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Soil Nutrient Status and Maize (Zea Mays L.) Performance under Contrasting Legume-Maize Cropping Systems and Soils in Central Rift Valley, Kenya

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Abstract

The study investigated effect of low cost inputs on soil available N and P and maize performance under contrasting legume-maize cropping system and soils. Experiments were conducted during the short (SRS) and long rain season (LRS) of 2003 and 2004 in Njoro and SRS of 2004 SRS and LRS of 2005 in Molo with soils classified as mollic Phaeozems and mollic Andosols, respectively. Three cropping systems (CS) with or without diammonium phosphate fertilizer (DAP as control), minjingu phosphate rock (MRP), lime (L) and farm yard manure (FYM) applied were; tested in Molo using a randomized complete block design (RCBD): (i) maize in rotation with natural fallow (NF- M and NF-$M_{(DAP)}$), (ii) maize in rotation with cowpea (CP-M and CP-$M_{(L,\ MRP)}$) and (iii) maize/cowpea intercropping in rotation with crotalaria (CR-/$CP_{(L,\ MRP)}$ and CR-M/$CP_{(L,\ MRP,\ FYM)}$. CR was either incorporated as green manure or removed and FYM applied instead. The experimental set-up in Njoro was a split plot fitted to RCBD. The main plots were two CS; sole maize and maize/bean intercrop preceded by CR, lablab (LB), garden pea (GP) and NF. The sub-plots were residue (i) incorporation and (ii) removal with FYM applied instead. MRP was applied to all treatments in Njoro. Soil available N and P were monitored with maize growth and grain yield determined at maturity. Soil available N and P were significantly ($P<0.05$) higher in CR – M/$CP_{(lime,\ MRP)}$ and CR – M/$CP_{(lime,\ MRP,\ FYM)}$ in Molo. For Njoro, soil available P was higher in the rotation than intercropping system and did not vary significantly with the pre-maize legume and residue management. Legume residue incorporation resulted in significantly ($P<0.05$) higher amounts of available N in soil than FYM application in Njoro. Soil available N did not differ significantly between rotation and intercropping in Njoro but was significantly higher following LB. The SRS legumes increased soil available N and P and maize yield in the LRS in comparison to NF in both sites. Maize grain yield ranged from 1.48 to 3.85 t ha^{-1} in Molo and was higher in intercropping system. In Njoro, maize grain yield ranged from 2.2 to 4.6 t ha^{-1} and was higher in the rotation system. In both sites use of low cost inputs increased availability of N and P in soil and subsequently maize yield. The levels contrasted with cropping system and soil type, and thence site specific research cognizant of the soil limitations recommended.

Keywords: Intercrop; legumes; Nitrogen; Phosphorus; Rotation; Soil properties

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1.0 Introduction

Maize (*Zea mais,* L.) production dominates the cropping systems of East Africa (Groote et al., 2002). It is conventionally grown in rotation or as an intercrop with a legume, commonly the bean (*Phaseolus vulgaris,* L.) (Giller, 2001). A major characteristic in maize farming systems in Kenya is the dominance of intercropping (Hassan et al., 1998) and production on a wide range of soils (Muchena et al., 1988); i.e. Andosols, Vertisols, Phaeozems, Cambisols, Luvisols, Nitisols, Acrisols and Ferralsols (Muchena et al., 1988).

Soils of Molo and Njoro, situated in the central rift valley highlands, are classified as mollic Andodols and mollic Phaeozems, respectively and have contrasting properties (FAO-UNESCO, 1990). For instance, soils in Molo are acidic and high P fixing (Onwonga et al., 2008; Braun et al., 1997). In contrast soils in Njoro have neutral pH (FAO-UNESCO, 1990). Despite differences in pH, both soils pose the same constraints to maize production – notably N and P deficiencies (Onwonga et al., 2008: Lelei et al., 2009).

Deficiency of N and P in soils of Molo and Njoro has resulted into declining maize yields (Onwonga et al. 2008; Lelei et al., 2009). Nitrogen (N) and phosphorus (P) are important macronutrients required in the production of maize (Kogbe and Adediran, 2003).The nutrient deficiencies are attributable to application of less than recommended rates of inorganic fertilizer due to high costs (Onwonga et al. 2008; Lelei et al., 2009) and P fixation in the acid soils of Molo (Onwonga et al., 2008). Other alternatives that are effective, within farmers' resource constraints and can increase maize production and enhance soil N and P fertility are of importance to small holder farmers.

These include application of low cost inputs such as farm yard manure (FYM), phosphate rock (PR), lime (L) and integration of legumes into cropping cycles.

The availability of N and P in soil with use of low cost inputs may vary with cropping system and soil type. The objective of the current study was therefore to evaluate effect of legume maize cropping systems with application of FYM, MPR and L on soil available N and P, and maize yields in soils with contrasting properties.

This study will contribute towards development of site specific technological packages involving legume-maize cropping cycles and low cost inputs for enhanced soil fertility and maize productivity..

2.0 Materials and Methods

2.1 Site Description

Rainfall, Temperature and Soils

The experiments were carried out at the Kenya Agricultural Research Institute (0°12´S, 35°41´E, 2500 m asl), Molo and Field 7 stations of the Department of Agronomy, Egerton University (0°13'S, 35°30'E, 2200 m asl), Kenya. The experimental periods were; short rain season (SRS) of 2003 and long rain seasons (LRS) of 2004 in Njoro and SRS of 2004 and LRS of 2005 in Molo. The mean annual rainfall in Molo is 1200 mm and ranges between 840 to 1000 mm in Njoro (Jaetzold et al., 2007). The rainfall distribution in both areas is bi-modal with the LRS occurring from March to August and SRS from September/October with peaks in April and November, respectively. The mean air temperatures are 13.75°C and 15.9°C for Molo and Njoro, respectively (Jaetzold et al., 2007). The total rainfall and mean air temperature received during the experimental period was 943 and 1048 mm; and 19.6°C and 16.7°C, in Njoro and Molo, respectively. The Molo soils are acidic, well drained, deep, dark reddish brown with a mollic A horizon, and classified as mollic Andosols whereas Njoro soils are well drained, dark reddish in colour and are classified as mollic Phaozems (FAO – UNESCO, 1990).

Table 1: Selected Physical and Chemical Properties of Molo and Njoro Soils

Property	Units	Molo/ Depth (cm)			Njoro/Depth (cm)		
		0-15	15-30	30-60	0-15	15-30	30-60
pH (H_20)	-	4.90	5.24	5.04	6.80	6.9	6.7
pH (KCl)	-	4.38	4.46	4.05	5.3	5.6	5.4
Organic C	%	1.56	0.87	0.68	1.50	1.45	1.20
Total N	%	0.17	0.15	0.07	0.32	0.31	0.27
C/N ratio	-	9.2	5.80	9.70	4.7	5.80	9.70
Available P	mg kg^{-1}	3.30	2.1	1.70	9.29	5.70	3.71
Exchangeable bases							
Ca	cmol kg^{-1}	4.20	3.96	3.87	3.8	3.7	3.5
Mg	”	0.94	0.94	0.82	0.87	0.96	0.72
Na	”	0.08	0.08	0.08			
K	”	1.18	1.14	1.12	1.12	0.74	0.67
CEC	”	20.1	19.4	18.9	26.32	24.4	23.6
Exc. Al	”	1.5	1.42	1.06			
Bulk density	g cm^{-3}	1.19	1.24	1.31	1.04	1.13	1.14
Texture							
Sand	%	29.3	27.5	30.2	26	24	27
Silt	%	32.4	26.4	34.4	29	30	28
Clay	%	38.3	46.1	39.4	45	46	45
Textural class	clay loam	clay loam	clay loam	clay loam	Clay	Clay	Clay

Socio-Economic Characteristics

The main economic activities of the residents of Molo County are pyrethrum production and saw milling whereas agribased industries including vegetable and milk processing, large-scale wheat and barley farming is the case for Njoro. Light manufacturing industries such as timber milling and quarrying are also a mainstay of the local economy of the two sites (Jaeztold et al., 2007))..

2.2 Treatments and Experimental Design

Molo: The experiment was laid out in a randomized complete block design (RCBD), with plot plot size of 3.75 m x 4.8 m, with four replicates. Three cropping systems (CS); (i) Maize in rotation with natural fallow (NF – M and NF-$M_{(DAP)}$), (ii) Maize in rotation with cowpea (CP–M and CP-$M_{(lime,\ MRP)}$), cowpea residue incorporated and (iii) Maize/cowpea intercropping in rotation with crotalaria (CR – M/$CP_{(lime,\ MRP)}$ and CR – M/$CP_{(lime,\ MRP,\ FYM)}$[4], with or without application of diammonium phosphate (DAP) fertilizer and amendments; minjingu phosphate rock (MRP), farm yard manure (FYM) and lime, were tested (Table 2):

Table 2: Cropping Systems, Residue Management and Input Application for Molo Site

Cropping system/inputs	Year, cropping season and Inputs		
	SRS of 2004	SRS biomass management	LRS of 2005
Natural Fallow– Maize			
1) NF – M	Natural fallow	RI	Maize
2) NF - $M_{(DAP)}$	Natural fallow	RI	Maize + DAP
Legume – Maize rotation			
1) CP – M	Cowpea	RI	Maize
2) CP - $M_{(lime,\ MRP)}$	Cowpea	RI	Maize + lime + MRP
Legume – maize/legume intercrop			
1) CR – M/$CP_{(lime,\ MRP)}$	crotalaria	GMI	Maize/Cowpea + lime+ MRP
2) CR – M/$CP_{(lime,\ MRP,\ FYM)}$	crotalaria	CC	Maize/Cowpea + lime+ MRP+FYM

Key: NF= natural weedy fallow; M=maize; CP=cowpea; CR=Crotalaria; RI = Residue incorporated; CC = cut and carry fodder; FYM = farm yard manure; GMI = green manure incorporated; DAP= diammonium phosphate; MRP = minjingu phosphate rock; SRS = short rain season; LRS = long rain season

Njoro: The experimental set up was a split plot fitted to a RCBD with four replicates. The main plots (3.75 x 4.8 m) were two cropping systems; sole maize and maize/bean intercrop preceded by improved legume fallows [Crotalaria (CR), lablab (LB), garden pea (GP) and natural fallow (NF) (Table 3).

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[4] Cowpea residue was incorporated with crotalaria incorporated as green manure or removed and FYM (1.1%N, 0.21% K and 0.9%K) applied instead.

Table 3: Cropping Systems and Input Application for Njoro Site

Cropping system/inputs	Year, cropping season and Inputs 2002 SRS	SRS Biomass management	2003 LRS
A] Natural – Maize rotation			
1) NF $_{(MRP)}$ – M	Natural fallow + MRP	RR	Maize + FYM
2) NF $_{(MRP)}$ – M$_{(FYM)}$	Natural fallow + MRP	RI	Maize
B] Legume – Maize rotation			
1) GP $_{(MRP)}$ – M	Legume + MRP	RR	Maize + FYM
2) GP $_{(MRP)}$ – M$_{(FYM)}$	Legume + MRP	RI	Maize
3) CR$_{(MRP)}$ – M	Legume + MRP	RR	Maize + FYM
4) CR$_{(MRP)}$ – M$_{(FYM)}$	Legume + MRP	RI	Maize
5) LB $_{(MRP)}$ – M	Legume + MRP	RR	Maize + FYM
6) LB$_{(MRP)}$ – M$_{(FYM)}$	Legume + MRP	RI	Maize
C] Natural Fallow – Maize/bean intercrop			
1) NF $_{(MRP)}$ – M/B	Natural fallow + MRP	RR	Maize/Bean + FYM
2) NF $_{(MRP)}$ – M/B$_{(FYM)}$	Natural fallow + MRP	RI	Maize/Bean
D] Legume – Maize/bean intercrop			
1) GP $_{(MRP)}$ – M/B	Legume + MRP	RR	Maize/Bean + FYM
2) GP $_{(MRP)}$ – M/B$_{(FYM)}$	Legume + MRP	RI	Maize/Bean
3) CR $_{(MRP)}$ – M/B	Legume + MRP	RR	Maize/Bean + FYM
4) CR $_{(MRP)}$ – M/B$_{(FYM)}$	Legume + MRP	RI	Maize/Bean
5) LB $_{(MRP)}$ – M/B	Legume + MRP	RR	Maize/Bean + FYM
6) LB $_{(MRP)}$ – M/B$_{(FYM)}$	Legume + MRP	RI	Maize/Bean

Key:- = Rotation, / = intercropping; MRP = minjingu phosphate rock; FYM = farm yard manure; RR= residue removed and FYM applied instead; RI= residue incorporated

The sub-plots were two residue management types; (i) residue incorporation and (ii) residue removal with manure (FYM) incorporated in its place (Table 3). MRP was applied to all treatments in Njoro

2.3 Field Practices

2.3.1 Land Preparation and Application of Treatments

In both sites land was ploughed mechanically, followed by secondary cultivation, which involved raking and leveling using hand implements (hoes and rakes). Lime (Molo) and MRP (Molo and Njoro) were applied once by broadcasting.

Lime was applied two months before planting in respective treatments to allow for sufficient time for reaction with soil. MRP was applied at planting. Lime and MRP were mixed well with the top soil. 40 kg P ha^{-1} MRP (290 kg ha^{-1}) and FYM (5 t ha^{-1}) were applied a week to planting by broadcasting and placing into planting holes, respectively. DAP (40 Kg ha^{-1} = 7.2 kg N ha^{-1} and 8 kg P ha^{-1}) was banded along the planting furrows to mimic farmers practice, at planting in the respective plots and thoroughly mixed with soil before seed sowing.

2.3.2 Planting of Maize and Legumes

Long rain season: Maize (Hybrid, 614) was sown in all the plots during the LRS of 2004 and 2005 in Njoro and Molo, respectively, at a spacing of 75 cm between and 30 cm within the row. Two seeds were sown into each planting hole and thinned to one plant per hill 30 days after sowing. In maize/beans (M/B) intercropping system in Njoro (NF-M/B, CR-M/B, LB-M/B and GP-M/B) one row of beans (B) was sown between two rows of maize. Cowpea (CP) was sown as an intercrop between maize (one row of CP between two maize rows) in the intercropping treatments in Molo (CR- $M/CP_{(lime,\ MRP)}$ and $CR\text{-}M/CP_{(lime,\ MRP,\ FYM)}$). Two seeds were sown per hill and thinned to one plants 30 days after sowing.

Short rain season: Legumes; CR, LB and GP, were planted during the SRS of 2003, in Njoro. Two seeds were planted per hole at spacing of 60 cm x 30 cm. In Molo; CR and CP were planted at spacing of 75 cm x 30 cm, at the start of the short rains of 2004. Two seeds were planted per hole. Thinning to one plant per hole was done a month after planting of legumes.

2.3.2 Management of Crop Residues During the Cropping Seasons in Molo and Njoro

SRS in Molo: CP residues, after harvest of grains, and weed biomass were chopped into 5-20 cm small pieces spread across the plots and incorporated into soil by hand hoes to a depth of 15 cm during land preparation for maize planting. CR green manure was either completely removed (uprooted by hand) from plots shortly prior to planting the maize and FYM applied instead or incorporated in a similar manner as described for CP residues (Table 2).

SRS in Njoro: At maturity of legumes; LB, GP and CR, seeds were harvested and residues either chopped into 5-20 cm small pieces, spread across the plots and incorporated into soil by hand hoes to a depth of 15 cm during land preparation for subsequent maize crop or recycled as livestock fodder and manure (FYM) at the rate of 5 t ha^{-1} applied instead. Weed biomass in the natural fallow plots was similarly managed (Table 3).

LRS: For both sites the residues produced after harvest of CP and beans in the respective intercropping systems were chopped into 5-20 cm small pieces spread across the plots and incorporated into soil (Tables 2 and 3)

2.4 Soil Sampling, and Analysis

Composite soil samples for determination of the initial physical and chemical properties were collected prior to planting from six profile pits at three soil depths (0-15; 15-30; 30-60 cm) in both sites. Samples for determination of soil available N and P were obtained across maize growth during the LRS and SRS in both sites. The soil samples were collected between plants within a row in every plot at random from the upper soil surface layer (0 - 15 cm) using a 5 cm diameter soil auger. Four augerings were done in every plot and soil bulked together to get one composite sample. The samples for analysis of available N were refrigerated before analysis. For the analysis of available P, soil samples were air dried by placing them in a shallow tray in a well-ventilated area. Soil available N and P analysis were determined using standard procedures as described by Okalebo et al. (2002).

2.5 Measurement of Crop Yields

Maize and legume samples for grain and dry matter (DM) yield determination were obtained from two internal rows of each plot. Grain yield was adjusted to 13% moisture content. Weed DM yield was determined from a 1 m^2 area. Sub samples for DM determination were taken to the laboratory and oven dried at 70°C for 48 hours. Grain and DM yields were expressed on a hectare basis.

2.6 Statistical Analysis

Analysis of variance (ANOVA) appropriate for a split plot design and randomized complete block design was used to determine statistical variation in measured parameters. Means were separated using t tests. The SPSS version 9 software (SPSS incorporated, 1999) was used for statistical analysis.

3.0 Results and Discussion

3.1 Soil available P

3.1.1 Effect of inputs

There was a general decline in soil available P from maize seedling to physiological maturity in both sites (Fig 1; Table 4).

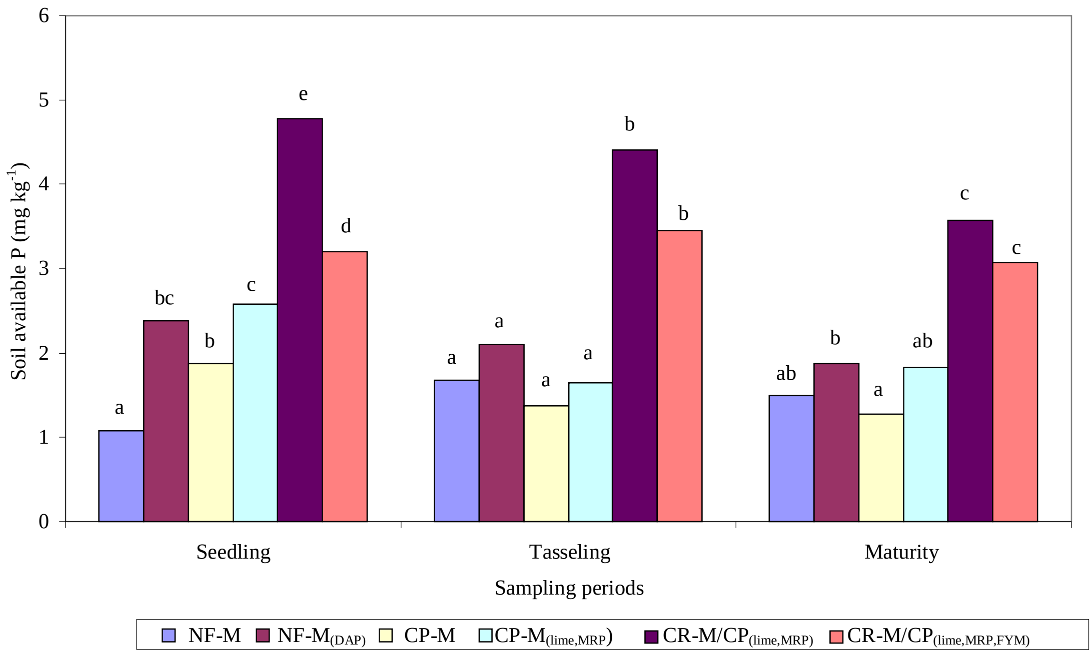

Fig 1. Soil Available P during the LRS of 2005 in Molo

The decline is partly attributable to uptake of P by maize during growth. Similar observations were made in a study on effect on soil amendments on P use and agronomic efficiencies of two maize hybrids (Onwonga et al., 2013). They attributed decline to uptake of P by maize which is continuous through out growth. P is an important plant macronutrient. It is a component of key molecules such as nucleic acids, phospholipids, and ATP, and, consequently, plants cannot grow without a reliable supply of this nutrient (Schachtman et al., 1998).

Table 4: Soil Available P (mg kg^{-1}) during LRS of 2004 in Njoro

Treatment	2 WAP	seedling	tasseling	cobbing	maturity
NF $_{(MRP)}$ – M	1.60 (0.20)	2.00 (0.20)	1.50 (0.12)	1.20 (0.26)	0.90 (0.52)
NF $_{(MRP)}$ – M$_{(FYM)}$	4.40 (0.28)	1.70 (0.26)	4.00 (0.36)	3.00 (0.10)	2.80 (0.42)
LB $_{(MRP)}$ – M	5.00 (0.28)	2.60 (0.14)	3.80 (0.42)	2.80 (0.20)	2.50 (0.30)
LB$_{(MRP)}$ – M$_{(FYM)}$	2.70 (0.24)	2.00 (0.10)	2.90 (0.17)	1.90 (0.21)	1.60 (0.10)
CR$_{(MRP)}$ – M	2.70 (0.10)	2.10 (0.36)	2.20 (0.10)	1.20 (0.26)	1.00 (0.46)
CR$_{(MRP)}$ – M$_{(FYM)}$	1.90 (0.23)	1.60 (0.50)	1.00 (0.26)	0.70 (0.46)	0.40 (0.33)
GP $_{(MRP)}$ – M	2.50 (0.36)	2.10 (0.16)	2.00 (0.20)	1.70 (0.43)	1.20 (0.10)
GP $_{(MRP)}$ – M$_{(FYM)}$	2.70 (0.44)	1.50 (0.10)	1.70 (0.18)	1.20 (0.10)	0.70 (0.36)
NF $_{(MRP)}$ – M/B	3.20 (0.56)	1.70 (0.20)	2.00 (0.75)	1.00 (0.26)	0.80 (0.10)
NF $_{(MRP)}$ – M/B$_{(FYM)}$	2.70 (0.44)	2.10 (0.40)	1.40 (0.17)	1.10 (0.28)	0.70 (0.17)
LB $_{(MRP)}$ – M/B	2.80 (0.26)	2.00 (0.20)	2.20 (0.10)	1.20 (0.34)	1.00 (0.41)
LB $_{(MRP)}$ – M/B$_{(FYM)}$	2.20 (0.70)	1.70 (0.26)	1.60 (0.17)	1.20 (0.52)	0.90 (0.26)
CR $_{(MRP)}$ – M/B	3.80 (0.58)	2.10 (0.10)	2.90 (0.12)	1.90 (0.28)	0.56 (0.56)
CR $_{(MRP)}$ – M/B$_{(FYM)}$	2.70 (0.24)	2.00 (0.10)	1.80 (0.17)	1.40 (0.21)	1.60 (0.10)
GP $_{(MRP)}$ – M/B	3.20 (0.20)	1.50 (0.12)	2.90 (0.46)	2.40 (0.35)	2.00 (0.41)
GP $_{(MRP)}$ – M/B$_{(FYM)}$	2.40 (0.20)	2.10 (0.18)	2.60 (0.20)	1.80 (0.10)	1.50 (0.26)

Key: MPR= minjingu phosphate rock, FYM = farm yard manure, LB= lablab, NF= natural fallow, CR = crotalaria, GP = garden pea; WAP= weeks after planting; / intercrop

The initial soil available P content (mg kg^{-1}) in Molo and Njoro was 3.3 and 9.29 (Table 1), respectively, and classified as low (Landon, 1991). The low initial value in Molo is partly attributable P fixation and nutrient removal through harvested products prior to set up of the experiment. Molo soil was acidic with pH (H_2O) of 4.9 (Table 1). Phosphorus (P) deficiency has been found to be widespread in the soils of the humid tropics (Olsen and Englestad, 1972). The low availability of P in the tropical soils is attributed to the nature of the chemical forms of P (Ogunwale et al., 2006). Phosphate fixation is a problem in acid soils (Sanchez and Uehara, 1980).

High contents of oxides of iron (Fe) and aluminium (Al) are associated with high P fixation (Brady and Weil, 1999). Aluminium cations can hydrolyze to produce hydrous oxide polymers which function as ion exchangers and reversibly sorb added phosphate (Wilson, 1968). In acid soils, inorganic P in the soil solution becomes adsorbed to surfaces of Fe and Al oxides and clay minerals (Garcia, 1999), thereby becoming unavailable to the crop plants. Soils of Njoro (mollic Phaeozems), on the other hand, were of neutral pH [pH (H_20=6.8; Table 1] and the low value may have been partly due to removal of P in harvested products. The field was previously cropped to maize prior to experimental setup. Continuous cultivation without adequate replenishment of the natural resource base leads to nutrient depletion (Saïdou et al., 2003).

The cropping systems with application of inputs; NF-$M_{(DAP)}$), CP–M, CP-$M_{(lime, MRP)}$, CR – M/$CP_{(lime, MRP)}$, and CR – M/$CP_{(lime, MRP, FYM)}$, had significantly ($P<0.05$) higher values of available P than NF-M at maize seedling in the LRS of 2005 (Fig 1). This can be attributable to amelioration of pH by lime and subsequent release of fixed P, supply of P by DAP fertilizer, MPR and mineralization of FYM or incorporated CP and CR residues. FYM used in this study had 1.1%N, 0.21% P_20_5 and 0.9%K, and supplied P on mineralization. Acid soils often have high phosphate-fixing capacity and application of both lime and phosphate are frequently required (Haynes and Swift, 1988). A study on effect of lime on P sorption on acid soils, lime reduced Al toxicity and increased available P in soil (Anjos and Rowell, 1987). In a study on effect of lime manure and P fertilization on soil fertility of a high P fixing acid soils, the application of manure and lime significantly reduced exchangeable acidity and increased soil pH (Verd et al., 2013). This was attributed to the release of organic acids (during mineralization of manure), which in turn suppressed Al content in the soil through chelation.

Farm yard manure (FYM) on average contains 0.5% N, 0.2% P_2O_5 and 0.5% K_2O and increases availability of P (Sharrif et al., 2011). Composting of manures and other organic materials with rock phosphate (RP) has been shown to enhance the solubility of P from phosphate rock (Mishra and Bangar, 1986; Singh and Amberger, 1991). The addition of organic materials to the soil helps microorganisms to produce polysaccharides and organic acids which improve the soil structure and help in P solubilization (Guar, 1994).

In Njoro, soil available P in the LRS of 2004 at maize seedling did not vary significantly with residue management i.e. with incorporation or removal and FYM applied (Table 4). This may partly be explained by uniform rates of P applied to all plots. In a study on screening for short term fallow in Western Kenya, Niang et al. (2002) reported phosphorus recycling by fallow species through deep uptake is likely to be negligible owing to the very low concentration of available P, an immobile element, in the subsoil. They argued that although organic inputs from planted fallows can supply enough N for crop growth, they cannot supply enough phosphorus required by subsequent crops. As such, P additions either in form of inorganic fertilizers or from P rich organic materials may alleviate P limitations and optimize crop yield benefits after the fallow. Immobilization of P by microorganisms may have also occurred. Soil microbes release immobile forms of P to the soil solution and are also responsible for the immobilization of P (Holford, 1997).

3.1.2 Effect of Cropping System

In Molo, soil available P values were significantly higher in the intercropping system: CR – M/$CP_{(lime,\ MRP)}$ and CR – M/$CP_{(lime,\ MRP,\ FYM)}$ across all stages of maize growth (Fig 1). This is attributable to increased mobilization of P by crotalaria intercrop. Intercropping legumes can increase the supply of nutrients, through N_2-fixation and P mobilization (Whitehead and Isaac, 2012). This has also been demonstrated in other plant species such as alfalfa wheat intercrops (Whitehead and Isaac, 2012) and faba bean and maize intercrops (Li et al.2007). Li et al. (2007) performed a 4-yr field experiment in which maize and faba bean were either planted as monoculture crops or were planted in alternating rows (intercropped) in an agricultural site in which P was the major limiting soil nutrient. Results of their study indicated a rhizosphere effect of faba bean on maize, especially when P was provided in an insoluble form such as $AlPO_4^-$ and $FePO_4^-$ P. Faba bean rhizosphere acidification mobilized P, resulting in increased availability of P for maize uptake. P availability due to legume intercrop is more pronounced under low P conditions (Li et al., 2007).

In Njoro, soil available P was higher in the rotation system (Table 4). This may have been because in Njoro, the initial soil available P was higher relative to Molo (Tables 1) and any increase was less pronounced.

There is more you can derive from the figure/Table (results) – what you have here is highly summarised. Talk more on your results and also support

3.2 Soil available N in Molo and Njoro

3.2.1 Effect of Inputs

In both sites, soil available N was higher at maize seedling and declined towards physiological maturity (Fig 2; Table 5).

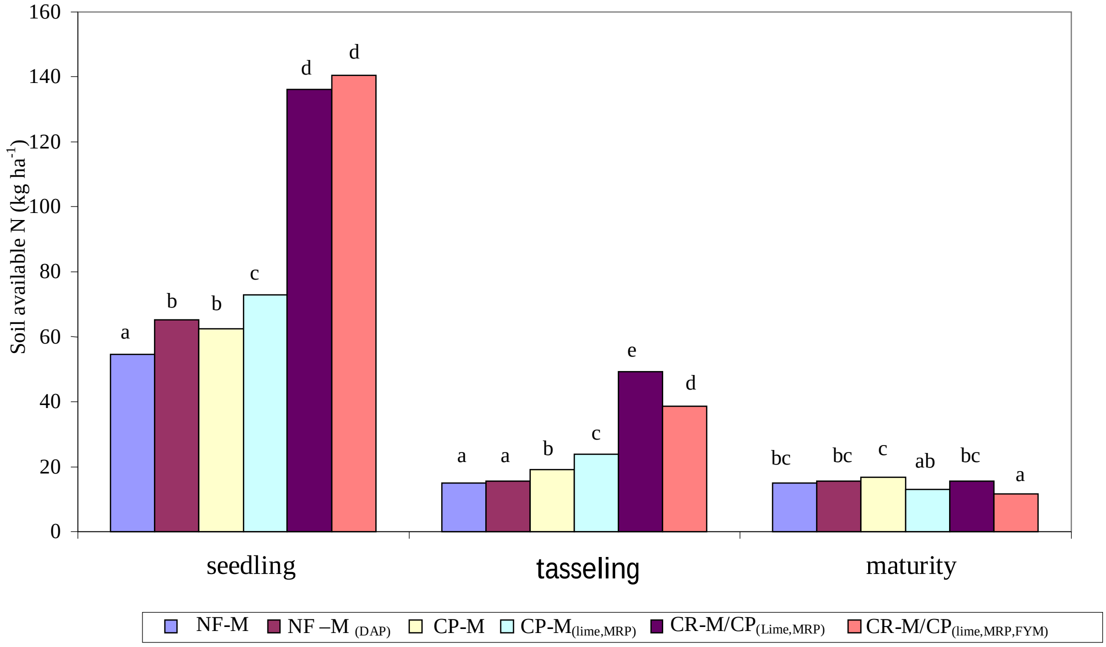

Fig 2: Soil available N (kg ha^{-1}) in the 2005 LRS in Molo in the different Cropping Systems

Table 5: Soil available N (kg ha^{-1}) Measured at the different Stages of Maize Growth in different Cropping Systems in the 2004 LRS in Njoro

Treatment	2 WAP	seedling	tasseling	cobbing	maturity
NF $_{(MRP)}$ – M	36.80 (1.56)	15.40 (1.52)	17.80 (0.93)	19.30 (2.35)	17.20 (1.46)
NF $_{(MRP)}$ – M$_{(FYM)}$	37.14 (2.18)	18.4 (2.00)	14.20 (1.26)	11.60 (2.62)	9.80 (1.50)
LB $_{(MRP)}$ – M	65.98 (2.56)	22.58 (2.24)	18.80 (1.47)	14.49 (0.93)	12.30 (2.30)
LB$_{(MRP)}$ – M$_{(FYM)}$	52.62 (1.80)	21.43 (2.30)	12.60 (1.18)	11.80 (1.28)	9.20 (1.68)
CR$_{(MRP)}$ – M	49.22 (2.36)	20.51 (2.90)	26.30(1.24)	19.70 (1.18)	18.56 (2.40)
CR$_{(MRP)}$ – M$_{(FYM)}$	46.70 (2.32)	24.80 (3.36)	16.70 (1.18)	11.10 (1.70)	9.38 (1.16)
GP $_{(MRP)}$ – M	41.26 (1.18)	15.39 (3.60)	14.90 (4.20)	17.20 (1.90)	14.80 (2.10)
GP $_{(MRP)}$ – M$_{(FYM)}$	40.80 (1.00)	14.23 (0.62)	12.70 (1.00)	14.49 (1.62)	12.60 (2.28)
NF $_{(MRP)}$ – M/B	34.04 (1.00)	14.20 (1.00)	12.20 (3.36)	10.20 (2.00)	9.90 (2.00)
NF $_{(MRP)}$ – M/B$_{(FYM)}$	34.55 (1.23)	19.50 (2.20)	15.90 (2.26)	9.41 (0.46)	7.80 (2.40)
LB $_{(MRP)}$ – M/B	62.94 (2.36)	17.35 (1.28)	14.80 (0.58)	12.70 (2.42)	11.60 (1.62)
LB $_{(MRP)}$ – M/B$_{(FYM)}$	50.56 (1.42)	16.33 (1.18)	14.30 (2.60)	10.70 (2.60)	8.60 (1.42)
CR $_{(MRP)}$ – M/B	43.34 (2.10)	29.60 (0.62)	18.90 (2.96)	14.60 (0.69)	8.60 (2.23)
CR $_{(MRP)}$ – M/B$_{(FYM)}$	48.18 (2.10)	16.42 (2.36)	13.70 (1.23)	10.62 (2.36)	12.5 (3.80)
GP $_{(MRP)}$ – M/B	39.79 (2.24)	28.74 (1.00)	23.60 (0.89)	20.08 (1.37)	18.5 (2.00)
GP $_{(MRP)}$ – M/B$_{(FYM)}$	36.70 (1.12)	17.7 (3.26)	20.20 (1.14)	15.60 (1.24)	14.30 (1.24)

Key: MPR= minjingu phosphate rock, FYM = farm yard manure, LB= lablab, NF= natural fallow, CR = crotalaria, GP = garden pea; WAP= weeks after planting; / intercrop

The decline is attributable to N uptake by maize for its growth and development. N is the mineral element required in the greatest quantity by cereal plants (Ma and Dwyer, 1998). Maize takes up N from soil throughout its growing season (Kamoni et al., 2000). Maize N uptake follows biomass accumulation (Zotarelli et al., 2008). N demand is typically relatively high due to the great aboveground dry matter accumulation which forms a large N sink (Zotarelli et al., 2008).

In Molo, the control treatment (NF-M) had significantly lower ($P<0.05$) levels of available N at all stages of maize growth. This was because no N inputs had been added to soil in this treatment and uptake of initial N by maize for its growth and development. Besides there was no legume crop in this treatment that could supply N through biological nitrogen fixation. Nitrogen sources include inorganic fertilizers, mineralization of soil organic matter and manure and biological nitrogen fixation (BNF) by legumes (Barbarick, 2013). In Africa, grain legumes fix about 15-210 kg N ha^{-1} seasonally (Dakora and Keya, 2007). The process of biological nitrogen fixation (BNF) accounts for 65% of the nitrogen currently utilized in agriculture.

At maize seedling in Molo treatments; NF-$M_{(DAP)}$), CP–M, CP-$M_{(lime,\ MRP)}$, CR – M/$CP_{(lime,\ MRP)}$, and CR – M/$CP_{(lime,\ MRP,\ FYM)}$, had significantly (P<0.05) higher levels of soil available N than NF-M. This was due to addition of N by DAP fertilizer and mineralization of CP residues or FYM. Mineralization or organic matter is a key process regulating microbial activity and the cycling of nutrients (Campbell et al., 1994). MPR has an indirect liming effect due to its high calcium content (Zin et al., 2005). The application of lime and MPR raised soil pH and provided a conducive environment for nitrifyers. In a study on transformation of nitrogen, pH increases was reported to favour the activity of nitrifyers (Alfaia et al 1995). Liming of soil increases nitrification rate (Lyngstad, 1992).

In Njoro, the NF-M treatment had significantly lower available N levels in soil two weeks after maize planting (Table 5). Since no N inputs were applied in this treatment, depletion of N reserves through crop uptake may have occurred. Crop uptake depletes mineral N reserves (Wortman (2000). Legumes are superior previous crops, compared to non-leguminous crops, because they fix atmospheric N (Vyn et al., 2000). In a study on response of maize to nitrogen fertilizer after different crops , use of legumes as previous crops in the present study out-yielded cereal and fallow interms of all traits, especially N yield . The application of legume residues resulted into higher amounts of N in soil than the application of FYM at all growth stages. This may be attributable to slow mineralization of manure and ammonia volatilization during application. A study on nitrogen and carbon mineralization dynamics of manures showed that nitrogen mineralization rate of manure were relatively slow (Hartz et al., 2000). Hadas et al. (1983) found as much as 22% of soil- applied poultry manure total N was lost after soil application, mostly through volatilization.

3.2.2 Effect of Cropping System

Significantly higher (P<0.05) values of soil available N were obtained in the intercropping than rotation system in Molo (Fig 2). At seedling and flowering, soil available N levels were significantly higher in M /$CP_{(lime,\ MRP,\ FYM)}$-CR and M/$CP_{(lime,\ MRP)}$-CR treatments (Fig 2). This may partly be attributed to N_2 fixed (BNF) by crotalaria from the prior SRS and intercropped cowpea in the LRS also fixed. 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).

Dalal et al. (1988) reported that the mineral N in the root zone of soil following legumes is often 30-60 kg N ha^{-1} higher than after cereal crops in the same environment. Mineralization of FYM (1.1 % N) and incorporated crotalaria green manure from the prior 2004 SRS were other N sources. In a study on use of CR as a green manure in maize bean cropping systems, CR green manure caused major differences in soil mineral nitrogen at the six-leaf stage of maize only (Fischler et al., 1999).

Soil available N did not differ significantly between the rotation and intercropping systems in Njoro (Table 5). The only differences observed were with respect to the pre maize legume whereby there was significantly higher soil available N content in soil following LB (Table 5). This may be attributed higher mineralization rate of N rich lablab residues. The N yield may have been higher in LB than GP and CR. In a study on effect of legume fallows on soil nitrogen, lablab residues significantly improved soil nitrogen status and the yield of the following cereals (Cheruiyot et al., 2003).

3.3 Cropping System and Input Effects on Maize Yield

Legumes increased maize yield in comparison to natural fallow in both sites (Table 7; Figs. 3 and 4). Maize grain yield ranged from 1.48 to 3.85 t ha-1 in Molo and was higher in the intercropping than rotation system (Table 7). Since there were no significant differences between organic input types on soil available P in Njoro, maize yields were averaged over input types (Fig 3; 4). In Njoro, maize yields ranged from 2.2 to 4.6 t ha-1 and were lower in intercropping (Fig 3) than the rotation system (Fig 4). In Njoro maize yields were higher following lablab in both the rotation (Figure 4) and maize/bean intercropping (Figure 3) systems but with higher yields realized in the rotation system. Cheruiyot et al. (2003) in a study on the effect of legume managed fallows (garden pea, common beans and lablab) on soil N found accordingly that among the legume species, lablab showed outstanding positive effect on succeeding maize yield.

Table 7: Maize grain and DM yields (t ha^{-1}) in 2005 LRS in Molo

Cropping system	Maize		Cowpea	
	Grain yield	DM yield	Grain yield	DM yield
NF-M	1.48^{a} (0.22)	3.16^{a} (0.05)	-	-
NF-M$_{(DAP)}$	2.88^{b} (0.34)	4.65^{b} (0.42)	-	-
CP-M	3.13^{bc} (0.10)	5.25^{b} (0.19)	-	-
CP-M$_{(lime, MRP)}$	3.45^{cd} (0.13)	5.95^{c} (0.24)	-	-
CR- M/CP$_{(lime, MRP)}$	3.85^{d} (0.17)	6.68^{cd} (0.40)	0.29^{a}(0.02)	2.1^{a}(0.06)
CR-M/CP$_{(lime, MRP, FYM)}$	3.80^{d} (0.28)	6.60^{d} (0.29)	0.25^{a}(0.04)	2.7^{a}(0.03)

Means in a column followed by the same letter are not significantly different at P<0.05, using the Tukey mean separation procedure. Values in parenthesis are standard deviations.

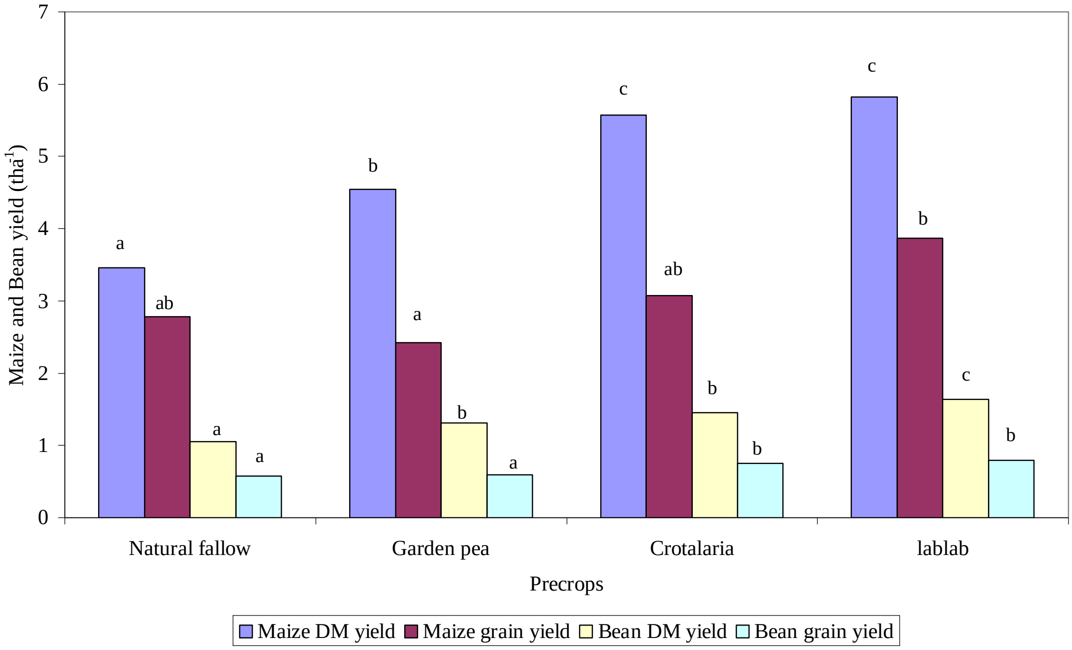

Fig 3: Maize and Bean yield in the Intercropping System in Njoro in 2004 LRS

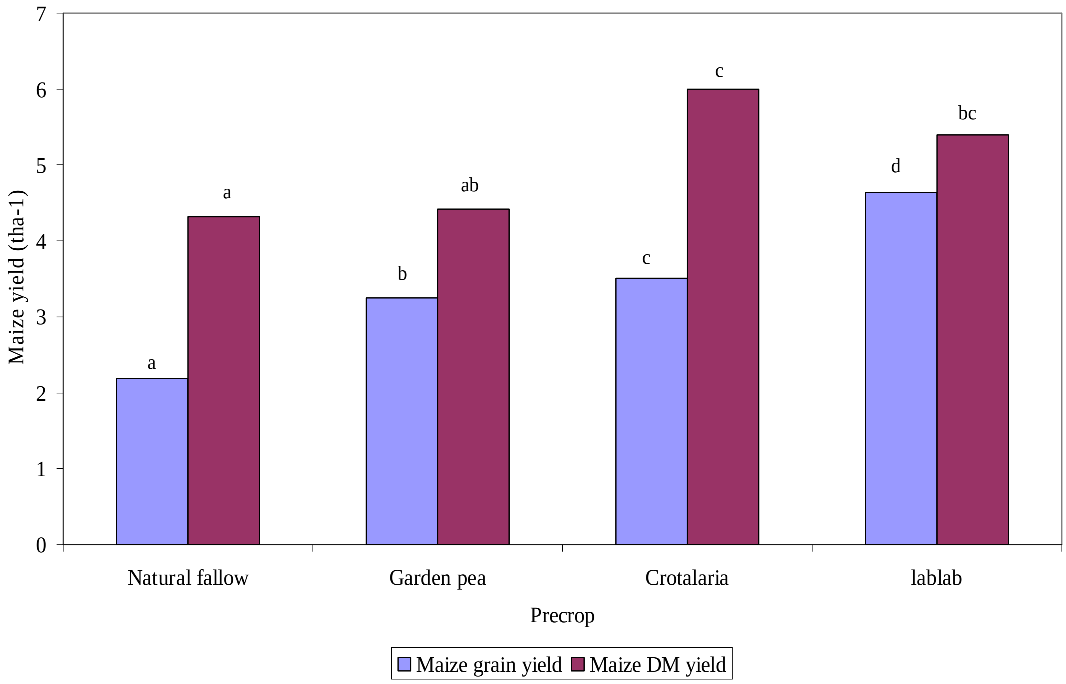

Fig 4. Maize yield in the Sole Maize Cropping System in Njoro in 2004 LRS

Higher Yields In The Intercropping Than Rotation System In Molo, But Not In Njoro, Might Have Been Caused By A Greater Competition Of The Legume Partner Of The Intercropping System In Njoro (I.E. Common Beans) Than In Molo (I.E. Cowpea). This However Is Unlikely Because A Greater Biomass Of Cowpea In The Intercrop (2.1 T Ha^{-1}) Compared To That Of Beans (0.9 T/Ha) Should Have Resulted In A Greater Competition Of Cowpea Than Of Beans. Based On Soil N And P Comparisons Afore Discussed, The Higher Yield Of Maize, Which Has High P Requirement, In The Intercropping System Than Rotation System In Molo Is Mainly Attributable To Mobilization Of P By Legume Intercrop. The Availability Of P Due To Legume Intercrop Was More Pronounced Under The Low P Conditions Of Molo Soils. Phosphorus Is An Essential Nutrient Required For Plant Growth And Reproduction (White And Brown, 2010).

Past Work Has Demonstrated Yield Advantages In Legume Intercrops Due To Mobilization Of P By Legumes. White Head And Isaac (2012) Reported That The Presence Of Alfalfa Intercrop Had A Facilitative Effect On Wheat P Uptake.

Li Et Al. (2007) Demonstrated That, When Intercropped With Faba Bean, Maize Grain Over Yielded By 43% (Range: 17–74%) ($P<0.0001$) Compared With Corresponding Mono Cultured Maize And Faba Bean, On Average Over 4 Years Experiment In An Agricultural Site In Which P Was The Major Limiting Soil Nutrient. The Over Yielding Maize Was Attributed To Below-Ground Interactions Between Faba Bean And Maize. On The P-Deficient Soils, A P Nutrition Improvement In Faba Bean/Maize Intercropping Played An Important Role In The Over Yielding Of Maize Through Interspecific Interactions Between Faba Bean And Maize. Li Et Al. (2007) Grew Maize And Faba Bean In Greenhouse Conditions In Three Types Of Pots And In Various Solubilities Of P Forms That Are Common, Reported Over Yielding Of Maize, Resulted From A Rhizosphere Effect Of Faba Bean On Maize, Especially Where P Was Provided In An Insoluble Form, Such As $Alpo_4^-$ And $Fepo_4^-$ P. The Results Of Their Study Demonstrated That An Interspecific Rhizosphere Effect Indeed Played An Important Role In The Interspecific Facilitation Between Intercropped Species.

In Addition The Differences In N Fixing Ability Of The Cowpea And Bean Intercrop May Have Played A Role. It Is Well Documented That Intercropping Legumes Can Increase The Supply Of Nutrients, Through N_2-Fixation And P Mobilization (Whitehead And Isaac, 2012). The Intercropped Cowpea (Molo) May Have Fixed Higher N Than The Intercropped Common Beans (Njoro). Common Bean Is Unfortunately Rather Poor At Fixing N_2 Due To Its Susceptibility To Environmental Stresses (Kamarasinghe Et Al., 1992).

4.0 Conclusion

In Both Molo And Njoro, Use Of Low Cost Inputs Increased Available N And P In Soil And Subsequently Maize Yields. In Both Sites Soil Available N And P Content And Maize Grain Yield Varied With Cropping System. In The Acid Mollic Andosols Of Molo, These Parameters Were Significantly Higher In Intercropping Treatments: CR – $M/CP_{(Lime,\ MRP)}$ And CR – $M/CP_{(Lime,\ MRP,\ FYM)}$. Conversly In Njoro With Soils Classified As Mollic Phaeozems, Soil Available N Did Not Differ Significantly Between The Rotation And Intercropping Systems In Njoro. Incorporation Of Legume Residues Increased Soil Available N In Soil Than The Application Of FYM At All Growth Stages In Njoro.

On The Other Hand Soil Available P And Maize Grain Yields Were Higher In The Rotation System And Did Not Vary Significantly (P<0.05) With The Pre-Maize Legume And Residue Management. The Contrasting Soils In The Two Sites May Explain Variation In Soil Nutrient Levels Especially P And Subsequent Maize Yields. Maize Has A High P Requirement.Higher Maize Yields In The Intercropping System Than Rotation System In Molo Is Mainly Attributable To Mobilization Of P By Legume Intercrop. Availability Of P Due To Legume Intercrop Was More Pronounced Under The Low P Conditions Of Molo Soils. Suitability Of Cropping Systems For Enhanced Yields With The Application Of Low Cost Inputs Should Also Consider Soil Properties.

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