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Full Length Research Paper

Use of Dolichos (*Lablab Purpureus* L.) and Combined Fertilizers enhance Soil Nutrient Availability, and Maize (*Zea Mays* L.) Yield in Farming Systems of Kabete sub-County, Kenya

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Abstract

Enhanced maize (*Zea mays* L.) production in Kabete sub-County, Kenya, is constrained by low soil fertility combined with continuous unsustainable agricultural practices. The current study evaluated the effects of incorporating dolichos (*Lablab purpureus* (L.) and combined fertilizer application on soil N, P and K balances, and maize yields in Kabete field station, University of Nairobi. The experiment was carried out, between mid-March to May 2015 (long rain season - LRS) and October to December 2015/16 (short rain season -SRS). The experimental set up was a Randomized Complete Block Design with a split-plot arrangement replicated three times. The main plots were; cropping systems i.e. incorporation of dolichos (i) as an intercrop (dolichos /maize intercrop) and (ii) in rotation with maize (dolichos-maize rotation). Sole maize, without dolichos integration, was included as control. The sub-plots were fertilizer types: (i) farmyard manure (FYM); (ii) triple superphosphate (TSP) and urea; (iii) integrated organic and organic fertilizer (FYM+TSP+Urea) and (iv) no fertilizer applied (control). Top soil samples (0-20 cm) were taken at the end of each cropping season, for determination of total N and available P and K. The NUTrient MONitoring (NUTMON/ MonQi,) tool box was used to calculate N, P and K balances. Maize was harvested at physiological maturity for yield determination. Significantly ($P \leq 0.05$) high soil N and P levels were obtained in maize/dolichos intercrop with application of FYM and TSP+FYM+Urea in both LRS (0.29% and 19.6 ppm; 0.3% and 16.5 ppm) and SRS (0.34% and 28.5 ppm; 0.28% and 26.1 ppm), respectively. The soil K (cmol/Kg) levels were significantly ($P \leq 0.05$) high in maize/dolichos intercrop with FYM application during the SRS (1.3) and LRS (1.8). Less negative N balances (-9.1 kg ha^{-1}yr^{-1}) were obtained in maize/dolichos intercrop with FYM application while pronounced N (-20.1 kg ha^{-1}yr^{-1}) losses were realized in maize/dolichos intercrop with TSP+Urea application. P losses were higher in maize/dolichos with TSP+FYM+Urea (-2.2 kg ha^{-1}yr^{-1}) and TSP+Urea (-2.4 kg ha^{-1}yr^{-1}) application. Significantly ($P<0.5$) higher K losses (kg ha^{-1}yr^{-1}), with TSP+Urea application, occurred in dolichos/maize intercrop (-6.7), dolichos-maize rotation (-4.9) and in sole maize (-4.5). Maize grain yields (t ha^{-1}) in the SRS and LRS were significantly ($P \leq 0.05$) higher in dolichos/maize intercrop with application of TSP+FYM+Urea (5.6 and 4.5) and FYM (5.4 and 4.9) with no significant differences across seasons. Dolichos-maize rotation with TSP+FYM+Urea application resulted in significantly higher dry matter yields (9.4 t ha^{-1}) compared to intercrop with FYM (9.5 t ha^{-1}) application in the SRS. When compared across seasons, soil NPK levels, maize grain and dry matter yields were consistently higher in maize/dolichos intercrop with application of FYM and TSP+FYM+Urea in the SRS compared to LRS. Pronounced negative N and P balances were realized in maize/dolichos intercrop and dolichos-maize rotation with application of FYM and TSP+FYM+Urea. It is evident that improved soil nutrient status led into increased maize yields. With the increase in maize yields, however, significant nutrient losses were realized. Adoption of the best performing technology, incorporation of dolichos in maize as an intercrop with application of FYM and TSP+Urea, ought therefore to be tapered (in the short run) with prudent nutrient management strategies to minimize nutrient losses through harvested products for cropping system sustainability.

Key words: Farm Yard Manure, Intercropping, NUTMON/MonQi, Nutrient balances, Rotation, Triple Super Phosphate, Urea; Soil nutrient Availability

Introduction

Soil fertility degradation is recognized as a major factor underlying the low crop productivity in sub-Sahara Africa (SSA). It affects the livelihoods of the population that depends directly on agriculture for food and income (Sanchez, 2002). Several reasons for the declining soil fertility have been advanced and include; continuous cropping with little or no replenishment of nutrients removed through either crop harvests or other losses such as leaching and likely soil degradation (Kibunja *et al.,* 2007). In Kenya, poor soil fertility is the most widespread, dominant limitation on maize yields, a major staple and food security crop (Mugwe *et al*., 2009; Henao and Baanante, 2006; KARI, 2002).

The smallholder farmers of Kabete sub-County are prone to and experience decline in soil fertility and crop productivity (Kibunja and Mugendi 2010). This is because, majority of the smallholder farmers lack financial resources to access sufficient amount of chemical fertilizers to replace soil nutrients removed through harvested crop products and crop residues (Jama *et al*., 2000). Additionally, mineral fertilizers use has also faced important limitations due to highly variable nature of soils and inherent low nutrient conversion efficiency (AGRA, 2007).

On the other hand, organic fertilizer, although mostly available, is of low quality due to poor quality livestock feeds (Lekasi et al., 1998; Lukuyu et al. 2011)). Adoption of improved and sustainable technologies that are within the farmer's socio-economic circumstances, to enhance soil fertility and thereby food productivity and security (Landers, 2007; Goletti and Yudelman, 2000) without causing damage to the environment (Topliantz *et al.,* 2005) is imperative. Such technologies include integrated soil fertility management practices (ISFM), which involves intercropping cereals with legumes as one of its main components (Sanginga and Woomer, 2009). This practice is an attractive strategy for increasing productivity and land labour utilization per unit area of available land through intensification of land use in small holder farms (Seran and Brintha, 2010).

Furthermore, intercropping cereals with legumes has huge capacity to replenish soil mineral nitrogen through its ability to biologically fix atmospheric nitrogen (Giller, 2001) and not compete with maize for nitrogen resources (Adu-Gyamfi *et al*., 2007 and Vesterager *et al*. (2008). Additionally, higher and sustained yield could be obtained through use of combined inorganic and organic fertilizers with integration of legumes (Bhatti *et al.,* 2008). To assess the impact of agricultural technologies on soil fertility and ensure future sustainability, calculation of nutrient balances is necessary (Vlaming *et al*., 2001), especially in sub-Saharan Africa where it is becoming increasingly difficult to satisfy short term production needs and long term sustainability demands concurrently (de Jager *et al*., 1998).

Farm productivity can be measured by quantifying nutrient balances (Segala *et al*., 2010), which are useful indicators in assessing the sustainability of farming systems (de Jager *et al*., 1998). NUTMON (now known as MonQi), a nutrient monitoring tool, has been applied to study ecological sustainability of various nutrient management strategies in different environments (Priess *et al.,* 2001; Onwonga *et al.,* 2015). The current study evaluated the effects of integrating dolichos with combined application of inorganic and organic fertilizers on soil nutrient status and balances, as a basis for determining system ecological sustainability, and maize yields in Kabete, sub- County, Kenya.

Materials and Methods

Site Description

The field experiment was conducted at Kabete field station of the University of Nairobi, located about 10 km north of Nairobi, during the short rain season (SRS) of 2015/2016 and long rain seasons (LRS) of 2015. The field station (1940 m asl), is located at latitude 1° 15' S and longitude 36° 41' E and is categorized under agro-ecological zone III (Sombreak *et al*., 1982). The climate is typically sub humid with minimum and maximum mean temperatures of 13.7°C and 24.3°C, respectively. The site has a bimodal rainfall distribution (mid-March to May, long rains and October to December, short rains). The average annual precipitation is 1000 mm (Jaetzold *et al*., 2006). Soils at the research site are predominantly deep red Humic Nitisols containing 60-80% clay (WRB, 2006). The measured initial soil characteristics (0-20 cm depth), (Table 1) indicated; clay texture, moderate acidity, moderate organic carbon, moderate nitrogen, high potassium and low available P levels according to Landon (1991) soil nutrient classification method.

Table 1: Initial physical and chemical soil properties at experimental site (0-20 cm depth)

Soil property	Units	Value	Soil Property	Units	Value
Soil pH (H20)	-	6.1	Ca	$CmolKg^{-1}$	8.22
Soil pH (CaCl2)	-	5.7	Mg	$CmolKg^{-1}$	1.6
Available P	$Mg Kg^{-1}$	11	% Sand	%	6
Total N	%	0.28	% Silt	%	28
Organic C	%	1.96	% Clay	%	62
Potassium	$CmolKg^{-1}$	1.07	Textural Class	-	Clay

Treatments and Experimental design

The treatments used in the study were inorganic and organic fertilizers applied singly or in combination, and dolichos incorporated as an intercrop or grown in rotation with maize. The experimental set up was a Randomized Complete Block Design with a split-plot arrangement replicated three times. The main plots were; cropping systems i.e. incorporation of dolichos (i) as an intercrop (dolichos /maize intercrop) and (ii) in rotation with maize (dolichos-maize rotation). Sole maize, without dolichos integration, was included as control. The sub-plots were fertilizer types: (i) farmyard manure (FYM); (ii) triple superphosphate (TSP) and urea; (iii) integrated organic and organic fertilizer (FYM+TSP+Urea) and (iv) no fertilizer applied (control).

Agronomic practices

Land was prepared manually using hand hoes followed by secondary cultivation which involved leveling. Planting was done by placing seeds directly into the planting hole. Two maize (Duma 43 variety) seeds were planted per hill, at a depth of about 5cm and spacing of 75 cm by 30cm in respective plots (Table 2).

Table 2: Treatments and crop sequence during the LRS and SRS of 2015/2016

Cropping System	Treatments	Description	Fertilizers	Crop/Season	
				LRS	SRS
Monocrop/Sole maize	1	Maize Monocrop	Control	Maize	Maize
	2	Maize Monocrop	FYM	Maize	Maize
	3	Maize Monocrop	TSP+FYM+Urea	Maize	Maize
	4	Maize Monocrop	TSP+Urea	Maize	Maize
In rotation	5	Lablab-Maize	Control	Lablab	Maize
	6	Lablab-Maize	FYM	Lablab	Maize
	7	Lablab-Maize	TSP+FYM+Urea	Lablab	Maize
	8	Lablab-Maize	TSP+Urea	Lablab	Maize
As an intercropping	9	Lablab/Maize	Control	Lablab/Maize	Lablab/Maize
	10	Lablab/Maize	FYM	Lablab/Maize	Lablab/Maize
	11	Lablab/Maize	TSP+FYM+Urea	Lablab/Maize	Lablab/Maize
	12	Lablab/Maize	TSP+Urea	Lablab/Maize	Lablab/Maize

Key: FYM – Farm Yard Manure; TSP – Triple Superphosphate; Control – no fertilizer; LRS – Long Rain Season; SRS – Short Rain Season.

Farm yard manure (10 t ha^{-1}), applied in planting holes a week to planting, TSP and Urea (each applied at 60 kg ha^{-1}) were placed in the planting holes (banding) at about 5 cm deep, and mixed well with soil before planting, in both the LRS and SRS. In rotation system, two seeds of dolichos, black variety, were planted at a depth of about 5 cm and spacing of 75 cm by 30 cm. In the intercrop, dolichos was planted between maize rows at the same inter-plant spacing as in dolichos pure stands, at the start of the LRS of 2015 and SRS of 2015/16. Sole dolichos was planted, at spacing of 75 cm by 30 cm, during LRS and rotated with maize in the SRS. Thinning to one seedling per hill was done four weeks after planting for all crops. Weeding was done by hand hoeing, three weeks after crop germination and at flowering.

Soil, Plant sampling and analysis

Soil sampling and analysis

Composite top soil (0-20cm) samples were collected in a zigzag manner before set up of the experiment, for determination of initial physical and chemical properties (Table 1). Subsequent, composite samples were collected from each plot at crop harvest for determination of Total N, available P and extractable K, and quantification of N, P and K flows and balances. The samples were collected between the plants within a row in every plot, using a 5cm diameter soil auger. The soil samples were kept in polythene sampling bags, sealed and transported to laboratory in portable cool boxes. Air-dried soil, sieved through 2 mm mesh was analyzed for soil available P using the Mehlich III Double Acid method (Mehlich *et al.,* 1984), total N by Kjeldahl digestion method (Black, 1965;

Anderson and Ingram, 1993), exchangeable K by Flame Emission Spectrophotometry (Jonca and Lewandoski, 2004) and texture using hydrometer method (Black *et al*., 1965). Undisturbed core samples were used in bulk density determination (Blake 1965). Soil organic carbon was determined using Walkley-Black wet oxidation method (Nelson and Sommers, 1982).

Plant sampling and analysis and yield determination

Grain (adjusted to 13% moisture content) and dry matter yield (70 ^{0}C) were determined at crop physiological maturity, from three center rows of each plot. Grain yield was determined by weighing seeds from the sampled plants per plot and converting the yield to kg ha^{-1}. For dry matter measurement, plant stems were cut immediately above ground and weighed to determine fresh weight. Sub-samples were taken to the laboratory and oven dried at 70 °C for 48 hours and thereafter weighed for DM determination.

The grain and DM yields were expressed on hectare basis using the following formula:

Grain yield (kg/ha) = Grain yield m^2 (kg) x 10000.

The dried plant samples were finely ground and 5 grams used analysis of N and P concentration using the methods described by Okalebo *et al. (*2002). K was measured by Flame Emission Spectrophotometry (Jońca and Lewandoski, 2004).

Quantification of Nutrient Balances

The NUTmon MONitoring (NUTMON) Tool box (now known as MonQi) was used in quantification of nutrient (N, P and K) flows and balances (Vlaming *et al*., 2001). The toolbox has within it a structured questionnaire, a database and a simple static model. Data entry and extraction is possible from the database through a user interface to produce inputs for the model. A detailed description of the model is provided in the NUTMON manual (Vlaming *et al*. (2001); Surendran and Murugappan, (2006) and also on www.monqi.org website.

Farm Conceptualization

In NUTMON, farms are conceptualized as a set of dynamic units depending on management, which form the source and destination of nutrient flows. Consequently, the following units relevant to the study were defined: Farm Section Unit (FSU), these are areas within the farms with relatively homogenous properties; Primary Production Unit (PPU)/crop activities, formed the piece of land with different possible activities such as one or more crops which are either annual or perennial. These units are located within FSUs; Stock, the amount of staple crops, residues and fertilizers temporarily stored for later use; Outside (EXT): external nutrient pool consisting of markets (de jager *et al.,* 1998).

The study assessed the nutrient balances at primary production unit. The method used was adjusted to enable generation of output within an experimental area. Consequently, the blocks/replicates were the equivalent of the FSU, the primary production units (PPUs) were the plots comprising of the 12 treatments (Table 2). In line with de Jager *et al*. (1998), the modified concept upheld nutrient inputs (Table 3) through mineral fertilizer (IN 1) but omitted that through subsoil exploitation (IN 6) because of the shallow to moderate rooting depths (0-20cm) of the crops involved.

Table 3: Sources of nutrient flows into and out of the farm

IN flows	OUT flows	Internal flows
IN1 Inorganic fertilizers	OUT1 Harvested products	FL1 Feeds
IN2a Organic inputs: purchased manure and feeds	OUT2 Crop residues and manure	FL2 Household waste
IN2b Organic inputs: manure from grazing outside the farm	OUT3 Leaching	FL3 Crop residues
IN3 Atmospheric deposition	OUT4 Gaseous losses	FL4 Grazing of vegetation
IN4 N-fixation	OUT5 Erosion	FL5 Animal manure
IN5 Sedimentation	OUT6 Human excreta	FL6 Farm products to household

Source: De Jager *et al*. (1998)

Fertilizers (IN1 - TSP/Urea and IN 2a - FYM), (IN 3), atmospheric deposition and (IN 4) biological nitrogen fixation were identified as nutrient flows into PPU. Nutrient output flows were identified as crop harvest (OUT 1), leaching (OUT 3), volatilization (OUT 4) and soil erosion (OUT 5). Flows and balances of N, P and K were calculated at the end of the experimental period through independent assessment of the major inputs and outputs. Harvested crop products were analyzed for N, P and K content as a basis of quantifying the respective nutrient amounts contained in the harvested products.

Calculation of Partial and Full nutrient balances

To distinguish between primary data and estimates, two different balances were calculated in NUTMON: the partial balance at farm level (IN1 + IN2) - (OUT1 + OUT2) made up solely of primary data and the full balance (ALL IN - ALL OUT) made up of a combination of the partial balance and the immissions (atmospheric deposition and nitrogen fixation) and emissions (leaching, gaseous losses, erosion losses) from and to the environment (Vlaming *et al.,* 2001). In this study, particular interest was on how cropping systems and application of fertilizers affect the full balances of major nutrients, N, P and K in soil after harvest. Calculation of nutrient balances therefore involves a number of methods: Product flows for N, P and K (IN 1 and IN2 and OUT1 and OUT 2) (obtained from experimental records and through sampling and analysis crop products) and use of transfer functions (IN3, IN4 and IN 5, and OUT 3, OUT4, OUT5 and OUT6) (van den Bosch *et al.,* 1998). NUTMON-toolbox calculated nutrient balances by subtracting sum of nutrient outputs from sum of nutrient inputs and presents then in Kg ha^{-1} (van den Bosch *et al.,* 1998).

Statistical Analysis

The data recorded on soil nutrients and yields was subjected to statistical analysis of variance using GenStat statistical software (Payne *et al.,* 2006). N, P, and K balances for the various PPUs were generated by NUTMON-toolbox and then exported to GenStat 15th Edition, 2012 for further analysis. The effects of cropping systems and application of fertilizers on soil nutrient balances were compared by analysis of variance (ANOVA) and separated using the Fisher's Protected Least Significant Differences P ≤ 0.05.

Results and Discussions

Soil Nutrient Concentrations as affected by use of dolichos and fertilizers

Available Phosphorus

During the SRS, significantly (P≤0.05) high soil available P was obtained in sole maize with FYM, TSP/Urea and TSP+FYM+Urea application. This was however not significantly different from dolichos-maize rotation, with FYM, TSP+FYM+Urea and TSP/ Urea application and dolichos/maize intercrop with FYM and TSP+FYM+Urea application in the SRS. The control treatment had significantly lower amounts of available P than other treatments, with no significant differences across cropping systems. During the LRS, the P values were not significantly different across cropping systems and fertilizer type (Table 4).

Table 4: Effect of dolichos incorporation and fertilizer application on available P (ppm)

Season	Treatment	Dolichos-Maize	Maize/dolichos	Maize
LRS	CONTROL	11.4^{a}	11.0^{a}	11.0^{a}
	FYM	17.1^{abcde}	19.6^{abcdef}	17.2^{abcde}
	TSP/FYM/UREA	13.3^{ab}	16.5^{abcde}	14.6^{abc}
	TSP/UREA	15.4^{abc}	16.1^{abcd}	16.0^{abcd}
	Mean	14.3a	15.8^{a}	14.7^{a}
SRS	CONTROL	15.5^{abc}	16.8^{abcde}	15.1^{abc}
	FYM	26.9^{bcdef}	28.5^{cdef}	26.1^{bcdef}
	TSP/FYM/UREA	29.6^{def}	26.1^{bcdef}	31.1^{f}
	TSP/UREA	28.6^{cdef}	27.2^{b}	29.4^{ef}
	Mean	24.3^{b}	24.7^{b}	25.4^{b}

Lsd 0.05: Dolichos incorporation*Fertilizers = 8.16; Season*Dolichos incorporation*Fertilizers =11.54

Note. Means within a row followed by the same letter are not significantly different at P ≤0.05. LRS – Long Rain Season, SRS – Short Rain Season

The significantly high soil available P with FYM and TSP+FYM+Urea application compared to other treatments across cropping systems in the SRS could be attributed to FYM decomposition and subsequent release of nutrients in addition to mineralization of crop residues, from the LRS, resulting from high plant biomass produced following FYM application.

The incorporation of manure has been shown to increase the amount of soluble organic matter which are mainly organic acids that increase the rate of desorption of phosphate and thus improves the available P content in soil (Zsolnay and Gorlitz 1994). Higher P losses in rotation and intercrop involving dolichos could partly be attributed to higher uptake of P by legume crops that is essential for BNF process and root development (Cassman *et al.,* 1981). Increased crop yields under legume rotation and intercrop could have equally played a part in increased mining of P (Onwonga *et al.,* 2008a).

Similarly, Kouyate *et al.* (2012) observed higher soil P under monocropped sorghum compared to rotation with legumes attributing it to export of P to grains. They further noted that P losses from soil increase with increasing grain yields due to most of the P being transported to the grain (Cassman *et al.,* 1981). Furthermore, it has been demonstrated that legumes can increase uptake of P for the companion crop when intercropped or rotated (Li *et al.,* 2004). Legumes particularly dolichos, has shown to increase the uptake of P for the subsequent crop in rotation or the associated crop in intercropping systems Nuruzzaman and Veneklaas (2005).

Maize/dolichos intercrop however resulted in significantly ($P \leq 0.05$) higher soil P with FYM application compared to monocrop and rotation in both seasons. This was probably due to the mineralization of FYM. In addition, the higher dolichos biomass produced in addition to better litter quality may also have been contributory factors to increased P levels. Ayoub (1986) reported mineralization of crop residues that had been returned to soil. Higher P under legumes has also been reported by Bagayoko *et al.* (2000) and Li *et al.* (2008). High P levels ($P<0.05$) obtained in the SRS compared with LRS can be explained by the residual effects of FYM due to slow decomposition rate and release of nutrients to the soil.

According to Rowell *et al.* (1994) and Lydie-Stella et al. (2013), the rapid adsorption of P onto soil particle surfaces is followed by a slower conversion into less available forms including mineral phosphates. The P in FYM is therefore available in the LRS after application but remains over long periods of time hence their residual effects. These findings agree with those of Tognetti *et al.* (2008) who reported an increase in available P in soil with application of compost in a study conducted in Argentina. Similar findings were also reported by Guo and Sims, (2002) in a study conducted in New Zealand which reported an increase in P by more than 60% with litter application.

Total Nitrogen

Significantly ($P \leq 0.05$) high soil total N levels were obtained in maize/dolichos intercrop with application of FYM having no significant difference with TSP+FYM+Urea and TSP+Urea application in the SRS. The control treatment had significantly lower ($P<0.05$) levels of N across cropping systems in the LRS and SRS. Similarly, high N levels were observed in intercrop with TSP+FYM+Urea application with no significant difference with FYM application in the LRS (Table 5). Significantly ($P<0.05$) high soil N was obtained with FYM and TSP+FYM+Urea application across cropping systems in the SRS. This could be attributed to direct addition of N to soil as FYM and TSP+FYM+Urea mineralized as well as crop residue addition. Higher soil organic matter due to addition of FYM has shown to closely correlate with the amount of N in the soil (Kapkiyai *et al.,* 1999). Adekayode and Ogunkoya (2011) observed higher N content in plots treated with FYM attributing this to direct input of N and ability of manure to make N available for a long time due to slower release of N. Increased N in the soil due to application of organic residues has been reported by Mbah and Nneji (2010) in Nigeria. Mutegi *et al.* (2012) also reported an increase in N as a result of organic residue incorporation in a study conducted in Meru south, Kenya.

Higher N levels obtained in intercrop with FYM application compared to monocrop and rotation could be attributed to higher fixation of nitrogen in addition to high litter quality of incorporated dolichos. Ayoub (1986) had also observed higher rates of nitrogen release through biological fixing and decomposition under dolichos based cropping systems. It has also been reported that intercropping with dolichos compared to rotation may result in increased amount of nitrogen fixed by legumes as the companion non-fixing crop utilizes excess nitrates in the root zone which would otherwise retard N fixation if they accumulate (Li *et al.,* 2003).

Table 5: Effect of dolichos incorporation and fertilizer application on total N (%)

Season	Treatment	Dolichos-Maize	Maize/dolichos	Maize
LRS	CONTROL	0.21^{a}	0.19^{a}	0.19^{a}
	FYM	0.29^{bc}	0.29^{bcd}	0.27^{bc}
	TSP/FYM/UREA	0.27^{bc}	0.30^{bc}	0.29^{bc}
	TSP/UREA	0.29^{bc}	0.27^{bc}	0.28^{bc}
	Mean	0.27^{ab}	0.27^{ab}	0.27^{ab}
SRS	CONTROL	0.19^{a}	0.19^{a}	0.19^{a}
	FYM	0.29^{bc}	0.34^{c}	0.29^{bc}
	TSP/FYM/UREA	0.26^{b}	0.28^{bc}	0.28^{bc}
	TSP/UREA	0.28^{bc}	0.31^{bc}	0.28^{bc}
	Mean	0.26^{a}	0.29^{b}	0.26^{a}
Lsd 0.05: Dolichos incorporation*Fertilizers = 0.03				

Note. Within rows means followed by the same letters are not significantly different at $P \leq 0.05$. LRS – Long Rain Season, SRS – Short Rain Season

A significant amount of N can be added to soil through BNF which is then made available to the same crop or subsequent crops (Wortmann *et al.,* 2000). The control treatment had significantly lower ($P<0.05$) levels of N across cropping systems. This could be due to the fact that nothing was added to the soil and hence N uptake by maize for its growth and development was limited to soil reserves. Besides there was no legume crop in this treatment that could supply N through biological nitrogen fixation.

Available Potassium

Significantly ($P<0.05$) higher amount of K were observed in intercrop with FYM application as compared to monocrop in the LRS. However, there were no significant differences in K levels in crop rotation with FYM application. The control treatment had low K levels across monocrop, crop rotation and intercrop in the LRS (Table 6). The same trend was observed during SRS where high K levels were obtained with FYM application in maize/dolichos intercrop.

Soil K increased as compared to the initial values (Table 1) across treatments and seasons. The K increased significantly in maize/dolichos with FYM application across the LRS and SRS. This could be attributed to the slow buildup of organic matter due to incorporation of residues and FYM which lead to an increase in soil K (Gikonyo and Smithson 2003). Kapkiyai *et al.* (1999) had also shown a closer link between amount of soil organic matter and the quantity of available K. similarly, Kihanda (1996) and Hunter *et al*. (1997) reported increase in potassium due to farmyard manure application.

Such increase in potassium could be explained by the fact that manure contains high and readily decomposable potassium (Gachengo, 1996; Hunter *et al*., 1997; Jama *et al*., 2000). Kaur and Benipal (2006) also reported increased concentration of K in the soil with application of farm yard manure. According to Paradelo *et al.* (2012) application of compost increased K concentration in the soil from 150-200 mg/kg which was a 50% increase.

Table 6: Effect of dolichos incorporation and fertilizer application on available K (cmolkg^{-1})

Season	Treatment	Dolichos-Maize	Maize/dolichos	Maize
LRS	CONTROL	1.14^{abcde}	1.17^{abcde}	1.07^{ab}
	FYM	1.71^{fg}	1.83^{f}	1.62^{f}
	TSP/FYM/UREA	1.64^{f}	1.57^{f}	1.64^{f}
	TSP/UREA	1.60^{f}	1.68^{fg}	1.55^{f}
	Mean	1.52^{bc}	1.57^{c}	1.47^{b}
SRS	CONTROL	1.08^{ab}	1.10^{abc}	1.01^{a}
	FYM	1.27^{cde}	1.32^{e}	1.28^{b}
	TSP/FYM/UREA	1.27^{cde}	1.29^{de}	1.28^{b}
	TSP/UREA	1.32^{e}	1.23^{bcde}	1.25^{b}
	Mean	1.24^{a}	1.23^{a}	1.19^{a}

Lsd 0.05: Dolichos incorporation*Fertilizers =9; Season*Dolichos incorporation*Fertilizers = 0.12

Note. Within rows means followed by the same letters are not significantly different at $P \leq 0.05$. LRS – Long Rain Season, SRS – Short Rain Season

Maize/dolichos had significantly ($P<0.05$) higher K with FYM and TSP+FYM+Urea application compared to sole maize in both seasons. This could be attributed to higher biomass production from dolichos which ensured more K release upon decomposition. Dolichos-maize and sole maize did not increase soil K in the SRS. Bagayoko *et al.* (1996) showed that sole cropping, intercropping and rotation of millet and cowpea led to a decline in K levels. Murugappan *et al.* (1999) similarly reported that crops tend to have luxury consumption of K, which could lead to decline in soil K. Soil K significantly reduced during SRS compared with LRS. This could be as a result of soil K losses due to nutrient mining from the harvested products. These losses are more pronounced especially when the biomass is removed as most losses of K occur through removal of above-ground biomass (Smaling, 1993) that led to less marked increase in soil organic matter hence K decline.

Nutrient Balances as affected by dolichos integration and fertilizer application

Nitrogen Balance: Averaged across the two seasons, significantly ($P \leq 0.05$) less negative N balances were obtained in (Table 7) maize/dolichos intercrop (FYM), maize/dolichos intercrop (control), dolichos-maize rotation (FYM), dolichos-maize rotation (control), sole maize (control) and sole maize (TSP + Urea). More negative (i.e. high losses) N balances were noted in intercropping and dolichos-maize rotation with application of TSP+Urea and TSP+FYM+Urea. Negative N balances across all treatments could be attributed to nutrient removal in harvested products obtained from the grain yields. Fatima et al. (2008) noted that nutrient removal of above ground plant parts through harvesting has implications on residual effect of legumes on N balance in soil.

Additionally, negative N balances in the maize monocrop with TSP+FYM+Urea and FYM are attributable to the cereal's inability to fix N on its own and other processes such as leaching, erosion and N immobilization. Ndufa (2001) also noted low levels of soil N in continuously cropped maize even after residue incorporation in soil. There is also good evidence that adding organic matter and fertilizers together improves nitrogen use efficiency (NUE), as nutrients are held by the microbial biomass which in turn plays an important role in facilitating nutrient loss from soils in some situations (Turner & Haygarth, 2001).

Table 7: Effect of Dolichos incorporation and Fertilizers application on N (Kg ha^{-1} yr^{-1}) balances

Cropping System	Fertilizers	N balance (Kg ha^{-1} yr^{-1})
Sole maize Maize (M)	CTRL	-6.81^{c}
	FYM	-14.53^{ab}
	FYM+TSP+UREA	-14.73^{ab}
	TSP+UREA	-11.41^{bc}
Dolichos-Maize	CTRL	-9.41^{bc}
	FYM	-11.07^{bc}
	FYM+TSP+UREA	-15.13^{ab}
	TSP+UREA	-14.01^{ab}
Maize/dolichos	CTRL	-10.73^{bc}
	FYM	-9.14^{bc}
	FYM+TSP+UREA	-15.67^{ab}
	TSP+UREA	-20.13^{a}
Lsd 0.05:	Dolichos incorporation*Fertilizers	2.96

Key: CTRL = Control; TSP = Triple superphosphate; FYM =Farmyard Manure. Means in a column followed by the same letter(s) are not significantly different at *P*≤0.05 according to Fisher's Protected Least significant Difference Test

Additionally, this could be due to nutrient supplied by TSP+FYM+Urea leading to high N levels being lost through leaching and gaseous loss. The N release from TSP+Urea fertilizer is readily available for crop uptake and hence its effects may not be long lasting. It has also been observed that some ammonia-N may be lost through volatization thus reducing the content of N that could be supplied from Urea compared to FYM. Gachimbi *et al.* (2005) reported that most of the losses of N from soil could mainly be as a result of factors which are difficult to control such as erosion, leaching and vitalization. Similarly, Kroeze *et al*. (2003) attributed negative nitrogen balance to the high outflow of nitrogen through harvested products and leaching. Similar results were reported by Ehabe *et al.* (2010) and Kanmegne *et al.* (2006) in the Southern part of Cameroon on perennial and annual crops.

Less negative N balances obtained in rotation and intercrop with application of FYM and Control could be attributed to supply of N through biological nitrogen fixation (BNF) by dolichos and decomposition of its incorporated residues. The ability of legumes to fix N symbiotically has been previously observed by Baldwin and Creamer (2014). In a study on effect of organic based nutrient strategies on nutrient availability, a higher N content was observed following lablab and was partly attributed to its deep root systems that captured nitrate from the subsoil (Lelei *et al.,* 2009).

Phosphorus Balances: Significantly (P ≤ 0.05) less negative P balances were obtained in crop rotation system with the application of FYM compared to intercrop and monocrop. The intercrop system with TSP+Urea application obtained higher negative P balances compared to FYM+TSP+Urea and FYM. The maize-dolichos rotation with control treatment had significantly (P ≤ 0.05) more negative P balances compared to monocrop and intercrop (Table 8).

Table 8: Effect of Dolichos incorporation and Fertilizers application on P (Kg ha^{-1} yr^{-1}) balances

Dolichos incorporation method	Fertilizers	P balance (Kg ha^{-1} yr^{-1})
Sole Maize (M)	CTRL	-1.33^{cd}
	FYM	-1.93^{abc}
	FYM+TSP+UREA	-1.97^{abc}
	TSP+UREA	-1.43^{cd}
Dolichos-Maize	CTRL	-2.31^{ab}
	FYM	-0.37^{e}
	FYM+TSP+UREA	-0.47^{de}
	TSP+UREA	-0.49^{e}
Maize/dolichos	CTRL	-1.97^{abc}
	FYM	-1.53^{bcd}
	FYM+TSP+UREA	-2.17^{abc}
	TSP+UREA	-2.41^{a}
Lsd 0.05:	Dolichos incorporation*Fertilizers	0.375

Key: CTRL = Control; TSP = Triple superphosphate; FYM =Farmyard Manure. Means in a column followed by the same letter(s) are not significantly different at P≤0.05 according to Fisher's Protected Least significant Difference Test.

Higher negative P balances were realized even with addition of P through TSP+FYM+Urea and TSP+Urea in intercrop (Table 8). The additional supply of P from TSP could have contributed to increased root development hence better P uptake and plant growth eventually resulting to more negative P balances due to its subsequent removal in harvested products. Grant *et al*. (2001) noted that plants required adequate P from the very early stages of growth for optimum crop production and hence high soil P uptake from the soil. Nuruzzaman *et al*. (2005) also documented that the presence of a legume in a cropping system often increases P uptake for the subsequent crop in rotation or companion crop in an intercropping system. Onwonga *et al*. (2015) also noted that legumes had significantly higher yields and attributed the same to their efficiency in P acquisition from soils resulting to P mining from the harvested products.

Integration of lablab into the cropping systems resulted in higher P balances compared to sole maize cropping system. Decline in soil P could be as a result of higher biomass productivity due to increased P uptake from and inclusion of legume. Veneklaas (2007) and Pearse (2006) revealed that more P was lost through crop uptake under dolichos based cropping system and this could be attributed to efficiency of P acquisition by the legume. Dolichos-maize rotation with TSP+FYM+Urea application resulted in significantly ($p \leq 0.05$) more negative P balances (Table 8). This was due to higher P input through FYM as well as higher biomass production, which may have led to more P release upon decomposition. Mpairwe *et al.* (2002); Onwonga et al. (2008a) had also noted an increase in biomass production due to application of manure and that the main contributing factor was the uptake of P which was removed at harvest. Higher levels of soil P under FYM could similarly be as a result of direct input of P into the soil through decomposition of manure. Eghball and Power (1999) reported that application of FYM could improve P status of soil.

Potassium Balances: Averaged across the two seasons, less K negative balances were realized in FYM across cropping systems as compared to TSP+FYM+Urea and TSP+Urea. Higher negative K balances were obtained in intercrop with control treatment having no significant difference in crop rotation and monocrop. There were pronounced negative K balances in intercrop with application of TSP+Urea compared to monocrop and crop rotation (Table 9). Negative K balances with addition of TSP+FYM+Urea across all cropping systems is indicative of the fact that nutrient inputs were more than outputs through harvested products and other nutrient loss pathways. Increased K losses through biomass have also been reported by Smalling (1993) who found that most K losses occurred due to export of harvested residue. This also confirms observation by Murugappan et al. (1999) that mining of soil K always occurred regardless of whether K is added or not due to luxury consumption of K by most crops.

Table 9: Effect of Dolichos incorporation and Fertilizers application on K (Kg ha^{-1} yr^{-1}) balances

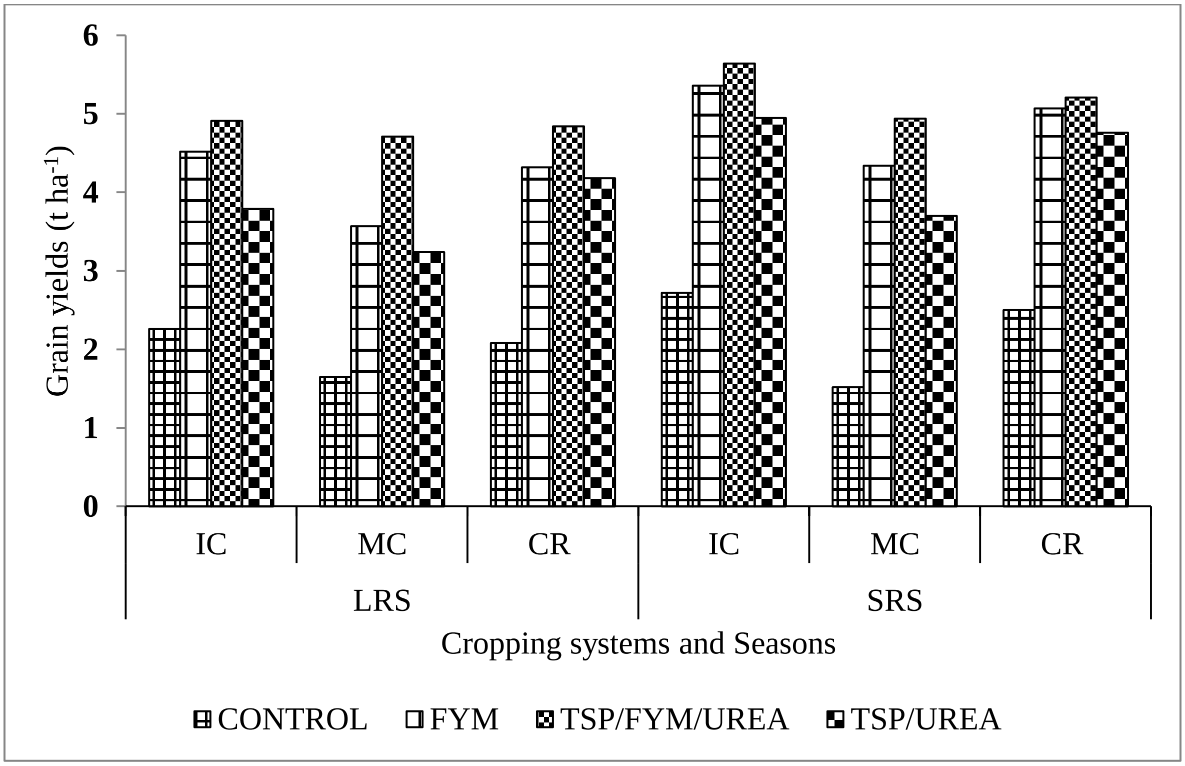
Dolichos incorporation method	Fertilizers	K balance (Kg ha^{-1} yr^{-1})
Sole Maize (M)	CTRL	-1.93^{de}
	FYM	-0.41^{ef}
	FYM+TSP+UREA	-2.87^{bcd}
	TSP+UREA	-4.53^{bc}
Dolichos-Maize	CTRL	-2.67^{cd}
	FYM	-0.21^{ef}
	FYM+TSP+UREA	-2.13^{de}
	TSP+UREA	-4.93^{ab}
Maize/dolichos	CTRL	-3.01^{bcd}
	FYM	-1.13^{f}
	FYM+TSP+UREA	-3.07^{bcd}
	TSP+UREA	-6.67^{a}
Lsd 0.05:	Dolichos incorporation*Fertilizers	0.944

Key: CTRL = Control; TSP = Triple superphosphate; FYM =Farmyard Manure. Means in a column followed by the same letter(s) are not significantly different at $P \leq 0.05$ according to Fisher's Protected Least significant Difference Test.

Higher negative K balances in intercrop with TSP+Urea application were due to readily available nutrients supplied that enhanced biomass production and subsequent removal in harvested products. Onwonga *et al.* (2008b) noted that in legume rotations, increase in yield corresponded to K acquisition hence its decline in soil. This is also in agreement with Fermont *et al.* (2007) who found that intercropping systems increased nutrient losses due to harvest of combined products at the same time. Potassium losses from soil commonly occur via leaching to greater depths, which is influenced by the production system.

Maize Grain and Dry Matter Yields

Maize grain yield: Significantly ($P \leq 0.05$) higher maize grain yields were obtained in dolichos/maize intercrop system with application of TSP+FYM+Urea and TSP+Urea as compared to monocrop in the LRS. The yields were however not significantly different with FYM application for intercrop and monocrop (Fig. 1).



Key: IC - intercrop (Dolichos/Maize), MC - Monocrop (sole maize), CR - Crop rotation (Dolichos –maize), LRS – Long Rain Season, SRS – Short Rain Season

Fig 1: Effect of cropping systems and fertilizer application on Maize grain yields (t/ha).

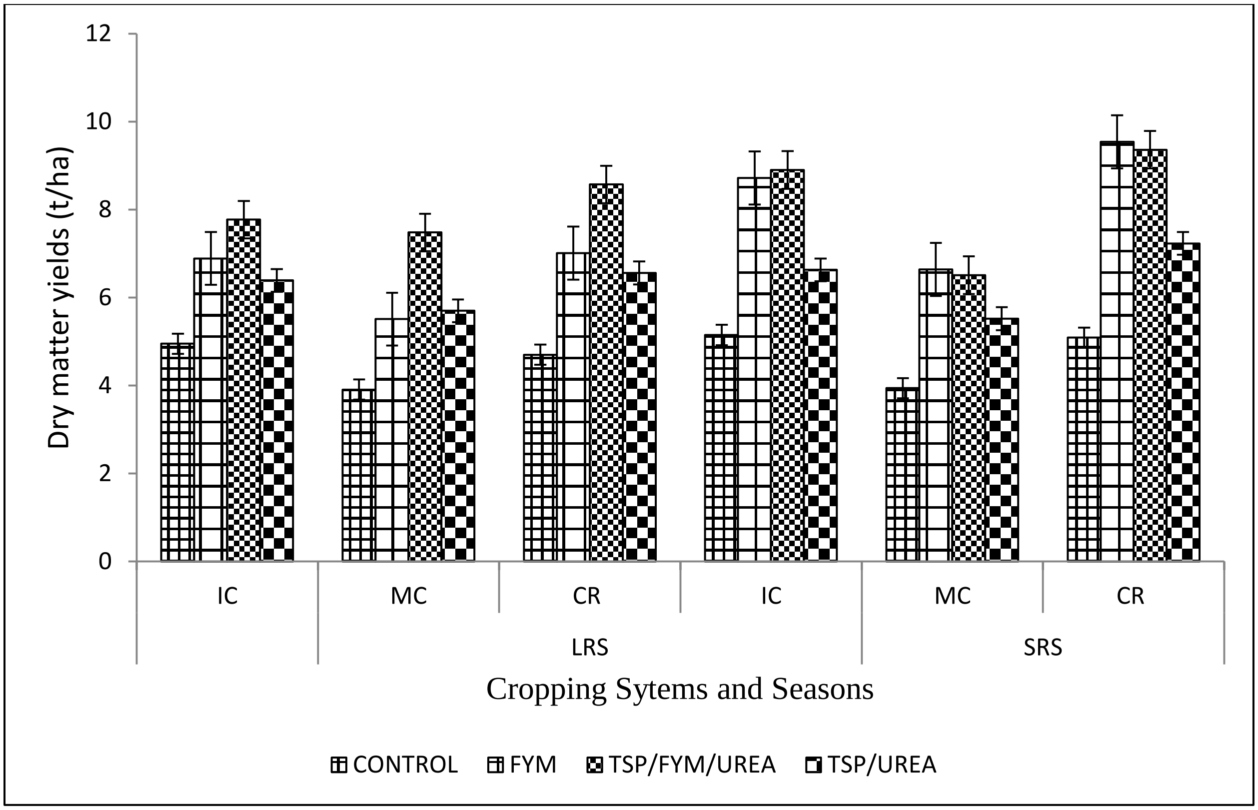
During the SRS, significantly ($P \leq 0.05$) higher maize grain yields were obtained in the dolichos/maize intercrop with application of FYM and TSP+FYM+Urea. The grain yields were however not significantly different in crop rotation and monocrop with FYM, TSP+FYM+Urea and TSP+Urea application (Table 10). The highest grain yield was recorded in the plots with TSP+FYM+Urea while the lowest in the control treatment. The maximum grain yield attained by the interaction of the combined fertilizers might be due to the synergistic effects of nutrients supplied. Bayu *et al.* (2006) and Makinde and Ayoola (2010) stated that high and sustainable crop yields are only possible with combined use of inorganic and organic fertilizers than yields from sole organic fertilizer application. Tadesse *et al.* (2013) also noted that applying FYM at 15 t/ha with 120 kg N ha^{-1} and 100 Kg P ha^{-1} responded the maximum grain yield which increased by123.0% compared to the control. Similarly, Bhandari *et al.* (2002); Ladha *et al.* *(*2003); Regmi *et al.* (2002) similarly observed that continued use of mineral fertilizers alone results in lower grain yields, while the use of organic fertilizer combined with appropriate mineral fertilization helps to maintain high yields.

Significantly ($P<0.05$) higher maize yields were obtained in maize/dolichos intercrop with application of TSP+FYM+Urea and FYM compared to sole maize with application of TSP+FYM+Urea during LRS. This could be due to inclusion of dolichos into the maize system that potentially fixed N and thence available for maize uptake leading to enhanced grain yield. Cheruiyot *et al.* (2003) in a study on the effect of legume managed fallows (common beans and lablab) on soil N reported that among the legume species, lablab showed outstanding positive effect on succeeding maize yield, this could be attributed to improved nutrient synchronization. Li Yang *et al.* (1999) reported that if a legume is integrated with another crop commonly a cereal, the N nutrition of the associated crop may be improved by the direct N transfer from the legume to the cereal. The legume uses fixed atmospheric N which can be exploited by the companion crop (Stern 1993). Higher yields obtained in intercrop with TSP+FYM+Urea and TSP+Urea application can be attributed to the readily available nutrients released by the applied fertilizers translating to higher maize grain yields. Studies by Murwira and Kirchmann (1993) showed that synchrony between N release and crop uptake was best achieved by applying combinations of manure and mineral N. This is evident in Zimbabwe where Supplementation of 5 t ha^{-1} with 40 kg N ha^{-1} (inorganic fertilizer) resulted in a statistically higher yield than sole manure treatment (Murwira *et al.* 2002). Ibewiro *et al.* (1997) assessed nitrogen contribution by legume roots to succeeding maize crops in Ibadan, Nigeria and showed that the root biomass of velvet bean and *Lablab purpureus* (L.) sweet variety increased maize yields. Higher grain yields obtained in intercrop with TSP+FYM+Urea during SRS was not significantly different from FYM application. Maize yield, across cropping systems, following combined inorganic and organic fertilizers and with sole inorganic fertilizer application were comparable. This is because of the faster nutrient release from inorganic fertilizer and maize, being an aggressive feeder, was able to utilize it for its growth. Murwira and Kirchmann (1993) have observed that nutrient use efficiency of a crop is increased through a combined application of organic manure and mineral fertilizer.

Tejada *et al.* (2006) reported that manure is a good fertilizer on soil that supplies P and N to produce high yields. This is attributed to manure's slow release of plant nutrients especially N and P. High grain yields were obtained in the SRS compared to the LRS across all cropping systems with FYM application. This may be attributed to the ability of farmyard manure to provide plant nutrients and increase nutrient holding capacity of soil, as well as water holding capacity and infiltration rates (Gateri, Muriuki, & Kanyanjua, 2006; Fening et al., 2005). This could be explained in terms of the elevated available nutrients in soil due to residual effect and slower decomposition of FYM application which caused longer lasting effects on soil properties (Brady & Weil, 1996) and its subsequent uptake by maize (Buresh *et al.,* 1997).

Maize Dry Matter Yields: Higher dry matter yields (DM) were obtained in monocrop with application of FYM and TSP+Urea compared to intercrop. There were no significant ($P<0.05$) differences in monocrop and intercrop with application TSP+FYM+Urea in the LRS. Similarly, there were no significant differences under intercrop across all fertilizer treatments during the LRS. Higher dry matter yields were obtained in crop rotation with application of TSP+FYM+Urea and FYM compared to intercrop and monocrop in the SRS.

The DM yield were however not significantly different in monocrop and intercrop with FYM, TSP+FYM+Urea and TSP+Urea application. Maize dry matter yield was significantly ($P<0.05$) high following TSP+FYM+Urea and FYM application for intercrop during the SRS compared with LRS. Higher biomass production during SRS could be due to improvement in soil productivity as a result of maintenance of soil organic matter levels and residual effects of TSP+FYM+Urea and FYM treatments.



Key: IC - intercrop (Dolichos/Maize), MC - monocrop (sole maize), CR - Crop rotation (Dolichos –maize), LRS – Long Rain Season, SRS – Short Rain Season

Fig. 2: Effect of cropping systems and fertilizer application on dry matter yields (t/ha)

There was a general reduction in dry matter yields in control plots compared to TSP+FYM+Urea and FYM application where it showed consistent increment of dry matter yields. The most probable explanation for this event is that FYM application improved structure and water holding capacity of soils which in turn promoted the vegetative growth of a plant together with nutrient uptake translating to increased dry matter yields. Similar results were reported by Cassman *et al*. (2003) and Gupta (2004) in which the average dry matter maize yield for combined mineral and organic fertilizers application had a yield increment of 25 to 75% and 6 to 68% over the control treatments, respectively. Similar results were reported by Nyongesa *et al.* (2009) in Nandi district, Kenya who observed that organic residues application increased grain yield and stover in maize. Chung *et al*. (2000) have shown that application of organic manures with an adequate amount of chemical N fertilizer gave higher dry matter yield of maize.

Kibunja *et al.* (2010) reported that total dry matter of maize was higher in treatment combinations of inorganic and organic fertilizers than mineral fertilizers alone. High N fertilizer application could improve the growth and above ground biomass production of maize crop as maize is the heavy feeder of N. The integration of legumes potentially enhanced the yields of the following maize crop, an effect which can largely be attributed to the increase in plant available nitrogen in the soil for uptake by the same crop and the following crops (Herridge and Ladha, 1995).

Conclusions

Soil N, P and K were consistently high in maize/dolichos intercrop with the application of FYM and TSP+FYM+Urea in SRS. Negative N, P and K balances were pronounced in maize/dolichos intercrop and dolichos-maize rotation with application of FYM and TSP+FYM+Urea. Significantly ($P<0.05$) higher K losses were observed across cropping systems; dolichos/maize intercrop, dolichos-maize rotation and monocrop with TSP+Urea application. Significantly ($P\leq 0.05$) high dry matter yields were obtained in dolichos-maize rotation with FYM application and higher grain maize yields were realized in intercrop with application of FYM and TSP+FYM+Urea in SRS as compared to the LRS. It is obvious that improved soil nutrient status and balances in maize/dolichos intercrop with the application of FYM and TSP+FYM+Urea led into increased maize yields. With the increase in yields, significant nutrient losses were realized and were pronounced in the intercrop system compared to the rotation system. Adoption of the best performing technology, maize/dolichos intercrop with combined application of 5 t ha^{-1} FYM and 60 kg ha^{-1} TSP+Urea, ought therefore to be tapered (in the short run) with prudent nutrient management strategies for system sustainability.

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