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Combined Effects of Legumes with Phosphorus Fertilizer on Nutrient Balances and Gross Margins in Maize (*Zea mays* L.) systems of Kabete sub-County, Kenya

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Abstract
Calculation of soil nutrient balances and gross margins (GM) is imperative in ascertaining effect of innovative technologies on soil fertility and farm profitability. A field experiment to evaluate effect of combined legumes and phosphorus fertilizer on soil N, P and K balances and crop GM in maize (*Zea mays* L.) systems was set up in Kabete Division, Kenya, in the long and short rainy seasons of 2012. The experimental set up was a randomized complete block design (RCBD) with a split plot arrangement. The main plots comprised cropping systems; (i) monocropping (sole maize), (ii) intercropping [white lupin (*Lupinus albus* L.)/maize (L/M) and chickpea (*Cicer arietinum* L.)/maize (CP/M)], and (iii) rotation [white lupin-maize (L-M) and chickpea-maize (CP-M)]. The split plots were phosphorus (P) fertilizers; Minjingu phosphate rock (MPR) and triple superphosphate (TSP), and (iii) no P fertilizer applied (CTRL). Soil N, P and K balances and gross margins were analyzed at plot level using NUTrient MONitoring (NUTMON - now known as MonQi) Tool box. Nutrient balances were negative across cropping systems and P sources except for K in M/CP (CTRL and TSP) intercrop. Significantly less negative N balances were obtained in maize monocrop (MPR), CP/M (CTRL) intercrop, CP-M (TSP) rotation, and L/M (MPR) intercrop. L/M (CTRL and TSP) intercrop and L-M (CTRL and TSP) rotation recorded more negative (highest losses) N balances. Across P sources, the maize monocrop, M/L intercrop and L-M rotation had significantly more negative P balances, than CP-M rotation and M/CP intercrop. P balances, across P fertilizers, were significantly less negative in M/CP compared to M/L intercrop. Less negative P balances were recorded in CTRL treatment compared to TSP and MPR across cropping systems. M/L (CTRL and TSP) intercrop system had pronounced negative K balances. In the rotation systems, significantly less negative balances were observed when maize was rotated with chickpea compared to lupin across all P sources. Pronounced GMs were realized in M/L intercrop (TSP) followed by L-M (TSP) and lowest in M/L (TSP and CTRL). The N, P and K nutrient balances in response to P sources and cropping systems exhibited a negative relationship with crop GM. The positive GMs obtained were thus at the expense of soil nutrient mining as treatments with high nutrient losses, case for N and P, had the highest GMs. Considering nutrient balance studies alongside economic analysis has thus demonstrated the hidden environmental costs in the positive crop GMs and by extension the efficiency of such production systems. As a result, increased GMs under introduced technologies are not sustainable unless the same is matched with adequate nutrient replenishments to balance those lost through harvested products and other nutrient loss pathways. Farmers would, actually, go for those technologies that not only maximize yields but also accrue high profits. In the context of this study, and in order of GM (from highest) analysis, M/L intercrop, maize monocrop and L-M rotation with application of TSP are such technologies. In the long-run however these technologies will prove untenable due to nutrient mining. Nonetheless to guarantee efficient production and sustainable maize systems, following application of P fertilizer and legume integration, it is important that profits accrued from farm sales be used to purchase fertilizers and/or support practices geared towards replenishing mined soil nutrients. This way farm profits realized will not be at the expense of nutrient mining.
Keywords: Cropping systems; gross margins; Kabete sub-County; MonQi; Nutrient Balances; Rock phosphates

1. Introduction

Tropical soils around the world are widely known to be deteriorating in productivity (Chase and Singh, 2014) mainly due to agricultural land use systems that cause significant soil property modifications (Pal *et al*., 2013). In the central highlands of Kenya, for instance, soil nutrient mining is the major cause of declining land productivity especially in small holder maize (*Zea mays* L.) farming systems (Mugendi *et al*., 2003; Stoorvogel *et al*., 1993). Nutrients lost through harvested products, especially nitrogen (N) and phosphorus (P) are not adequately replenished owing to prohibitive cost of inorganic fertilizers (Gachimbi *et al*., 2002) and this, in the long run, poses a risk of food shortages in the predominantly low-input agro ecosystems (Mtei *et al*., 2013).

While N and P are the main nutrients critical in maize production (De Jager *et al*., 2001), N is the most limiting nutrient in smallholder farms (Chemining'wa *et al*., 2007). Plants require larger quantities of N compared to any other primary nutrient and plant assimilation of soil N often exceeds the amount being replenished (Epstein and Bloom, 2005). Consequently, the N nutrition of crops is largely based on supply from native soil N pool and to a lesser extent on animal manure or other organic resources (Gachimbi *et al*., 2002). The constraints to inorganic fertilizer use in sub Saharan Africa (SSA) calls for investigation into the possibility of reducing fertilizer rates by substituting and or complementing with alternate means to meet the nutrient requirements of crops without any significant decrease in yield (Mutala, 2012). Rock phosphate (RP) application and integration of legumes; white lupin (*Lupinus albus* L.) and chickpea (*Cicer arietinum*) in maize cropping systems could provide a feasible and low cost alternative for rebuilding soil fertility (van Straaten and Jama, 2006; Opala *et al*., 2013; Lelei et al., 2014). Apart from fixing N (Giller, 2001), legumes can also solubilize RP through rhizosphere processes (Horst *et al*., 2001; Lelei et al., 2014) resulting to increase in available nitrogen and phosphorus (P) in soil.

Most studies on use of rock phosphates and integration of legumes in cereal based cropping systems are biased towards their influence on soil fertility and crop yield improvement and averse to assessing their possible environmental and socio-economic effects. The assumption that inputs effectively replace off takes commonly and erroneously constitutes the basis of agronomic advice (Herlihy *et al*., 2004). 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 SSA 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)[1], which are useful indicators in assessing the sustainability of farming systems and also socio-economic aspects, in this case, farmer incomes (de Jager *et al*., 1998). NUTMON (now known as MonQi), a nutrient monitoring tool, has been used to review levels of N, P and potassium (K) in soil (Priess *et al*., 2001; Onwonga et al., 2008). Accompanying nutrient balance studies by economic (costs and returns) analysis will shed light on the efficiency of production systems (Kipsat *et al.,* 2004). The fundamental point is that farmers would go for technologies that not only maximize yields but also accrue high profits. Therefore, it is important to move to economic analysis of the farm (Yadvinder-Singh, 2004) in addition to the ecological evaluation. Against this backdrop, the current study investigated effects of P fertilizer application and legume integration in maize systems on soil nutrient balances and gross margins.

2.0 Materials and Methods

2.1 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 (SRS) and long rain (LRS) seasons of 2012. The station is about 1940 m above sea level and on a latitude 1° 15' S and longitude 36° 41' E. The site has a bimodal rainfall distribution (mid - March – May, long rains; October – December, short rains). The average annual precipitation is 1000 mm (Jaetzold *et al*., 2006). Kabete has minimum and maximum mean temperatures of 13.7°C and 24.3°C, respectively. Soils at the research site are predominantly deep red humic nitisols containing 60 – 80% clay particles (FAO, 1990; KSS, 2004; WRB, 2006). Analyzed soil properties prior to the experimental set-up were: clay texture, moderate acidity, low available P, organic carbon and N (Table 1) according to Landon (1991).

Table 1: Initial physical and chemical soil properties at experimental site (0-30 cm depth)

Soil Property	Units	Value	Soil Property	Units	Value
Soil pH (H_2O)	-	6.3	Ca	$cmol_c\ kg^{-1}$	8.13
Soil pH ($CaCl_2$)	-	5.8	Mg	$cmol_c\ kg^{-1}$	1.7
Available P	$mg\ kg^{-1}$	10	% Sand	%	5
Total N	%	0.32	% Silt	%	27
Organic C (%)	%	2.75	% Clay	%	68
Potassium	$cmol_c\ kg^{-1}$	1.05	Textural Class	-	Clay

2.2 Experimental design and Treatments

The experimental set up was a randomized complete block design (RCBD) with a split plot arrangement. The main plots were cropping systems; (i) monocropping (sole maize [*Zea mays* L.]), (ii) intercropping (white lupin [*Lupinus albus* L.]/maize; chickpea [*Cicer arietinum* L.]/maize) and (iii) crop rotation (white lupin-maize; chickpea-maize). The split plots were phosphorous (P) fertilizers; Minjingu Phosphate Rock (MPR) and Triple superphosphate (TSP), both applied at 60 kg P ha^{-1}, and a control (without P). Calcium ammonium nitrate (CAN)

[1] A nutrient balance is a land quality indicator that describes the rate at which soil fertility changes under actual management (Segala *et al*., 2010). It quantifies the input of a particular nutrient to an area of land and subtracts from this the output of the same nutrient from the same area of land (Stoorvogel *et al*., 1993).

was top dressed at the rate of 60 kg N ha^{-1} in all plots, a month after planting. Plot sizes measured 3.75 by 4.8 m, with a 0.5 m and 1 m wide footpath between the plots and blocks, respectively.

2.3 Agronomic practices

Land was ploughed manually and any crop residues present removed before application of treatments. MPR was broadcasted and incorporated into soil to a depth of 0 – 0.15 m three days before planting, in both the LRS and SRS. TSP was applied at planting in both seasons. Maize (*Zea mays* L*;* Hybrid 513) was planted at rate of two seeds per hole at a spacing of 75 × 30 cm in respective treatments (Table 2).

Table 2: Treatments and crop sequence during the LRS and SRS of 2012

Cropping System	Treatment	Description	P Source	Crop/Season	
				LRS	SRS
Monocrop	1	Maize Monocrop	MPR	Maize	Maize
	2	Maize Monocrop	TSP	Maize	Maize
	3	Maize Monocrop	CTRL	Maize	Maize
Rotation	4	Lupin-Maize	MPR	Lupin	Maize
	5	Lupin-Maize	TSP	Lupin	Maize
	6	Lupin-Maize	CTRL	Lupin	Maize
	7	Chickpea-Maize	MPR	Chickpea	Maize
	8	Chickpea-Maize	TSP	Chickpea	Maize
	9	Chickpea-Maize	CTRL	Chickpea	Maize
Intercropping	10	Lupin/Maize	MPR	Lupin/Maize	Lupin/Maize
	11	Lupin/Maize	TSP	Lupin/Maize	Lupin/Maize
	12	Lupin/Maize	CTRL	Lupin/Maize	Lupin/Maize
	13	Chickpea/Maize	MPR	Chickpea/Maize	Chickpea/Maize
	14	Chickpea/Maize	TSP	Chickpea/Maize	Chickpea/Maize
	15	Chickpea/Maize	CTRL	Chickpea/Maize	Chickpea/Maize

Key: P - phosphorus; MPR – *Minjingu* Phosphate Rock; TSP – Triple Superphosphate; CTRL – Control with no P applied; SRS – Short Rain Season; LRS – Long Rain Season

In the intercropping system one row of legume, either lupin or chickpea was sown between two maize rows, at the rate of two seeds per hole. Intra cropping distance of 30 cm for the legumes was maintained. For rotation system, in the SRS, chickpea and lupin were sown at the rate of two seeds per hole as sole crops and at a spacing of 75 × 30 cm. Thinning to one seedling per hole was done four weeks after sowing for all crops. The plots were kept weed free throughout the crop growing season through manual control. Residues of all crops were returned back to plots where they were obtained, after harvesting the grain. Chopping of residues into 0-20 cm pieces was done for easier incorporation in soil and to increase surface area for decomposition.

2.4 Soil, Plant sampling and analyses

2.4.1 Soil Sampling

Composite top soil (0-20 cm) samples, for determination of initial soil properties (Table 1) were collected in a zigzag manner, from experimental area before set up of the experiment. For assessment of N, P and K nutrient balances, composite soil samples were collected from top soil (0-20 cm) in all plots at termination of the experiment. The samples were kept in polythene sampling bags and transported to laboratory in portable cool boxes for analysis. Grain and dry matter (DM) yields were determined at harvest, within a quadrat area of $1m^2$ from three center rows of each sub plot. For DM 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.

2.4.2 Soil and plant analyses

Air-dried soil, sieved through 2 mm mesh was analyzed for pH (in H_2O and KCl solution), nitrogen (Kjeldahl method), Phosphorus (double acid method) and organic C (Walkley – Black method) as compiled and described by Okalebo *et al.* (2002). Exchangeable bases (K, Ca and Mg) were extracted with 1.0 M-ammonium acetate at pH 7. K was measured by Flame Emission Spectrophotometry, whereas Ca and Mg were measured by Atomic Absorption Spectrophotometry (Jońca and Lewandoski, 2004). Soil texture was determined using hydrometer method (Black *et al*., 1965). Undisturbed core samples were used in bulk density determination (Blake and Hartge, 1986). The dried plant samples were finely ground and 5 grams used for analysis. The nutrient concentrations were determined based on the Kjeldahl digestion method (Black, 1965) after which N and P concentration were determined colorimetrically using the procedures compiled and described by Okalebo *et al.* *(*2002). K was measured by Flame Emission Spectrophotometry (Jońca and Lewandoski, 2004).

2.5 Quantification of Nutrient Balances and Gross margins

The NUTmon MONitoring (NUTMON) Tool box was used in quantification of nutrient (N, P and K) flows and balances. NUTMON-Toolbox is a user friendly computerized software for monitoring nutrient flows and stocks especially in tropical soils (Vlaming *et al*., 2001). The toolbox has within it a structured questionnaire, a database and a simple static model (NUTCAL for calculating nutrient and economic flows). 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.

2.5.1 Farm Conceptualization

In NUTMON, farms are conceptualized as a set of dynamic units depending on management, from the source and/or destination of nutrient flows and economic flows. Consequently in NUTMON farm conceptualization, the following units, relevant to the current study, are defined: Farm Section Unit (FSU), these are areas within the farms with relatively homogenous properties; Primary Production Unit (PPU)/crop activities, basically 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 as presented sought to determine the nutrient balances and economic returns (Gross margins) at crop activity level and so the approach was adjusted to enable generation of output within an experimental area. Consequently, the blocks/replicates involving either of the legumes were the equivalent of the FSU, the primary production units (PPUs) were the plots comprising of the 15 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 (0-30cm) of the crops involved. Nutrient flows into PPUs were identified as P fertilizers (IN 1 - TSP and IN 2 - MRP), atmospheric deposition (IN 3) and biological nitrogen fixation (IN 4) and returned plant residue (OUT 2). 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 (Table 3).

Table 3: Nutrient flows in NUTMON[2]

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)

2.5.2 Types of and formula for calculating nutrient balances

To distinguish between primary data and estimates, two different balances were calculated in NUTMON Tool box: 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 the cropping systems affected the full balances of major nutrients, N, P and K in soil after harvest. Calculation of nutrient balances therefore involved a number of methods: Sampling and analysis of product flows for N, P and K (IN 1 and IN2 and OUT1 and OUT 2) and use of transfer functions (IN3, IN4 and IN 5, and OUT 3, OUT4, OUT5 and OUT6) (van den Bosch *et al.,* 1998).

The nutrient balances (kg ha^{-1}) were calculated (equation 1) based on a set of *inflows* and *outflows* (Table 3).

$$Net\ Soil\ Nutrient\ Balance = \sum Nutrient\ Inputs - \sum Nutrient\ Outputs \ldots (i)$$

[2]Considering the nature and set-up of the current study, certain parameters included in the conceptual framework by De Jager *et al*. (1998) were omitted. Examples are IN 2b, OUT 6, FL 1, FL 2, FL 4 and FL 5 (Table 3).

2.5.2 Gross Margin Analyses
The gross margins (GM) were calculated as the difference between the revenue and the variable cost (GM = Revenue (Sales) – Variable Costs). At plot level, gross margins were calculated based on the inputs; fertilizers, seeds and labor hire while the outflows were the returns (both crops and crop residues). The calculated crop GMs were expressed per hectare basis. A semi-structured questionnaire developed by van den Bosch *et al*. (1998) was adapted to collect data on quantity and prices of inputs and outputs of crop over the cropping seasons.

2.6 Statistical analyses
N, P, and K balances and GM for the various PPUs were generated by NUTMON-toolbox and then exported to GenStat 15th Edition, 2012 for further analysis. The effects of cropping system and P source on soil nutrient balances and Gross margins were compared by analysis of variance (ANOVA) at plot level. The significant treatment means were separated by Least Significant Differences (LSD) at $P \leq 0.05$.

3.0 Results and Discussion
3.1 Nitrogen balances
Nitrogen balances were negative in all treatments. Significantly less negative N balances were obtained in maize monocrop (MPR, TSP and control), chickpea/maize (MPR, TSP and CTRL) intercrop, lupin-maize rotation (MPR), chickpea-maize (MPR, TSP and control) rotation, and maize/lupin (MPR) intercrop. The lupin/maize intercrop (CTRL and TSP) and lupin-maize (CTRL and TSP) rotation systems recorded more negative (highest losses) N balances (Table 4). In control treatment (without P), intercropping maize with lupin (M/L) led to significantly more negative N balances compared to maize/chickpea (M/CP) intercrop. However, with MPR application, less negative balances were noted in M/L compared to M/CP intercrop system. The P source had no significant effect on N balances in CP-M, M/CP and maize monocrop.

Table 4: N balances (kg $ha^{-1}yr^{-1}$) as affected by cropping systems and P source

Cropping system	P source	N balance (kg $ha^{-1}yr^{-1}$)
Maize (M)	CTRL	-60.7^{abcd}
	TSP	-63.3^{abcd}
	MPR	-49.4^{ab}
Maize/Lupin (M/L)	CTRL	-74.9^{cde}
	TSP	-70.1^{bcde}
	MPR	-40.5^{a}
Maize/Chickpea (M/CP)	CTRL	-46.5^{ab}
	TSP	-56.5^{abcd}
	MPR	-58.2^{abcd}
Lupin-Maize (L-M)	CTRL	-76.9^{de}
	TSP	-91.2^{e}
	MPR	-52.8^{abc}
Chickpea-Maize (CP-M)	CTRL	-44.5^{a}
	TSP	-35.4^{a}
	MPR	-45.9^{a}
LSD 0.05	Cropping System (CS)	23.65

Key: CTRL = Control; TSP = Triple superphosphate; MPR = Minjingu phosphate rock.
Means in a column followed by the same letter(s) are not significantly different at $P = 0.05$ (Fisher's Protected Least Significant Difference Test).

There were no significant interaction effects between cropping systems and P sources on N balance. Intercropping maize with lupin (M/L) led to significantly more negative N balances in control compared to maize/chickpea (M/CP) intercrop. However, with MPR, less negative balances were noted in M/L compared to M/CP intercrop system. The P source had no significant effect on N balances in CP-M, M/CP and maize monocrop. Significantly less negative N balances were noted in L-M (-52.8) and M/L (-40.5) with MPR application (Table 4).

Negative N balances in all treatments could be attributed to nutrient removal in harvested products i.e. grain. 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. N will largely be derived from underground plant biomass and/or leaf fall during crop growth. Negative N balances in the maize monocrop is attributable additionally to the cereal's inability to fix N for itself and other processes such as leaching, erosion and N immobilization. The high carbon to nitrogen ratio of incorporated maize residues may have favored immobilization of N (Saidur and Rahman, 2004). Ndufa (2001) also noted low levels of soil N in continuously cropped maize even after residue incorporation in soil. Less negative nitrogen balances obtained in CP-M and M/CP cropping systems could be attributed to supply of N through biological nitrogen fixation (BNF) by chickpea and decomposition of its incorporated residues. However, these amounts may have been insufficient to offset higher crop N uptake hence the negative balance. A tremendous potential for contribution of fixed nitrogen to soil ecosystems exists among legumes indicating their significant role as complementary sources of N in farming systems (Peoples *et al*., 1995; Brockwell *et al*., 1995). Rao and Sharma, (1987) and Herridge, (1993) showed that in most cases, grain legumes were generally able to leave 17-23 kg N ha^{-1} in the form of nitrate in soil. Giller *et al*. (1997) also noted that residue quality and quantity affects amount of N availed in soils and so does the type of legume.

Highest losses of N in L-M and L/M cropping systems with use of MPR could have been as a result of higher N accumulation by maize, a large proportion of which was removed through harvested products. Kroeze *et al*. (2003) attributed negative nitrogen balance to the high outflow of N through harvested products and leaching. Even though this is the case, lupin has a high above ground biomass (Engedaw, 2012) and upon residue incorporation possibly enhanced N supply to maize, after decomposition, resulting to higher maize grain yields and subsequently higher losses of N through grain harvest. 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 but that the microbial biomass plays an important role in facilitating nutrient loss from soils in some situations (Turner & Haygarth, 2001).

3.2 Phosphorous balances

The P balances were negative in all treatments (Table 5). There were however no significant interaction effects (P=0.053), between cropping systems and P sources. Both cropping systems and P source therefore had an influence on P balances (Table 5). For this reason, the mean P balances across cropping systems and P sources are used. The maize monocrop, M/L intercrop and L-M rotation had significantly more negative P balances, across P sources, compared to CP-M rotation and M/CP intercrop. P balances, were significantly less negative in M/CP (-14.83) compared to M/L (-28.14) intercrop system. There were however no significant difference between CP-M rotation and CP/M intercrop (Table 5).

Table 5: P balances (kg $ha^{-1}yr^{-1}$) as affected by cropping systems and P source

Cropping System	*P Source*			Mean
	CTRL	TSP	MRP	
Maize (M)	-18.00	-22.04	-24.42	-21.49a
Maize/Lupin (M/L)	-23.08	-31.93	-29.42	-28.14b
Maize/Chickpea (M/CP)	-12.92	-12.16	-19.42	-14.83c
Lupin-Maize (L-M)	-23.60	-25.43	-27.90	-25.64ab
Chickpea-Maize (CP-M)	-12.40	-18.65	-20.94	-17.33c
Mean	-18b	-22.04a	-24.42a	
LSD 0.05	Cropping System			3.5255
	P Source			2.6664

Key: CTRL = Control; TSP = triple superphosphate; MPR = *Minjingu* phosphate rock. Means in a column followed by the same letter(s) are not significantly different at P = 0.05 (Duncan's multiple range test).

Across cropping systems, less negative (-18 $kgha^{-1}yr^{-1}$) P balances were recorded in control compared to TSP and MPR treated plots. There were, however, no significant differences between TSP and MPR treatments in P balances (Table 5). The additional supply of P, after addition of P fertilizers (TSP and MRP), 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 require adequate P from the very early stages of growth for optimum crop production.

Negative P balances across all cropping systems tested, despite application of P fertilizer, could be attributed to P uptake by both maize and legumes, with the latter being more efficient in p uptake and thence translating to increased yields. The increased yields meant varied degree of P losses through harvested crop products. In previous studies, Li *et al*. (2004) and Nuruzzaman *et al*. (2005) recorded the important ability of legumes to increase P uptake from soil for subsequent crop in rotation or the companion crop when intercropped through nutrient mobilization. The more negative P balances in M/L intercrop could be due to higher plant uptake of P by both component crops after lupin mobilization of unavailable P and solubilization of MRP. Jones *et al*. (2003), and Lambers *et al*. (2006) noted the important role of plant roots in releasing large amounts of organic acids such as citric acid, in order to mobilize nutrients like P when bound to soil particles and inaccessible for direct plant uptake.

Cu *et al*. (2005) and Li *et al*. (2010) also documented that P availability to a less P efficient crop, in this case maize, was increased through intercropping with a P efficient species. Liu *et al*. (2004) and Nuruzzaman *et al*. (2005) also found 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. The inability of maize to acidify its rhizosphere means reliance on legumes for this and also takes up P upon its mobilization (Li *et al*. 2007). Liu *et al*. (2004) in a study of maize growth under different cropping systems also found that improved maize growth was not caused by better N nutrition but rather better P uptake. Onwonga *et al*. (2008) also noted that legume rotations had significantly higher yields and this could be attributed to their efficiency in P acquisition from soils.

3.3 Potassium balances

The K balances in soil were positive in maize/chickpea (CTRL and TSP) intercrop with all other treatments registering negative K balances. Maize/lupin (CTRL and TSP) intercrop system had more negative K balances (Table 6). In the rotation systems, significantly less negative balances were observed when maize was rotated with chickpea compared to lupin across all P sources. The least K losses (less negative) were noted in the control treatment of CP-M treatment and M/CP (MPR, CTRL and TSP) intercrop system.

Table 6: K balances (kg $ha^{-1}yr^{-1}$) as affected by cropping systems and P source

Cropping system	P source	K balance (kg $ha^{-1}yr^{-1}$)
Maize (M)	CTRL	-36.61^{bcde}
	TSP	-42.01^{cdef}g
	MPR	-40.39^{cdef}
Maize/Lupin (M/L)	CTRL	-85.26^{hi}
	TSP	-105.36^{i}
	MPR	-77.96^{gh}
Maize/Chickpea (M/CP)	CTRL	12.05^{a}
	TSP	21.34^{a}
	MPR	-2.82^{a}
Lupin-Maize (L-M)	CTRL	-63.44^{efgh}
	TSP	-66.0^{fgh}
	MPR	-59.41^{defgh}
Chickpea-Maize (CP-M)	CTRL	-9.77^{ab}
	TSP	-18.03^{bc}
	MPR	-21.38^{bcd}
LSD 0.05	Cropping System (CS)	27.22

Key: CTRL = Control; TSP = triple superphosphate; MPR = *Minjingu* phosphate rock. Means in a column followed by the same letter(s) are not significantly different at P = 0.05 (Fisher's Protected Least Significant Difference Test).

Positive K balance in the M/CP (TSP and CTRL) cropping system, implies that nutrient inputs into the systems were more than the outputs through harvested products and other nutrient loss pathways. This is in addition to better K mobilization and recycling by chickpea. Ahlawat *et al*. (2005) while conducting chickpea-maize cropping studies noted that stover recycling from crops was able to economize 50% of the recommended NPK fertilizer rates. Negative balances in other treatments were due to acquisition of nutrients from soil and removal in harvested products. Onwonga *et al.* (2008) noted that in legume rotations, increase in yield corresponded to K acquisition hence its decline in soil. The more negative K balances noted in M/L intercrop system could be due to combined harvested products (grain) from both maize and lupin. This is in agreement with the findings of Namoi *et al*. (2014), who also recorded pronounced K losses in sorghum/pigeon pea intercrops and attributable the same to harvesting of the said crops from the same area.

3.4 Gross margin analysis

The crop gross margins (GMs) were significantly influenced by P source and integration of legumes. The maize/lupin cropping system with TSP application had considerably higher GM than other cropping systems (Figure 1). The GMs for treatments; maize/lupin (CTRL) and lupin-maize (TSP) were significantly different from chickpea-maize (TSP), maize (CTRL) and lupin-maize (MPR) whereas the GMs of chickpea-maize (CTRL) was significantly different from chickpea-maize (MPR), maize (TSP), lupin-maize (CTRL and TSP) and maize/lupin (TSP). The lowest gross margins were recorded in chickpea/maize intercrop (CTRL and TSP) and chickpea-maize (CTRL) rotation. The use of TSP led to higher crop GM in cropping systems involving white lupin compared to use of MPR as a P source. For chickpea cropping systems, higher gross margins were realized with MPR compared to TSP application. The GMs across P sources were in the order; M/L, L-M, CP-M, M, M/CP (Figure 1).

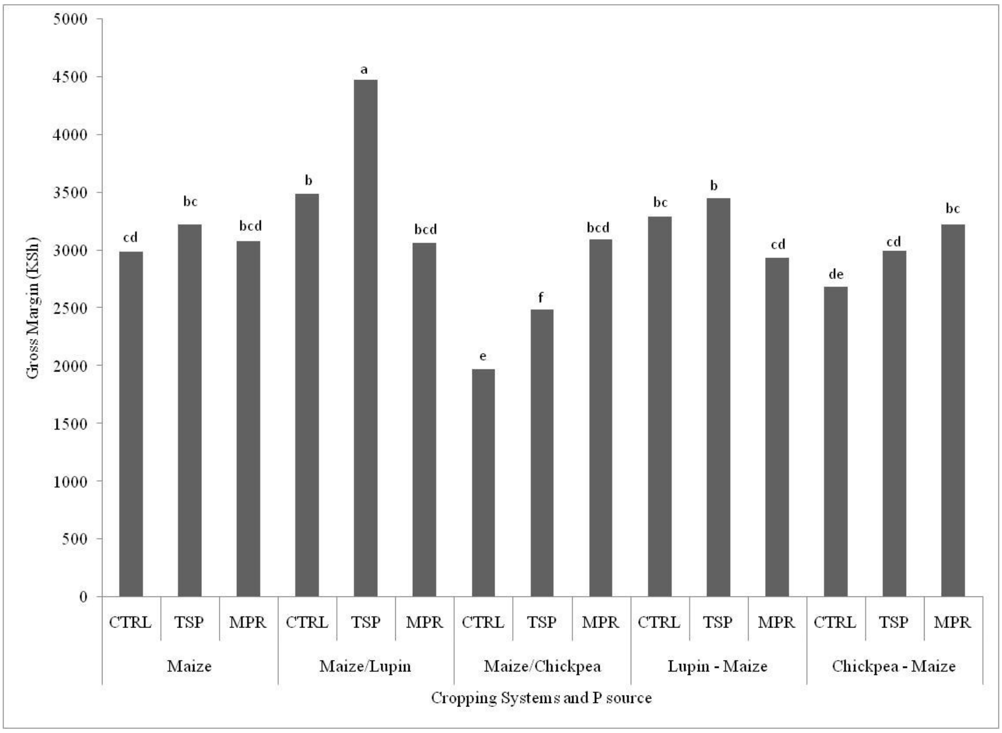

Figure 1. Crop gross margins as influenced by P source and legume type

Key: CTRL = Control; TSP = Triple Superphosphate; MPR = Minjingu phosphate rock. Means in a bar followed by the same letter(s) are not significantly different at *P* = 0.05 (Fisher's Protected Least Significant Difference Test).

Pronounced GMs were realized in maize/lupin intercrops (TSP) followed by lupin-maize (TSP) and lowest in Maize chickpea intercrop (TSP). The high crop GMs in treatments involving lupin with TSP application are attributable to high yields possibly due to better N fixation by lupin, compared to chickpea, and P availability. The high yield thus translated to higher GMs. Lupins rank among the top legumes with respect to fixing N. Lupins not only have effective nitrogen symbiotic fixing bacteria, but also have symbiotic root fungi that make soil phosphate available to plants (Hill, 1977; Lelei et al., 2014). The differences in GMs would therefore be attributed to two major factors; namely, high productivity originating from use of TSP and lupin's superior N fixation ability and relative high price for lupin grain. According to Chengappa *et al.* (2003), this kind of scenario is expected given that profit is a function of price and yield and a change in any of the two could influence the crop profitability.

The high gross margins in maize/lupin intercrop with application of TSP could be attributed to better lupin response to P compared to chickpea. This in turn translated to better N fixation and hence higher yield of the companion crop. Under P deficiency conditions, lupin has been found to respond in grain yield to P fertilizer application (Lelei et al., 2014). It has also been stated that the rate of applied P fertilizer is a prime determinant of grain yield. On the other hand chickpea appear to show a marked variability in response to P fertilizer (Shukla and Yadav, 1982; Onwonga et al., 2015). Similarly Saxena (1980) reported that grain yield responses by chickpea to applied P fertilized were rare.

In terms of cropping systems, there were no marked differences in GM between maize monocrop and legume-maize rotation (lupin-maize and chickpea-maize) systems across all P sources. Significant differences in GMs were however noted between maize monocrop and maize/legume intercrop for control and TSP with MPR application registering no significant differences. This may be due to the fact that in respective cases, the crops at any given time were stand alone and hence no competition for growth parameters leading to better grain yields. These findings are in agreement with those of von Richthofen et al. (2006) who reported that GMs of crop rotations with grain legumes in most cases equal those of crop rotations without grain legumes.The authors further noted that there was a tendency toward slightly higher values in rotation systems.

Kasenge (2000) further reported that intercropping of maize with beans was more beneficial in terms of reduced nutrient decline and higher economic gains than monocropping of either crop. This collaborates the findings of Francis, (1978) and Nadar (1984) who found intercropping of maize with beans to results in higher economic gains than monocropping of either crop, when maize-bean price relations were taken into account

3.5 Nutrient balances vs. Gross margins

The N, P and K nutrient balances in response to P sources and cropping systems exhibited a negative relationship with gross margins. This in essence means that the positive gross margins obtained were at the expense of soil nutrient mining. These findings are in agreement with those of Schmutz et al. (2014) who reported a negative relationship involving N, P and K rotational nutrient balances with rotational gross margins and emphasized the need for balancing fertility management and economic gains. Significantly high gross margins were realized in Maize/lupin intercrop with TSP application. Coincidentally, in the same treatment high nutrient losses were realized (Figure 2). This is particularly true for P and N. Most nutrient losses were as a result of harvested products and hence with application of TSP, more crop yield was realized and subsequently translated to more sales hence the high GM. These results are in agreement with the earlier findings by Mugisha *et al.* (2011) who observed that soil nutrient mining continues to be a big challenge to production as harvesting removes nutrients that need to be replenished regularly which is not the case. Lowest GMs were realized in maize/chickpea intercrop with application of TSP. Again, in the same treatments, moderate nutrient losses (especially N) were noted. The losses due to harvested product were minimal and hence the calculated low GMs.

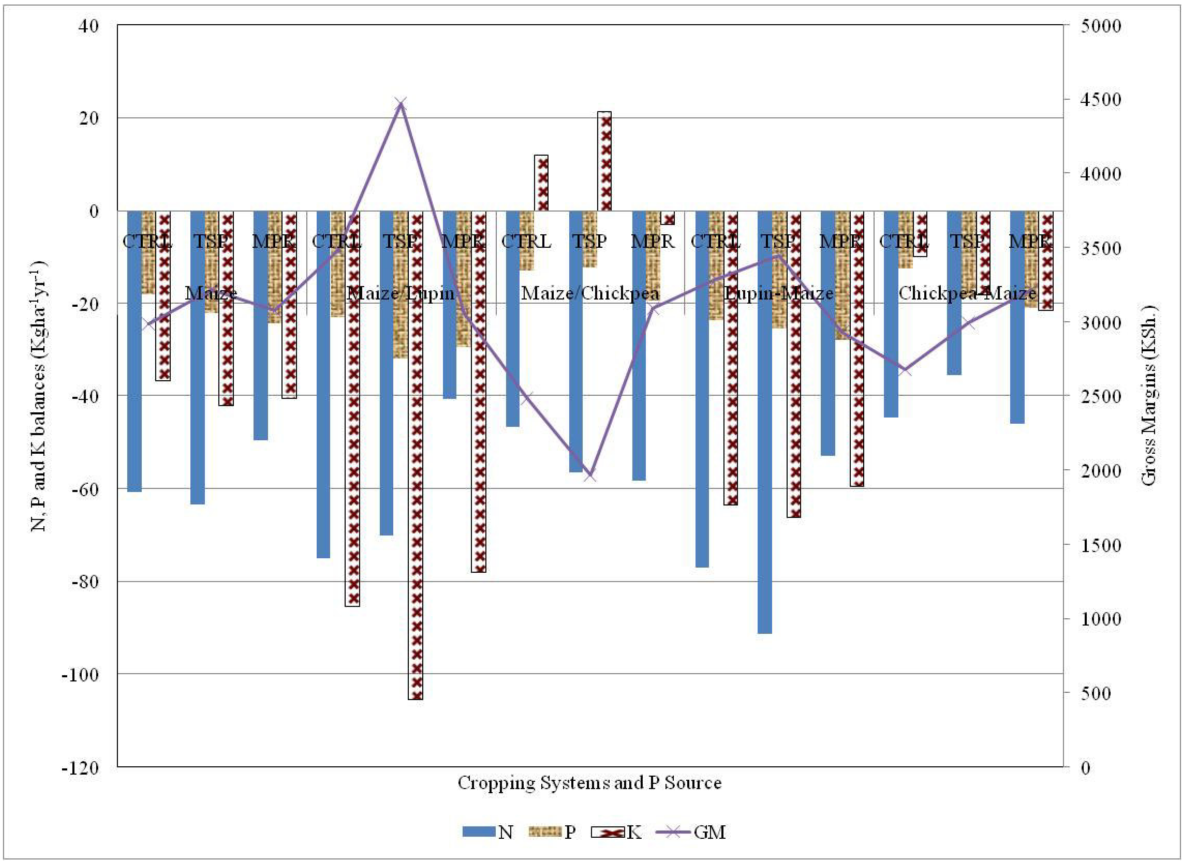

Figure 2: Influence of cropping systems and P sources on nutrient balances and gross margins

According to Esilaba et al. (2005), harvesting of crops for food and surplus for sale are the most important sources of nutrient mining in the crop production system. Therefore attempts to correct the imbalance need to address these and other socioeconomic factors. Profits from sold grain may be used to buy inorganic fertilisers (Harris, 1998) and hence certifying that farm profits are not at the expense of nutrient mining. On the other hand, Buresh et al. (2010) argued that realistic nutrient drawn could be derived for each soil and crop growing environments whereby yield could be optimized and profit could be maximized without substantial mining of nutrients from the soil.

4.0 Conclusion

The NPK balances were negative across cropping systems and P sources except for K in M/CP (CTRL and TSP) intercrop. Significantly less negative N balances were obtained in maize monocrop (MPR), chickpea/maize (CTRL) intercrop, chickpea-maize (TSP) rotation, and maize/lupin (MPR) intercrop. Similarly, lupin/maize (CTRL and TSP) intercrop and lupin-maize (CTRL and TSP) rotation systems recorded more negative (highest losses) N balances. The maize monocrop, M/L intercrop and L-M rotation had significantly more negative P balances, across P sources, compared to CP-M rotation and M/CP intercrop. P balances, were significantly less negative in M/CP compared to M/L intercrop system. Less negative P balances were recorded in control treatment compared to TSP and MPR across cropping systems. Maize/lupin (CTRL and TSP) intercrop system had pronounced negative K balances. In the rotation systems, significantly less negative balances were observed when maize was rotated with chickpea compared to lupin across all P sources. Pronounced GMs were realized in maize/lupin intercrops (TSP) followed by lupin-maize (TSP) and lowest in maize chickpea intercrop (TSP and CTRL). The N, P and K nutrient balances in response to P sources and cropping systems exhibited a negative relationship with gross margins. The positive gross margins obtained were thus at the expense of soil nutrient mining as treatments with high nutrient losses, case for N and P, simillarly had the highest GMs.

Considering nutrient balance studies alongside economic analysis has thus demonstrated the hidden environmental costs in the positive crop GMs and by extension the efficiency of such production systems. As a result, increased GMs under introduced technologies are not sustainable unless the same is matched with adequate nutrient replenishments to balance those lost through harvested products and other nutrient loss pathways. Farmers would, actually, go for those technologies that not only maximize yields but also accrue high profits. In the context of this study, and in order of GM (from highest) analysis, M/L intercrop, maize monocrop and L-M rotation with application of TSP are such technologies. In the long-run however these technologies will prove untenable due to nutrient mining. Nonetheless to guarantee efficient production and sustainable legume-maize systems, following application of phosphorus fertilizer and integration of legumes, it is important that profits accrued from farm sales be used to purchase fertilizers and/or support practices geared towards replenishing mined soil nutrients. This way farm profits realized will not be at the expense of nutrient mining.

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