International Journal of Plant & Soil Science

19(2): 1-9, 2017; Article no.IJPSS.34972
ISSN: 2320-7035

Effect of Legume Integration and Phosphorus Use on Maize N and P Concentration and Grain Yield in Kabete - Kenya

N. A. Templer[1*], J. J. Lelei[2] and R. N. Onwonga[1]

[1]Department of Land Resource Management and Agricultural Technology, University of Nairobi, P.O.Box 29053, Nairobi, Kenya.
[2]Department of Crops, Horticulture and Soils, Egerton University, P.O.Box 536 - 20115, Egerton, Njoro, Kenya.

Authors' contributions

This work was carried out in collaboration between all authors. Authors JJL and RNO designed the study and wrote the protocol. Author NAT wrote the first draft, managed the analyses of the study and literature searches. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/IJPSS/2017/34972
Editor(s):
(1) Kofi Agyarko, College of Agricultural Education, University of Education, Winneba, Ghana.
Reviewers:
(1) Alminda M. Fernandez, University of Southeastern Philippines, Philippines.
(2) Anibal Condor Golec, Peru.
Complete Peer review History: http://www.sciencedomain.org/review-history/21269

Original Research Article

Received 21st June 2017
Accepted 25th August 2017
Published 6th October 2017

ABSTRACT

Aims: Investigate effect of legume integration and phosphorus application on nitrogen (N) and phosphorous (P) concentration and yield of maize.
Place and Duration of Study: The study was carried out in Kabete Field Station of the University of Nairobi during the long (LRS) and short rainy (SRS) seasons of 2012.
Methodology: A split plot layout in a randomized complete block design (RCBD), with three replicates was used. The main plots were sole maize, intercropping (chickpea/maize; lupin/maize) and rotation systems (chickpea-maize; lupin-maize) systems. The sub plots were Minjingu rock phosphate (MPR) and triple superphosphate (TSP) fertilizers, applied at 60 kg P ha^{-1}. Maize P and N concentrations were measured at seedling, mid-flowering and physiological maturity/harvest. Maize grain and dry matter (DM) yield were determined at physiological maturity.
Results: During the LRS, significantly (*P*=0.05) higher maize P concentrations were recorded in

**Corresponding author: E-mail: colnltempler@gmail.com;*

chickpea/maize intercrop (C/M) with TSP at seedling; sole maize, chickpea/maize (C/M) and lupin/ maize (L/M) intercrops, with MPR and TSP at mid flowering and L/M intercrop with TSP at harvest. In the SRS at seedling and harvest stages, significantly higher values were recorded in the lupin-maize rotation (L-M) with MPR. At mid flowering, significantly higher P values were observed in L/M with MPR. During the LRS, N concentration in maize was significantly higher in L/M with TSP and L/M with MPR at seedling and mid flowering stages, respectively. At harvest L/M with TSP had significantly higher values. In the SRS, maize N concentration was significantly higher in L-M and chickpea-maize (C-M) rotation with MPR and sole maize with TSP at seedling; and L/M with MPR and TSP, at mid flowering and harvest, respectively. During the LRS, maize grain yields were significantly higher in L/M with TSP and MPR and C/M with MPR. In the SRS, significantly higher maize grain yields were recorded in L/M with TSP and L-M with MPR. DM yields in the LRS were significantly higher in L/M with TSP applied. In the SRS, DM yields were significantly higher in L/M with MPR, C/M with MPR, L-M with MPR and C-M with MPR.

Conclusion: The integration of MPR or TSP and legumes increased maize N and P concentration and yields. The use of cost effective MPR in an intercropping system may be preferred by small holder farmers.

Keywords: Chickpea; lupin; Minjingu PR; Triple superphosphate.

1. INTRODUCTION

Nitrogen (N) and phosphorus (P) are critical macronutrients in the production of maize (*Zea mays* L.) the primary staple of Kenya [1,2]. Intensive use of soils coupled with irregular mineral fertilizer use in small holder farms of Kabete, Kenya have caused deficiencies of these nutrients and consequently low yields. The use of chemical fertilizers, to enhance soil fertility, is limited by high costs. On the other hand, the quantity of organic manures available in small holder farms is insufficient to meet maize nutrient requirements [3]. Organic manures require application in large quantities [4]. Integrating legumes white lupin (*Lupinus albus* L.) and chickpea (*Cicer arietinum* L.), in maize cropping systems with application of Minjingu phosphate rock (MPR), would be a feasible alternative for increasing N and P nutrition and yields of maize.

Legumes supply fixed N to non-legume crops grown in association or rotation with them [5]. Legume roots, rhizodeposits [6,7,8] and residues [9,10] are important N pools. MPR is a cost effective P source. It costs about 50% of processed P fertilizers on elemental basis. It also rebuilds soil capital P due to residual effect [11]. Prior studies in Kenya by Okalebo and Nandwa [11] and Onwonga et al. [12] have revealed an average effectiveness of about 65% for MPR compared with processed fertilizers. The major impediment to its use is its insolubility [13] which may constrain P uptake by plants. Plants have adapted strategies to enhance insoluble P acquisition and use [14,15]. Where there is exudation of organic acids and acid phosphatase, bound forms of P are solubilized and this increases the availability of P for plant uptake [14,16]. Cluster-rooted plants such as white lupin and members of the *Proteaceae* excrete carboxylic acids and mediate desorption of significant amounts of soil phosphorus [14]. Some carboxylic acids (carboxylates), for example citrate and malate, can mobilize (in)organic phosphorus into the soil solution [17, 18]. Chickpea (*Cicer arietinum* L.), like lupin, exudes carboxylates from its roots [19] and can thus mobilize calcium-bound phosphate (Ca-P) for uptake by plants.

The objective of the study was therefore to investigate effect of integration of legumes white lupin (*Lupinus albus* L.) and chickpea (*Cicer arietinum* L.) and application of MPR and Triple superphosphate (TSP) fertilizers on N and P concentrations and yield of maize in Kabete, Kenya.

2. MATERIALS AND METHODS

2.1 Site Description

A field experiment was conducted at Kabete Field Station of the University of Nairobi in Kenya, during the short (SRS) and long rain (LRS) seasons of 2012. The site (1940 m asl) is geographically located in agro-ecological zone UM3 (Upper Midland) at 1° 15' S and 36° 41' E and receives an average annual precipitation of 1000 mm [20]. The minimum and maximum mean temperatures are 13.7°C and 24.3°C, respectively. The soil is predominantly deep (>180 cm), dark red to dark reddish brown, friable clays and classified as a humic Nitisol [21, 22]. The site is representative, in terms of soil and climate, of large areas of the central Kenya highlands. Initial soil properties were: clay texture, medium available P, organic carbon and N (Table 1) according to Landon [23] soil nutrient classification.

2.2 Experimental Design and Treatments

A split plot layout in a randomized complete block design (RCBD), with three replicates was used. The main plots were sole maize, intercropping (chickpea/maize; lupin/maize) and rotation (chickpea- maize; lupin-maize) systems. The sub plots were MPR and TSP, both applied at 60 kg P ha^{-1}.

2.3 Agronomic Practices

Land was ploughed manually. This was followed by raking and levelling before application of treatments. MPR was applied by broadcasting, in both the LRS and SRS, three days before planting and was incorporated into the top soil. TSP was applied in both seasons, by banding and mixed well with soil before sowing. Maize (*Zea mays* L.; Hybrid 513) was sown at the rate of two seeds per hill at spacing of 75 cm × 30 cm, in respective treatments (Table 2). In the intercropping system, in both LRS and SRS, one row of legume, either lupin or chickpea, was sown between two maize rows, at the rate of two seeds per hill. For the rotation system, chickpea and lupin were sown at the rate of two seeds per hill as sole crops during the SRS at a spacing of 75 cm × 30 cm. Thinning to one seedling per hill was done four weeks after sowing for all crops. The plots were kept weed free throughout the growing season through manual control. After harvesting of grain, crop residues were chopped into 5-20 cm and incorporated into the plots they were removed from, during land preparation for planting in the second season.

2.4 Soil Sampling and Analysis

Soil samples (0-20 cm) were collected, in a zig-zag manner, from the field before experimental set up. Air-dried composited sample, sieved through 2 mm mesh, was analyzed for initial properties; pH (Soil: H_2O: 1:2.5), total nitrogen

Table 1. Initial physical and chemical soil properties (0-30 cm)

Property	Units	Value	Class*	Property	Units	Value	Class*
pH (H_2O)	-	6.3	Medium	Ca	cmol$_c$ kg^{-1}	8.13	Medium
Available P	mg kg^{-1}	10	Medium	Mg	cmol$_c$ kg^{-1}	1.7	Medium
Total N	%	0.32	Medium	Sand	%	5	
Organic C	%	2.75	Medium	Silt	%	27	
Bulk density	Mg m^{-3}	1.00		Clay	%	68	
Exc. K	cmol$_c$ kg^{-1}	1.05	High	Textural class		Clay	

**Landon [23] classification*

Table 2. Treatments and cropping sequence in the LRS and SRS of 2012

Cropping system	P source	Cropping sequence	
		LRS	SRS
Sole maize	MPR	Maize	Maize
	TSP	Maize	Maize
	None (control)	Maize	Maize
Rotation			
Lupin-Maize (L-M)	MPR	Lupin	Maize
	TSP	Lupin	Maize
	None (control)	Lupin	Maize
Chickpea-Maize (C-M)	MPR	Chickpea	Maize
	TSP	Chickpea	Maize
	None (control)	Chickpea	Maize
Intercropping			
Lupin/Maize (L/M)	MPR	Lupin/Maize	Lupin/Maize
	TSP	Lupin/Maize	Lupin/Maize
	None (control)	Lupin/Maize	Lupin/Maize
Chickpea/Maize (C/M)	MPR	Chickpea/Maize	Chickpea/Maize
	TSP	Chickpea/Maize	Chickpea/Maize
	None (control)	Chickpea/Maize	Chickpea/Maize

(Kjeldahl method), available P (double acid method) and organic C (Walkley – Black method), as described by Okalebo et al. [24]. Mineral nitrogen was determined by KCl Extraction/Cadmium reduction column method [25], exchangeable K by Flame Emission Spectrophotometry and Ca and Mg by Atomic Absorption Spectrophotometry [26]. Texture was determined using the hydrometer method [27]. Undisturbed core samples were used for bulk density determination [28].

2.5 Plant Sampling, Analysis and Yield Determination

At maize seedling four whole plants were randomly sampled per plot. At mid flowering, the leaf opposite the ear was sampled from ten randomly selected plants. At physiological maturity the above ground portion of the plant was harvested from three center rows in all plots and separated into stover (stalk and leaves) and cobs. Sample (plant tissue) fresh weights were determined immediately in the field using a weighing balance. Sub-samples, for calculation of DM yield and nutrient concentration, were chopped into small pieces, placed into paper bags and oven dried (65°C) for 72 hours. The oven dried samples were weighed, ground and sieved (2 mm mesh). Analyses of N and P concentrations of the samples were performed using standard methods [24]. Maize cobs were de-husked, dried, and threshed. The grains were weighed to obtain yield. Grain (13% moisture) and DM yields were expressed in kg ha^{-1} using the following formulae:

$$\text{Yield (kg ha}^{-1}) = \text{yield (kg) / area (m}^2) \times 10000$$

2.6 Statistical Analysis

Data collected were subjected to analysis of variance (ANOVA) using GenStat 15th Edition, 2012. Means were separated using Fisher's protected least significant difference test (P=0.05).

3. RESULTS AND DISCUSSION

3.1 Phosphorous Concentration in Maize

During the LRS at seedling stage, significantly higher maize P levels were recorded in chickpea/maize intercrop (C/M) with TSP (Table 3). At mid flowering significantly higher values were recorded in sole maize, chickpea/maize (C/M) and lupin/ maize (L/M) intercrops, with MPR and TSP. At harvest, highest P values were noted in L/M intercrop with TSP. During the SRS at seedling and harvest stages, significantly higher values were recorded in the lupin-maize rotation (L-M) with MPR. At mid flowering, significantly higher P values were observed in L/M with MPR (Table 3).

Higher maize P levels in chickpea/maize (C/M) and lupin/maize (L/M) intercrops with MPR and TSP at mid flowering, in both seasons, can be attributed to mobilization of MPR by intercropped legume in addition to enhanced uptake of P from soluble TSP. Olivera et al. [29] similarly noted that phosphorous application increased shoot P content. Similarly, Dahmardeh et al. [30] reported that maize-cowpea intercropping increased nitrogen, phosphorus and potassium contents compared to maize monocrop. Whitehead and Isaac [31] and Li et al. [32] reported interspecific facilitation of P uptake between intercropped species. During the SRS, mobilization of MPR by acids released during decomposition of lupin residues from previous season might have contributed to higher maize P concentration in L-M with MPR at seedling and harvest [33].

3.2 Nitrogen Concentration in Maize

During the LRS, N concentration in maize was significantly higher in L/M with TSP at seedling stage (Table 4) At mid flowering, significantly higher values were observed in L/M with MPR. At harvest L/M with TSP had significantly higher values (Table 4). In the SRS at seedling stage, N concentration in maize was significantly higher in L-M and chickpea-maize (C-M) rotation with MPR and sole maize with TSP (Table 4). At mid flowering and harvest L/M with MPR and TSP, respectively had significantly higher N concentration (Table 4).

Higher N values in L/M during the LRS and SRS at mid flowering and harvest could be attributed partly to N recycling by lupin. Seran and Brintha [34] noted that an intercrop is more efficient at uptake as compared to a monocrop. This is because when only one species is grown, all roots tend to compete with each other for nutrients since they are all similar in their orientation and below surface depth. Significantly higher N uptake in lupin-maize (L-M) rotation and chickpea-maize with MPR, at seedling during the SRS of 2012 was due to rotational benefits of legumes on succeeding maize crop. Mineralization of legume residues contributed to the N pool for uptake by maize. This is in agreement with findings of Lpoez-Bellido et al. [35], Kuo and Jellum [36] and Shah et al. [37]. Shafi et al. [38] observed increased N uptake in maize stover with crop residues retention on trial fields. Stevenson and van Kessel [39] and Staggenborg et al. [40], in pea and sorghum/soy bean studies, respectively also noted the role played by crop residues in improving the soil physicochemical condition hence improved N uptake.

3.3 Maize Grain and Dry Matter (DM) Yields

In the LRS of 2012, maize grain yields were significantly higher in L/M with TSP and MPR and C/M with MPR (Table 5). In the SRS of 2012, significantly higher maize grain yields were recorded in L/M with TSP and L-M with MPR. Treatment effects on DM yields closely followed maize grain yields. DM yields in the LRS 2012 were significantly higher in L/M with TSP. In the

Table 3. Effect of cropping system and P source on maize P concentration

Cropping system	P source	Plant P (g/kg)					
		LRS			SRS		
		Seedling	Flowering	Harvest	Seedling	Flowering	Harvest
Sole Maize	CTRL	0.81^{c}	0.86^{b}	1.41^{c}	0.79^{g}	0.83^{i}	0.75^{k}
	TSP	0.77^{d}	0.99^{a}	1.36^{d}	0.94^{e}	0.97^{f}	0.92^{f}
	MPR	0.92^{b}	1.01^{a}	1.33^{e}	0.96^{d}	0.99^{e}	0.94^{e}
C/M	CTRL	0.82^{c}	0.85^{b}	1.41^{c}	0.74^{h}	0.69^{j}	0.80^{j}
	TSP	0.97^{a}	1.03^{a}	1.36^{d}	0.98^{d}	1.07^{d}	0.89^{g}
	MPR	0.91^{b}	0.92^{a}	1.33^{e}	0.92^{f}	1.12^{b}	0.73^{l}
L/M	CTRL	0.71^{e}	0.86^{b}	1.25^{g}	0.59^{k}	0.58^{l}	0.60^{n}
	TSP	0.73^{e}	0.95^{a}	1.52^{a}	1.14^{b}	0.86^{g}	1.15^{b}
	MPR	0.88^{bc}	1.09^{a}	1.47^{b}	1.00^{c}	1.25^{a}	1.04^{c}
C-M	CTRL				0.70^{i}	0.67^{k}	0.55^{o}
	TSP				0.66^{j}	0.86^{g}	0.65^{m}
	MPR				0.97d	1.10c	0.83i
L-M	CTRL				0.92^{f}	0.84^{h}	0.71^{i}
	TSP				0.91^{f}	0.99^{e}	0.84^{h}
	MPR				1.22^{a}	1.12^{b}	1.33^{a}

Key: LRS – long rain season; SRS – short rain season; CS – cropping system; P – phosphorous source; 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)

Table 4. Effect of cropping systems and P sources on maize N concentration

Cropping system	P source	Total N (%)					
		LRS			SRS		
		Seedling	Flowering	Harvest	Seedling	Flowering	Harvest
Sole Maize	CTRL	1.23^{e}	1.08^{e}	1.16^{d}	1.64^{bc}	0.26^{i}	0.60^{j}
	TSP	1.36^{c}	1.16^{d}	1.26^{c}	1.69^{ab}	1.98^{e}	1.73e
	MPR	1.30^{d}	1.16^{d}	1.23^{c}	1.52^{g}	1.75^{g}	1.91^{c}
C/M	CTRL	0.94^{h}	1.02^{f}	0.98^{f}	0.55^{g}	1.97^{e}	1.26^{g}
	TSP	1.16^{f}	1.03^{f}	1.13^{de}	0.91^{f}	0.77^{h}	0.84^{h}
	MPR	1.08^{g}	1.18cd	1.10^{e}	1.47^{d}	1.79^{fg}	1.63^{f}
L/M	CTRL	0.63^{i}	0.77^{g}	0.70^{g}	0.94^{f}	2.01^{e}	1.86^{d}
	TSP	1.97^{a}	1.84^{b}	1.75^{a}	1.38^{e}	2.41^{b}	2.14^{a}
	MPR	1.60^{b}	1.90^{a}	1.70^{b}	1.47^{d}	2.58^{a}	2.02^{b}
C-M	CTRL				0.65^{f}	0.72^{h}	0.65^{i}
	TSP				1.61^{c}	1.77^{g}	1.61^{f}
	MPR				1.66^{abc}	1.83^{f}	1.66^{f}
L-M	CTRL				0.53^{g}	0.16^{j}	0.35^{k}
	TSP				1.39^{e}	2.12^{d}	1.75^{e}
	MPR				1.74^{a}	2.26^{c}	2.00^{b}

Key: LRS – long rain season; SRS – short rain season; CS – cropping system; PS – phosphorous source; 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)

Table 5. Maize grain and DM yields over the SRS and LRS of 2012

Cropping system	P source	Grain yield (ton ha^{-1})		DM yield (ton ha^{-1})	
		LRS	SRS	LRS	SRS
Sole Maize	CTRL	3.03^{cd}	3.78^{d}	5.0^{cd}	5.84^{g}
	TSP	4.04^{b}	5.06^{b}	6.17^{bc}	7.46^{cde}
	MPR	3.16^{cd}	3.32^{cd}	4.9^{d}	6.98^{f}
L/M	CTRL	2.95^{d}	3.68^{d}	5.16^{bc}	6.84^{f}
	TSP	4.61^{a}	5.28^{ab}	7.65^{a}	7.66^{cd}
	MPR	4.18^{ab}	4.51^{bc}	6.4^{b}	9.4^{a}
C/M	CTRL	3.11^{cd}	3.89^{cd}	4.84^{d}	4.83^{h}
	TSP	3.47^{c}	4.84^{bc}	4.69^{d}	7.27^{def}
	MPR	4.13^{ab}	4.12^{cd}	5.4^{bc}	8.57^{ab}
L-M	CTRL		4.62^{bc}		5.98^{g}
	TSP		4.53^{bc}		7.91^{c}
	MPR		5.66^{a}		9.0^{a}
C-M	CTRL		2.95^{e}		5.69^{g}
	TSP		4.46^{bc}		7.01^{ef}
	MPR		4.11^{cd}		8.97^{a}

Key: LRS – long rain season; P – Phosphorous 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)

SRS, DM yields were significantly higher in L/M with MPR, C/M with MPR, L-M with MPR and C-M with MPR.

Higher grain yield in L/M with TSP and MPR and C/M with MPR in the LRS and in L-M with MPR and L/M with TSP in the SRS can partly be attributed to improvement in N nutrition by maize through symbiotic N fixation by the legumes. Jansen [41] in a study involving white lupin, reported a potential atmospheric nitrogen fixation rate of up to 400 kg N ha^{-1} yr^{-1} for lupin. In a study on chickpea nitrogen fixation rates in the production of wheat, fixation rates of between 100- 238 kg N ha^{-1} were reported [42]. In the SRS, mineralization of incorporated lupin residues possibly enhanced N supply to maize, resulting to higher grain yields in the L-M and L/M systems. Lupin has high above ground biomass [43]. Kamh et al. [44]) and Nuruzzaman et al. [45] also found out that there was better growth of wheat after lupin cropping in a pot experiment.

Improved P nutrition for maize after MPR and TSP application additionally improved yields. TSP is highly soluble and available for crop uptake. Chickpea and lupin, exude carboxylates from roots [19,46,47] and could have mobilized calcium-bound phosphate (Ca-P) in MPR for uptake by plants. Onwonga et al. [12] and Lelei et al. [48] made similar observations. Treatment effects on DM yields closely followed grain yields because nutrients that accumulate in the stover are transferred to grain as they develop. With plant growth, nutrients are partly translocated to newly formed leaves and reproductive parts [49,50,51]. An adequate supply of phosphorus is associated with greater strength of cereal stover [49,52,53]. Sufficient availability of nitrogen (N) is a prerequisite for high dry matter production and protein yields [54,55].

4. CONCLUSION

The application of MPR and TSP fertilizers and integration of legumes increased maize N and P concentration and grain yields. The use of cost effective MPR in an intercropping systems may be preferred by farmers and is recommended.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. White PJ, Brown PH. Plant nutrition for sustainable development and global health. Ann. of Bot. 2010;105:1073-1080.
2. Ministry of Agriculture (MOA). Economic survey, MOA and Tegemeo Computation reports. Western Province, Kenya; 2008.
3. Jens F, Magid J. Evaluating NUTMON nutrient balancing in Sub-Saharan Africa. Nutr. Cyc. in Agroecosyst. 2004;69(2): 101-110.
4. Withers PJ, Sylvester-Bradley R, Jones DL, Healey JR, Talboys PJ. Feed the crop not the soil: Rethinking phosphorus

management in the food chain. Environ. Sci. and Techn. 2014;48(12):6523-6530.
5. Ojiem JO, Vanlauwe B, De Ridder N, Giller KE. Niche-based assessment of contributions of legumes to the nitrogen economy of Western Kenya smallholder farms. J. Plant and Soil. 2007;292:119-135.
6. Russell CA, Fillery IRP. Estimates of lupin below-ground biomass nitrogen, dry matter and nitrogen turnover to wheat. Aust. J. Agric. Res. 1996;47:1047-1059.
7. Mayer J, Buegger F, Jensen ES, Schloter M, Heß J. Turnover of grain legume N rhizodeposits and effect of rhizodeposition on the turnover of crop residues. Biol. and Fertil. of Soils. 2004;39(3):153-164.
8. Laberge G, Franke AC, Ambus P, Høgh-Jensen H. Nitrogen rhizodeposition from soybean (*Glycine max*) and its impact on nutrient budgets in two contrasting environments of the Guinean savannah zone of Nigeria. Nutr. Cyc. in Agroecosyst. 2009;84(1):49-58.
9. Vesterager JM, Nielsen NE, Høgh-Jensen, H. Nitrogen budgets in crop sequences with or without phosphorus-fertilized cowpea in the maize-based cropping systems of semi-arid eastern Africa. Afric. J. of Agric. Res. 2007;2(6):261-268.
10. Carranca C, Torres MO, Madeira M. Underestimated role of legume roots for soil N fertility. Agron. for Sustain. Develop. 2015;35(3):1095-1102.
11. Okalebo JR, Nandwa SM. Effect of organic resources with and without inorganic fertilizers on maize yields, mainly on P deficient soils in Kenya. National Soil Fertility Plant Nutrition Research Programme Technical Report Series No. 12, KARI, Nairobi, Kenya; 1997.
12. Onwonga RN, Lelei JJ, Macharia JK. Comparative effects of soil amendments on phosphorus use and agronomic efficiencies of two maize hybrids in acidic soils of Molo County, Kenya. Amer. J. of Experim. Agric. 2013;3(4):939-958.
13. Okalebo J, Othieno CO, Woomer PL, Karanja NK, Sesmoka JRM, Bekunda MA, et al. Available technologies to replenish soil fertility in East Africa. Nutr. Cyc. in Agroecosyst. 2007;76:153-170.
14. Lamont BB. Structure, ecology and physiology for root clusters – a review. Plant and Soil. 2003;248:1-19.
15. Lambers H, Shane MW, Cramer MD, Pearse SJ, Veneklaas EJ. Root structure and functioning for efficient acquisition of phosphorus: Matching morphological and physiological traits. Ann. of Bot. 2006; 98(4):693-713.
16. Ramaekers L, Remans R, Rao IM, Blair MW, Vanderleyden J. Strategies for improving phosphorus acquisition efficiency of crop plants. Field Crops Res. 2010;117(2):169-176.
17. Plassard C, Dell B. Phosphorus nutrition of mycorrhizal trees. Tree Physiol. 2010; 30(9):1129-1139.
18. Fujii K. Soil acidification and adaptations of plants and microorganisms in Bornean tropical forests. Ecologic. Res. 2014;29(3): 371-381.
19. Veneklaas EJ, Stevens J, Cawthray GR, Turner S, Grigg AM, Lambers H. Chickpea and white lupin rhizosphere carboxylates vary with soil properties and enhance phosphorus uptake. Plant and Soil. 2003; 248:187–197.
20. Jaetzold R, Schimdt H, Hornetz B, Shisnaya C. Farm management handbook of Kenya. Natural Conditions and Farm Mannegement Information. Volume IIA. Nairobi Kenya. 2007;319.
21. FAO Production Yearbook. FAO statistics series no. 94. FAO, Rome; 1990;43.
22. World Reference Base for Soil Resources (WRB). A framework for International Classification, Correlation and Communication. World Soil Resources Reports 103; 2006.
23. Landon JR. Booker tropical soil manual. A handbook for soil survey and agricultural land evaluation in the tropics and subtropics. Longman Scientific and Technical Essex, New York. 1991;474.
24. Okalebo JR, Gathua KW, Woomer PL. Laboratory methods of soil and plant analysis: A working manual. TSBF: Nairobi, Kenya. 2002;128.
25. Bremner JM, Keeney DR. Steam distillation methods for determination of ammonium, nitrate and nitrite. Anal Chim. Acta. 1965;32:485-495.
26. Jońca Z, Lewandowski W. Verification of measurement capabilities of flame atomic spectrometry for the determination of sodium, potassium, magnesium, and calcium in natural fresh water part I. Comparison of Recommended Methods. Polish J. of Environment. Stud. 2004;13(3): 275-280.
27. Black CA, Evans DD, White JL, Esminger LE, Clark FE. Methods of soil analysis part

1: American society of agronomy, Madison, Wisconsin; 1965.
28. Blake GR, Hartge KH. Bulk density. In: Klute A, editor. Methods of soil analysis. Part 1. 2nd ed. Agron. Monogr. 9. ASA and SSSA, Madison, WI. 1986;363–375.
29. Olivera M, Tejera N, Iribarne C, Ocana A, Lluch C. Growth, nitrogen fixation and ammonium assimilation in common bean (*Phaseolus vulgaris*): Effect of phosphorus. Plant Physiol. J. 2004;121:498-505.
30. Dahmardeh M, Ghanbari A, Syahsar BA, Ramrodi M. The role of intercropping maize (*Zea mays* L.) and cowpea (*Vigna unguiculata* L.) on yield and soil chemical properties. African J. of Agric. Res. 2010; 5(8):631-636.
31. Whitehead M, Isaac ME. Effects of shade on nitrogen and phosphorus acquisition in cereal-legume intercropping systems. Agricult. 2012;2:12-24.
32. Li L, Li S, Sun J, Zhou L, Bao X, Zhang H, Zhang F. Diversity enhances agricultural productivity via rhizosphere phosphorus facilitation on phosphorus-deficient soils. Proc. of the Nation. Acad. of Sci. of the USA. 2007;104(27):11192–11196.
33. Lelei JJ, Onwonga RN. White Lupin (*Lupinus albus L.* cv. Amiga) Increases Solubility of Minjingu Phosphate Rock, Phosphorus Balances and Maize Yields in Njoro Kenya. Sustain. Agricult. Res. 2014; 3(3):37-49.
34. Seran TH, Brintha I. Review on maize-based intercropping. J. Agronomy. 2010; 9(3):135-145.
35. Lpoez-Bellido L, Lopez-Bellido RJ, Castillo JE, Lopez-Bellido FJ. Effects of tillage, crop rotation and nitrogen fertilization on wheat under rain fed Mediterranean conditions. Agron. J. 2000;92:1054–1063.
36. Kuo S, Jellum EJ. Influence of winter cover crop and residue management on soil nitrogen availability and corn. Agron. J. 2002;94:501–508.
37. Shah Z, Shah SH, Peoples MB, Schwenke GD, Herriedge DF. Crop residue and fertilizer N effects on nitrogen fixation and yields of legume–cereal rotations and soil organic fertility. Field Crops Res. 2003;83: 1–11.
38. Shafi M, Bakht J, Jan MT, Shah Z. Soil C and N dynamics and maize (*Zea mays* L.) yield as affected by cropping systems and residue management in North-western Pakistan. Soil and Till. Res. 2007;94(2): 520-529.
39. Stevenson FC, van Kessel C. The nitrogen and non-nitrogen benefits of pea to succeeding crops. Can. J. Plant Sci. 1996; 76:735–745.
40. Staggenborg SA, Whitney DA, Fjell DL, Shroyer JP. Seeding and nitrogen rates required to optimize winter wheat yields following grain sorghum and soybean. Agron. J. 2003;95:253–259.
41. Jansen PCM. *Lupinus albus* L. Record from Protabase. In: Brink M, Belay G, editors. Plant Resources of Tropical Africa, PROTA, Wageningen, Netherlands; 2006.
42. Zarrin F, Aslam M, Bamo A. Chickpea nitrogen fixation increases production of subsequent wheat in rain fed system. Pak. J. Bot. 2008;40(1):369-376.
43. Engedaw LY. Potential of Lupins (*Lupinus spp*. L.) for human use and livestock feed in Ethiopia. 1st Edn., Auflage, Koster, Berlin, Germany. 2012;198. ISBN-13:9783895747892
44. Kamh M, Horst WJ, Amer F, Mostafa H, Maier P. Mobilization of soil and fertilizer phosphate by cover crops. Plant and Soil. 1999;211:19–27.
45. Nuruzzaman M, Lambers H, Bolland MDA. Veneklaas EJ. Phosphorus uptake by grain legumes and subsequently grown wheat at different levels of residual phosphorus fertiliser. Austr. J. Agricult. Res. 2005;56: 1041-1047.
46. Wouterlood M, Cawthray GR, Scanlon TT, Lambers H, Veneklaas EJ. Carboxylate concentrations in the rhizosphere of lateral roots of chickpea (*Cicer arietinum*) increase during plant development, but are not correlated with phosphorus status of soil or plants. New Phytol. 2004;162(3): 745-753.
47. Wouterlood M, Lambers H, Veneklaas EJ. Plant phosphorus status has a limited influence on the concentration of phosphorus-mobilising carboxylates in the rhizosphere of chickpea. Funct. Plant Biol. 2005;32(2):153-159.
48. Lelei JJ, Onwonga RN, Macharia JK. Influence of amendments added to acid soils on biochemical properties, nitrogen uptake and hybrid maize yields in Nakuru County Kenya. Internat. J. of Plant and Soil Sci. 2014;3(5):467-484.
49. Tisdale SL, Nelson WL, Beaton JD. Soil fertility and fertilizers. Macmillian Publ. Co, New York; 1990.
50. Poorter H, Niklas KJ, Reich PB, Oleksyn J, Poot P, Mommer L. Biomass allocation to

leaves, stems and roots: Meta-analyses of interspecific variation and environmental control. New Phytolog. 2012;193(1):30-50.

51. Lemoine R, La Camera S, Atanassova R, Dédaldéchamp F, Allario T, Pourtau N, et al. Source-to-sink transport of sugar and regulation by environmental factors. Front. in Plant Sc. 2013;4:272.

52. Andrews SS. Crop residue removal for biomass energy production: Effects on soils and recommendations. US Department of Agriculture–Natural Resource Conservation Service. (Accessed 15 November 2012) Available:https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs142p2_053255.pdf

53. Fageria NK, Moreira A. The Role of Mineral Nutrition on Root Growth of Crop Plants. Adv. in Agron. 2011;110(1):251-331.

54. Fischler M, Wortmann CS, Feil B. Crotalaria (*C. ochroleuca* G. Don.) as a green manure in maize-bean cropping systems in Uganda. Field Crops Res. 1999;61:97-107.

55. Costa KA, Severiano EDC, Silva FG, Borges EF, Epifânio PS, Guimarães KC. Doses and sources of nitrogen on yield and bromatological composition of xaraés grass. Ciência Animal Bras. 2013;14(3): 288-298.

Peer-review history:
The peer review history for this paper can be accessed here:
http://sciencedomain.org/review-history/21269