acid and diluted to 1 litre with distilled water) and allow to stand for 15 minutes and then filter under suction. Wash the fibre with demineralising solution until is white in appearance. Filter under suction and thoroughly was with 80 percent ethanol (prepared by diluting 1690ml of 95 percent ethanol to 2,000ml with distilled water. Filter under suction and repeat twice and was similarly with acetone. Dry the crucible for 2 hours at 105 oC, cool in a desiccator and weigh (W4) Finally, ash the content at 550 oC for 1 hour, allow to cool in a desiccator and weigh (W5). The calculation of Ash (Eq. 13), Lignin (Eq.14) and Cellulose (Eq. 15) below.

Calculations:

$$\% AshADF = \frac{(W3 - W2)}{(W1)} * 100 \tag{13}$$

$$\% Lignin = \frac{(W3 - W4)}{(W1)} * 100 \tag{14}$$

$$\% Cellulose = \frac{(W4 - W5)}{(W1)} * 100 \tag{15}$$

*ADF means the acid detergent fibre.