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SOIL NUTRIENT SHIFTS FOLLOWING PHOSPHORUS APPLICATION IN INTEGRATED LEGUME-SORGHUM SYSTEMS

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Abstract: Phosphorus (P) and nitrogen (N) are pivotal nutrients essential for plant growth, serving as the foundation for modern agriculture. The conventional agricultural practice relies heavily on water-soluble chemical fertilizers to provide a steady supply of these nutrients, as highlighted by Yu et al. (2012) and Marschner (1995). However, this approach presents significant challenges, particularly for smallholder farmers, as it is cost-prohibitive and environmentally unsustainable, as noted by Ginkel (2011). The necessity to reduce the reliance on chemical fertilizers and explore cost-effective, eco-friendly alternatives is evident, as emphasized by Jayasinghearachi and Seneviratne (2006). This study delves into the quest for sustainable agricultural solutions by investigating strategies to reduce the dependence on chemical fertilizers. It explores economical and environmentally friendly technologies to address the challenges associated with nutrient supply in agriculture. By mitigating the environmental impact and economic burden, these innovative approaches aim to foster a more sustainable and accessible means of supporting agricultural productivity.

Keywords: Phosphorus (P), Nitrogen (N), Chemical Fertilizers, Sustainable Agriculture, Eco-Friendly Technologies

1.0 Introduction

Phosphorus (P) and nitrogen (N) are the two most critical nutrient elements for plant growth and development (Yu et al., 2012; Marschner, 1995).

Modern agriculture is mainly dependent on regular inputs of the nutrients in water soluble chemical fertilizers for continuous agricultural production (Shrivastava et al., 2011). Use of chemical fertilizers on a regular basis has, however, become a costly affair for small holder farmers and is also environmentally undesirable (Ginkel, 2011). There is therefore an obvious necessity to reduce the use of such agrochemicals and to develop economical and eco-friendly technologies (Jayasinghearachchi and Seneviratne (2006).

Phosphate rocks (PRs) are natural materials in agro ecosystems. A promising phosphate rock is Minjingu phosphate rock (MPR) from Tanzania, a sedimentary/biogenic deposit which contains about 13% total P and 3% neutral ammonium citrate (NAC) soluble P (Jama and Straaten., 2006). PRs are regarded as valuable alternatives for inorganic P fertilizers for a sustainable agriculture system (Jain et al., 2010), because they are cheaper sources of P (Vanlauwe and Giller, 2006). PRs have, however, low solubility (Aria et al., 2010). Solubility of phosphorus in the hard phosphate rocks may be increased by grinding, applying it low pH and P limiting soils, with the application of organics or by use of certain plant species (Aria et al., 2010; Kifuko et al., 2007). Evidences indicate that plants release enzymes like phosphatases, phytase and carboxylates under P deficiency stress in soil, allowing mobilization and utilization of P (Li et al., 2011). Some carboxylic acids (carboxylates), for example citrate and malate, can mobilize inorganic phosphorus into the soil solution (Gerke et al., 2000). Chickpea (*Cicer arietinum* L.) and white lupin, (*Lupinus albus* L.) exude carboxylates from their roots (Veneklaas et al., 2003; Weisskopf et al , 2006) and can thus mobilize calcium-bound phosphate (Ca-P).

Grain legumes have been recognized worldwide as an alternative means of improving soil fertility through their ability to fix atmospheric nitrogen, increase soil organic matter and improve general soil structure (Christiansen and Graham, 2002).

The objective of the study was to determine effect of phosphorus fertilizer application and integrating white lupin and chickpea in sorghum (*Sorghum bicolor*) cropping systems on soil pH, available N and P.

2.0 Materials and Methods

2.1 Study Area

The study was conducted at the Agricultural Field Experimental site, Egerton University, Kenya during the long (LRS) and short rains (SRS) of 2012 and LRS of 2013. The average maximum and minimum temperature in the area ranges from; 19 to 22°C and 5 to 8°C, respectively (Jaetzold and Schmidt, 2006). Total annual rainfall ranges from 1200 to 1400 mm and the soils are predominantly vitric mollic Andosols (Jaetzold and Schmidt, 2006). The soils were neutral in pH and had low amounts of available P and N (Table 1) according to Landon (1991) classification of nutrient levels in soil.

2.2 Treatments and Experimental Design

Two field experiments comprising either lupin or chickpea legumes were laid side by side, with sorghum variety *Know Kanty* as test crop.

Table 1: Initial Physical and Chemical Properties of Soil

	Soil depth (cm)				Soil depth (cm)		
Soil Property	0-15	15-30	30-60	Soil Property	0-15	1530	3060
pH	6.34	6.43	6.5	Exchangeable bases			
CEC (C mol kg $^{-1}$)	62.9	42.5	20.4	K (cmol$_c$kg^{-1})	6.0	6.55	5.44
Total N (%)	1.67	0.63	0.63	Mg (cmol$_c$kg^{-1})	0.25	0.25	0.24
Org. C (%)	1.57	1.59	1.5	Ca (cmol$_c$kg^{-1})	0.23	0.4	0.24
Available P (mg kg^{-1})	17.3	17	14.1	% clay	20	20	20
Mineral N (%)	0.79	0.73	0.59	% sand	50	40	36
Bulk density (g cm^{-3})	1.31	1.31	1.24	% silt	30	40	44

Exchangeable Al (%)	0.2	0.3	0.4	Textural class	sandy loam	Loam	Loam

The experiments are hereafter referred to as lupin sorghum (LS) and chickpea sorghum (CS), respectively. The experimental set up was a split plot arranged in a randomized complete block design and with three replicates The main plots were cropping systems; sorghum monocrop, legume - sorghum rotation and a legume/sorghum intercrop. The subplots, of size 4.8 m × 3.75 m, comprised P sources, triple super phosphate (TSP) and MPR, both applied at the rate of 60 Kg P ha^{-1}. There was a 0.5 m wide path between split plots. A 1 m wide foot path was similarly present between main plots and blocks.

2.3 Agronomic Practices

Land preparation was done prior to the start of the rains, using a mould board plough. Harrowing was then performed twice using a tractor to a depth of 30 cm so as to obtain a fine, firm and weed-free surface for planting. In all cropping systems, sorghum seeds were drilled to a depth of 1 cm in rows spaced at 75 cm by 20 cm. In the rotation system, chickpea and lupin seeds were planted at spacing of 30 by 10 cm and 50 by 30 cm, respectively. In the intercropping system, two lupin or chickpea seeds were planted per hole in the inter-row spaces of sorghum. Spacing of 30 cm and 10 between lupin and chickpea seeds was used, respectively. MPR and TSP were applied in all seasons, by banding method, and mixed well with soil before placement of the seeds. Treatments and cropping sequences in the LRS and SRS are shown in Table 2. Top dressing (60 kg N ha^{-1}) was done a month after planting in all treatments using calcium ammonium nitrate (CAN). After grain harvest, legume residues were chopped into 5-20 cm small pieces, spread across the plots and incorporated to a soil depth of 15 cm.

Table 2: Treatments and Cropping Sequences in the Long and Short Rains of 2012 and 2013

Cropping system	P source	Cropping sequence 2012 LRS	2012 SRS	2012 LRS
Lupin-sorghum experiment				
Monocropping	MPR	sorghum	sorghum	sorghum
	TSP	sorghum	sorghum	sorghum
Rotation	MPR	lupin	sorghum	lupin
	TSP	lupin	sorghum	lupin
Intercropping	MPR	Lupin/sorghum	Lupin/sorghum	Lupin/sorghum
	TSP	Lupin/sorghum	Lupin/sorghum	Lupin/sorghum
Chickpea-sorghum experiment				
Monocropping	MPR	sorghum	sorghum	sorghum
	TSP	sorghum	sorghum	sorghum
Rotation	MPR	chickpea	sorghum	chickpea
	TSP	chickpea	sorghum	chickpea

Intercropping	MPR	Chickpea/sorghum	Chickpea/sorghum	Chickpea/sorghum
	TSP	Chickpea/sorghum	Chickpea/sorghum	Chickpea/sorghum

Key; LRS= long rain season; SRS= short rain season; P= phosphorus; MPR = minjingu phosphate rock; TSP= triple superphosphate

2.4 Soil Sampling and Analysis

Composite soil samples for determination of initial physical and chemical properties (Table 1). were collected from six profile pits in the experimental area at three depths (0-15, 15-30 and 30-60 cm) before application of treatments.

Samples (0-15 cm depth) for the analysis of available N, P and pH, were subsequently collected at sorghum seedling, flowering and maturity. The samples were collected from at least four locations in every plot at random and bulked to get one composite sample. A sub sample was then taken and prepared for analysis. Air- dried soil, sieved through 2 mm mesh (Otingaa et al., 2013) was analyzed for pH (Soil: H_20: 1:2.5), texture (hydrometer method), total N (Kjedahl method), CEC (Chapman, 1965), organic carbon (Walkley– Black, 1934), mineral N and available P according to Okalebo et al. (2002). Exchangeable bases (K, Ca and Mg) were extracted with 1.0 Mammonium acetate at pH 7. K was measured by Flame Emission Spectrophotometry, whereas Ca and Mg were measured by Atomic Absorption Spectrophotometry (Okalebo et al., 2002). For bulk density determination, composite soil samples were taken from the six profile pits at 0-15 cm, 15-30 cm and 30-60 cm depth by use of core rings and bulk density determined according to standard method (Okalebo, et al., 2002).

2.5 Statistical Analysis

Data collected was subjected to analysis of variance (ANOVA) to detect statistical variation in treatment effects on soil pH, available N and P. Means that were significantly different according to the F-test were separated by LSD test at $P \leq 0.05$. The SPSS Statistical package (SPSS, 1999) was used in the analysis. The results in the tables are presented as mean values ± SD (standard deviations).

3.0 Results and Discussion

3.1 Effect of Fertilizer Type, Cropping Systems and Stage of Crop Growth on Soil pH

3.1.1 Effect of Fertilizer Type

Main effect of fertilizer type (F) on soil pH was significant in the CS experiment only (Table 3). In this experiment, pH values were higher in TSP than MPR plots in the LRS of 2012 but subsequent seasons showed higher values in MPR plots (Table 4)

3.1.2 Effect of Cropping System

Main effect of cropping system (CR) on soil pH was significant in both experiments (Table 3). In the LS experiment with the use of TSP, pH was higher in the rotation followed by monocropping system and was lowest in the intercropping. MPR plots in the LS experiment showed contrary results as soil pH was highest in the intercropping system, followed by rotation and lowest in monocropping in all seasons (Table 4). In CS experiment, soil pH was highest with the monocropping system, followed by crop rotation and lowest with the intercropping with the use of TSP. On the other hand, in MPR plots, in the

CS experiment, soil pH was highest in the intercropping system (Table 4). Thus in both experiments, intercropping system with the application of MPR gave the highest soil pH (Table 4).

3.1.3 Effect of Sorghum Growth Stage

Main effect of stage of crop growth (G) was significant in the CS experiment (Table 3). Soil pH increased from seedling to flowering stage but declined at maturity stage in both TSP and MPR plots in all seasons, in this experiment (Table 4).

Table 3: Summary of Analysis of Variance for Measured Parameters as Influenced by P Fertilizer Source, Growth Stage and Cropping System

Source of Variation	DF	soil pH	SAP	SAN
Lupin sorghum experiment				
Fertilizer (F)	1	ns	*	*
Stage (G)	2	ns	*	*
G × F	2	ns	*	*
Cropping System (CR)	8	*	*	*
CR × F	8	ns	*	*
CR× G	16	*	*	*
CR × G × F	16	ns	*	*
Chickpea sorghum experiment				
Fertilizer (F)	1	*	*	*
Stage (G)	2	*	*	*
G × F	2	*	*	*
Cropping System (CR)	8	*	*	*
CR × F	8	*	*	*
CR × G	16	*	*	*
CR × G× F	16	*	*	*

Key: SAP= soil available P; SAN= Soil available N

Table 4: Soil pH as Affected P Source, Sorghum Growth Stage and Cropping System Interaction Values are Mean ± SD

		2012 LRS				2012 SRS				2013 LRS			
		S1	S2	S3	Aver.	S1	S2	S3	Aver.	S1	S2	S3	Aver.
Lupin sorghum experiment													
S	T	5.03 ±0.5	5.9 ±0.2	5.3 ±0.1	5.4 ±0.3	5.3 ±0.01	5.9 ±1.1	5.0 ±0.1	5.4 ±0.7	5.0 ±0.01	5.7 ±0.01	5.5 ±0.2	5.4 ±0.07
	M	5.02 ±0.1	5.9 ±1.1	5.3 ±0.1	5.4 ±0.1	5.4 ±0.1	5.9 ±0.02	5.4 ±0.01	5.6 ±0.1	5.2 ±0.01	5.80 ±0.01	5.6 ±0.2	5.5 ±0.07
S/L	T	5.3 ±0.3	5.6 ±0.9	5.5 ±0.1	5.5 ±04	5.4 ±0.4	5.3 ±0.2	5.3 ±0.08	5.3 ±0.2	5.3 ±0.01	5.8 ±0.01	5.6 ±0.13	5.6 ±0.05
	M	5.2 ±0.7	5.7 ±0.4	5.5 ±0.1	5.5 ±0.4	5.5 ±0.5	5.9 ±0.02	4.9 ±0.1	5.4 ±0.2	5.3 ±0.01	5.8 ±0.1	5.6 ±0.12	5.6 ±0.04
S-L	T	5.3 ±0.7	5.7 ±0.6	5.5 ±0.1	5.5 ±0.5	5.5 ±0.01	5.7 ±0.03	5.1 ±0.01	5.4 ±0.02	5.3 ±0.01	5.1 ±0.01	5.6 ±0.07	5.3 ±0.03
	M	5.2 ±0.7	5.6 ±0.5	5.5 ±0.1	5.4 ±0.4	5.3 ±0.01	5.80 ±0.1	5.3 ±0.03	5.5 ±0.04	5.3 ±0.1	5.3 ±0.01	5.5 ±0.17	5.4 ±0.09
Chickpea sorghum experiment													
S	T	5.2 ±0.17	5.9 ±1.08	5.3 ±0.1	5.46 ±0.45	4.86 ±0.01	5.71 ±0.01	4.83 ±0.01	5.13 ±0.01	5.37 ±0.01	5.7 ±0.1	5.66 ±0.01	5.58 ±0.04
	M	5.4 ±0.39	5.7 ±0.24	5.1 ±0.02	5.4 ±0.22	5.08 ±0.01	5.77 ±0.01	5.07 ±0.01	5.31 ±0.01	5.34 ±0.01	5.72 ±0.63	5.86 ±0.01	5.64 ±0.22
S/C	T	5.04 ±0.03	5.8 ±0.3	5.3 ±0.1	5.38 ±0.14	4.84 ±0.01	5.3 ±0.01	4.9 ±0.01	5.01 ±0.01	5.54 ±0.01	5.7 ±0.63	5.68 ±0.01	5.64 ±0.22
	M	5.0 ±1.2	5.7 ±0.26	5.3 ±0.1	5.33 ±0.52	5.15 ±0.01	5.5 ±0.01	4.68 ±0.01	5.11 ±0.01	5.52 ±0.1	5.5 ±0.01	5.78 ±0.01	5.6 ±0.04
S-C	T	5.29 ±0.1	5.7 ±0.62	5.3 ±0.1	5.43 ±0.27	5.03 ±0.01	5.8± 0.01	4.97 ±0.01	5.27 ±0.01	5.57 ±0.01	5.09 ±0.2	5.74 ±0.01	5.47 ±0.07
	M	5.05 ±0.2	5.7 ±0.1	4.4 ±0.2	5.05 ±0.17	4.86 ±0.01	5.67 ±0.01	5.06 ±0.01	5.19 ±0.01	5.45 ±0.01	5.2 ±0.17	5.84 ±0.01	5.49 ±0.06

Key; SRS= short rain season; LRS = long rain season; S= sorghum monocropping system; / intercropping; -= rotation; L= Lupin; C= chickpea; M= Minjingu phosphate rock; T= triple superphosphate; S1= seedling; S2= 50% flowering; S3= maturity

3.1.4 Effect of Interactions

CR × G and CR × G × F interactions were significant in both CS and LS experiments. G × F and CR × F interactions were significant for soil pH only in CS experiment (Table 3).

3.2: Effect of Fertilizer Type, Cropping Systems and Stage of Crop Growth on Soil Available Nitrogen

3.2.1 Effect of Fertilizer Type

There was a higher available N (SAN) content in soil after application of P treatments (Table 5) compared to initial value (Table 1). The effect of fertilizer type was significant for SAN in both LS and CS experiments (Table 3).

Soil available N was lower in MPR plots than TSP plots in the LRS of 2012 in both experiments (Table 5). In the 2012 SRS, SAN in MPR plots approached that of TSP plots. SAN in MPR plots exceeded that of TSP plots in the LRS of 2013 in both experiments. CS experiment with the application of MPR had a higher SAN (Table 5) when compared to LS experiment (Table 5)

3.2.2. Effect of Cropping System

The effect of cropping system was significant for SAN in both CS and LS experiments (Table 3). Intercropping system with the use of MPR fertilizer source had the highest SAN across all the seasons in both experiments whereas monocropping system had lowest SAN (Table 5).

Table 5 Soil Available N (mg kg^{-1}) as Affected P source, Sorghum Growth Stage and Cropping System Interaction. Values are mean ± SD

		2012 LRS				2012 SRS				2013 LRS			
		S1	S2	S3	Aver	S1	S2	S3	Aver.	S1	S2	S3	Aver.
Lupin sorghum experiment													
S	T	24 ±0.02	54 ±0.05	28 ±0.03	35 ±0.03	35 ±0.45	55 ±0.01	48 ±0.01	46 ±0.16	97 ±0.01	68 ±0.01	130 ±0.08	98 ±0.03
	M	18 ±0.06	55 ±0.05	26 ±0.01	33 ±0.04	04 ±0.26	53 ±0.01	59 ±0.01	39 ±0.09	60 ±0.1	227 ±2.6	106 ±0.05	131 ±0.92
S/L	T	18 ±0.02	61 ±0.17	33 ±0.17	37 ±0.12	72 ±0.03	82 ±0.01	88 ±0.72	81 ±0.25	63 ±0.02	69 ±0.01	66 ±0.09	66 ±0.04
	M	20 ±0.08	51 ±0.17	31 ±0.17	34 ±0.14	108 ±0.1	91 ±0.01	115 ±0.12	105 ±0.08	53 ±0.01	360 ±2.6	66 ±0.01	160 ±0.87
S-L	T	17 ±0.02	55 ±0.05	47 ±0.04	40 ±0.04	3 ±0.01	70 ±0.01	91 ±0.01	55 ±0.01	83 ±0.01	71 ±0.04	99 ±0.01	84 ±0.02
	M	20 ±0.07	40 ±0.01	24 ±0.01	28 ±0.03	53 ±0.03	74 ±0.01	77 ±0.01	68 ±0.02	77 ±0.01	73 ±0.75	68 ±0.01	73 ±0.26
Chickpea sorghum experiment													
S	T	17 ±0.01	83 ±0.06	26 ±0.01	42 ±0.03	60 ±0.1	60 ±0.1	38 ±0.01	53 ±0.07	65 ±0.03	220 ±0.01	127 ±0.12	137 ±0.05
	M	15 ±0.01	33 ±0.08	120 ±0.09	56 ±0.06	60 ±0.1	75 ±0.01	60 ±0.1	65 ±0.07	70 ±0.1	255 ±0.01	106 ±0.49	144 ±0.2
S/C	T	15 ±0.1	51 ±0.04	37 ±0.03	34 ±0.06	84 ±0.01	97 ±0.01	74 ±0.01	85 ±0.01	54 ±0.01	24 ±0.1	99 ±0.01	59 ±0.04
	M	22 ±0.08	54 ±0.02	31 ±0.08	36 ±0.03	108 ±0.01	99 ±0.01	67 ±0.01	91 ±0.01	77 ±0.01	225 ±0.01	107 ±0.01	136 ±0.01
S-C	T	19 ±0.03	43 ±0.02	29 ±0.03	30 ±0.03	72 ±0.01	77 ±0.02	6 ±0.1	52 ±0.04	300 ±0.06	63 ±0.01	64 ±0.01	142 ±0.03
	M	13 ±0.08	48 ±0.01	29 ±0.03	30 ±0.04	72 ±0.01	81 ±0.01	77 ±0.01	77 ±0.01	315 ±0.01	58 ±0.01	144 ±0.01	172 ±0.01

Key; SRS= Aver. = average; short rain season; LRS = Long rain season; S= Sorghum monocropping system; / intercropping; -= rotation; L= Lupin; C= chickpea; M= Minjingu phosphate rock; T= triple superphosphate; S1= seedling; S2= 50% flowering; S3= maturity

3.2.3 Effect of Stage of Growth

Stage of growth had a significant effect on SAN in both CS and LS experiments (Table 3). In both experiments, SAN increased with stage of growth and with season from seedling to flowering stage but a drop was observed at the harvest stage in both TSP and MPR plots (Table 5).

3.2.4 Effect of Interactions

All interactions; G × F, CR × F, CR × G, G × F × CR were significant for SAN in both experiments (Table 3).

3.3: Effect of Fertilizer Type, Cropping Systems and Stage of Crop Growth on Soil Available Phosphorus

3.3.1 Effect of Fertilizer Type

Soil available phosphorus (SAP) increased with application of either MPR or TSP, compared to the initial values at the start of the experiment (Table 1; 6).

Fertilizer type had a significant effect on SAP (Table 3). SAP was lower for TSP than MPR plots in the first season but in the subsequent seasons, SAP was higher in MPR plots than TSP plots in both experiments (Table 6).

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3.3.2 Effect of Cropping Systems

Cropping system had a significant effect on SAP (Table 3). In both experiments, SAP was lowest in the intercropping and crop rotation system in all the seasons, but in 2013 LRS it was highest in the intercropping system in the CS experiment only (Table 6).

Table 6 Soil available P (mg kg^{-1}) as affected by P source and stage of crop growth interaction. Values are mean ± SD

		2012 LRS				2012 SRS				2013 LRS			
		S1	S2	S3	Aver	S1	S2	S3	Aver.	S1	S2	S3	Aver.
Lupin sorghum experiment													
S	T	31.67 ±2.9	23.5 ±4.4	25.0 ±33.5	26.7 ±1.3	75.0 ±1.3	61.0 ±1.6	126.0 ±11.59	87.3 ±4.83	83.1 ±0.1	2.50 ±0.5	6.10 ±0.1	30.6 ±0.23
	M	16.67 ±5.8	31.5 ±5.1	33.0 ±19.1	27.1 ±1.2	70.0 ±1.4	72.0 ±1.7	122.0 ±31.2	88.0 ±11.4	26.5 ±0.1	17.8 ±0.98	19.3 ±0.1	21.2 ±0.39
S/L	T	20.3 ±0.3	19.8 ±5.4	2.50 ±0.01	14.2 ±1.9	63.0 ±1.5	48.5 ±1.6	106.0 ±16.5	72.5 ±6.5	73.0 ±1.3	50.0 ±1.9	100.7 ±0.6	74.6 ±1.27
	M	11.3 ±1.2	17.0 ±4.2	27.0 ±0.1	18.0 ±1.8	73.0 ±1.6	60.0 ±1.7	105.0 ±0.12	79.0 ±1.14	100.7 ±1.15	54.0 ±1.5	114.3 ±10.7	89.7 ±4.5
S-L	T	42.67 ±0.6	20.2 ±2.1	6.10 ±0.1	23.0 ±0.9	73.0 ±1.3	50.0 ±1.6	100.0 ±0.6	74.0 ±1.17	26.0 ±1.6	31.0 ±1.5	6.50 ±0.2	21.2 ±1.1
	M	33.3 ±2.9	43.5 ±6.1	19.3 ±0.1	32.0 ±3.0	100.0± 1.2	54.0 ±1.4	114.0 ±10.1	89.0 ±4.23	17.2 ±0.1	31.0 ±1.73	33.5 ±19.1	27.2 ±7.0
Chickpea sorghum experiment													
S	T	21.5 ±1.32	30.5 ±1.3	24.15 ±0.01	25.4 ±0.8	0.8 ±1.6	95.0 ±1.7	87.0 ±1.5	60.9 ±1.6	27.9 ±0.1	5.80 ±0.1	5.5 ±0.1	13.06 ±0.1
	M	16.0 ±1.6	29.8 ±5.4	43.67 ±1.3	29.8 ±2.8	0.4 ±1.2	36.0 ±1.8	130.0 ±1.4.0	55.5 ±1.5	11.5 ±0.01	5.70 ±0.1	5.4 ±0.01	22.6 ±0.04
S/C	T	28.0 ±2.6	20.5 ±2.6	1.25 ±0.9	16.6 ±2.3	0.67 ±1.3	39.8 ±0.1	36.5 ±0.1	25.7 ±0.5	11.5±0 .1	5.57 ±0.6	51.9 ±0.01	23.0 ±0.24
	M	28.0 ±2.6	28.5 ±2.6	56.9 ±0.88	37.8 ±2.3	0.47 ±1.9	56.0 ±1.4	100.0 ±1.0	52.2 ±1.43	10.8 ±0.1	5.60 ±0.36	22.5 ±0.09	13.0 ±0.18
S-C	T	25.0 ±0.6	33.5 ±2.6	42.5 ±0.7	33.7 ±1.3	96.0 ±1.1	41.5 ±1.6	75.0 ±1.5	70.8 ±1.4	9.6 ±0.1	3.60 ±0.55	5.35 ±0.01	6.18 ±0.22
	M	4.0 ±0.92	25.0 ±2.7	35.5 ±1.8	21.5 ±1.8	73.0 ±1.4	50.5 ±1.3	92.0 ±1.6	71.8 ±1.43	10.5 ±0.01	16.2 ±0.15	5.35 ±0.01	10.7 ±0.06

Key; Aver. = average; SRS= short rain season; LRS = Long rain season; S= Sorghum monocropping; / intercropping; -= rotation; L= Lupin; C= chickpea; M= Minjingu phosphate rock; T= triple superphosphate; S1= seedling; S2= 50% flowering; S3= maturity ; SD= standard deviation

3.3.3 Effect of Stage of Growth

Stage of growth had a significant effect on SAP in both LS and CS experiments (Table 3). SAP decreased from seedling to flowering stage but rose again at the harvest stage in the SRS of 2012 and LRS of 2013 in both experiments (Table
6).

3.3.4 Effect of Interaction

All interactions; G × F, CR × F, CR × G, G × F × CR were significant for SAP in both legume experiments (Table 3).

4.0 Discussion

4.1: Soil pH as Affected by P Source, Sorghum Growth Stage and Cropping System

Higher soil pH obtained with application of MPR than TSP in the CS experiment in latter seasons was due to its liming effect. MPR contains sizeable quantities of lime, equivalent to 38.3% CaO (Nekesa et al., 2005). The dissolution of apatite in PR consumes H^+ ions and thus, it can increase soil pH, depending on PR reactivity (Nekesa et al., 2005). In a five-year field trial conducted in an Oxisol fertilized with various PR sources, soil pH increased from 4.1 in the control to 4.7-5.0 with the PR treatments (Chien et al. (1987).

The lower soil pH resulting from use of TSP in the 2012 SRS in the CS experiment could have been due to slow release of the acid it contains after application to soil. Production of TSP fertilizers requires the use of sulfuric acid that gets slowly released into the soil resulting into low soil pH (Jain et al., 2010; Shrivastava et al., 2011). In a laboratory investigation in Jimma research Center, Ethiopia, chemical fertilizers applied long term to the soil were reported to cause depletion of some plant nutrients and excess deposition of others in soil, and consequently caused increased acidity of soil (Kebede and Mikru, 2005).

Soil pH increase at flowering stage in the CS experiment may have been due to release $CaCO_3$ from MPR, which may have been at its peak at this growth stage. Legumes acidify the surrounding rhizosphere by acid secretion (Weisskopf et al., 2006). MPR contains calcium carbonate which has a liming effect on soil (Szilas et al., 2007). A decrease in soil pH at the maturity could be due to inefficiency of the roots due to aging. As plant roots age they release accumulated acids in the nodules leading to a low soil pH. Weisskopf et al., (2006) observed fastest citrate excretion at mature stage of lupin cluster roots.

Lower soil pH in the intercropping system in both CS and LS experiments was due exudation of carboxylates from legume roots. These acids were capable of lowering the soil pH. Chickpea, like lupin, exudes carboxylates from its roots (Veneklaas et al., 2003). White lupin is well known to exude large amounts of citric and malic acids, which are especially, released from cluster or proteoid roots.

Soil pH was also low in the crop rotation system due to the carboxylate exudation as legumes followed sorghum crop in succession (Mimmoa e*t al*., 2011). A study conducted by Dakora and Phillips (2002) showed that, legumes release a net excess of protons. These protons can markedly lower rhizosphere pH.

4.2: Soil available N as Affected by Fertilizer type, Cropping Systems and Stage of Growth

Higher SAN observed in the MPR compared to TSP plots in latter seasons in both experiments may be attributed to increased availability of P to legumes which caused proper root development, nodule formation and consequently a higher N fixed (Christiansen and Graham, 2002). Root length and number of cluster roots was observed to be greater in MPR experiments compared to TSP experiments (results not shown). Legumes can release locked P from MPR (Badawi et al., 2011). Besides, MPR had a liming effect to the soil as it contains calcium carbonate (Szilas et al., 2007) and thus raised soil pH creating suitable environment for the survival of rhizobium bacteria responsible for N fixation (Dakora and Phillips, 2002).

The higher SAN observed in the intercropping system and rotation systems than monocropping with MPR application in all seasons could have resulted from N fixed by the legume component (Zhang and Li, 2003) combined with CAN top dress. This is in addition to mineralization of incorporated legumes residues after harvest of grains. Most studies on intercropping have focused on the legume-cereal intercropping, and its effect on N input from symbiotic nitrogen fixation. Rotational fallows or relay intercrops have been shown to increases N input and structural stability of the soil (Sileshi et al., 2010). The higher SAN observed at the flowering stage in all treatments and seasons could have resulted from the CAN top dress and also the N fixation process by legume component in the rotation and intercropping systems (Zhang and Li, 2003). At crop seedling stage, there was no N fertilizer applied and at harvest stage, much of the N had been used in seed formation. This may explain the lower amounts of SAN at these two growth stages. N is a key component of enzymes and other proteins essential to all growth functions (Christiansen and Graham, 2002).

4.3: Soil Available P as Affected by Fertilizer Type, Cropping Systems and Stage of Growth

The higher SAP after fertilizer application compared to that at the start of the experiment (Table 3.1) signifies the importance of P fertilization in enhancing soil P fertility. The mean range of SAP of 14.2-88 mg kg^{-1} for TSP plots and 18- 89.7 mg $kg^{-1}$for MPR plots in LS experiment and 6.18- 70.8 mg kg^{-1} for TSP plots and 10.7- 71.8 mg kg^{-1} for MPR plots in CS experiment shows the soil was sufficient in soil available P. In most agricultural soils, organic P comprises 30–80 mg kg^{-1} of the total P range for sufficiency (Li et al., 2004).

Lower SAP values for TSP than MPR plots in the first season, in both CS and LS experiments, was because TSP is water soluble thus availed its P easily in soil, which was subsequently taken up by the crop. Low amounts were thus left in the soil. Higher soil available P in MPR than TSP plots in the subsequent seasons in both experiments was possible since MPR has high phosphate content (28-32% P_2O_5), last long in the soil and can release locked and bound minerals and build the capital P which can be released over a long period of time (Okalebo et al., 2007).

Low SAP at seedling stage in both experiments was because much of the P was taken in by the plant for root growth and development (Kimiti, 2011). Low amounts at the flowering stage were because much of the phosphorus was taken up for legumes nodule formation and N fixation as N fixation is a P requiring process (Christiansen and Graham, 2002). This left insignificant amounts in the soil at this stage. The higher P in the soil at harvest stage could be due to less P uptake by the plant after grain filling, thus higher amounts of P were accumulated in the soil at the harvest stage. The MPR also had residual effects (Nekesa et al., 2005).

In both of experiments, SAP was lowest in the intercropping and crop rotation system in all the seasons, because much of the P was taken in by the plants for root development and growth and also nodule formation by legumes (Li et al., 2011) leaving insignificant amounts in the soil. The legumes in these two systems also required P for N fixation as N fixation is a P requiring process (Christiansen and Graham, 2002). Legumes acidify the rhizosphere changing the pH from 7.5 to 4.8 and cereal crops sown mixed with lupin could increase the absorption efficiency of P from PR (Ligaba et al., 2004).

SAP was slightly higher in the monocropping system in both legume experiments. This was because sorghum crop was the sole crop at a stand unlike in the other two systems where P was required by the legume component for nodulation. In addition, there was low competition for P unlike in the other two systems, resulting in greater levels of SAP.

Higher SAP in MPR plots in the LRS 2013, within the intercropping system in the CS experiment could have been due to the release of locked P of MPR by legume intercrop. Interspecific rhizosphere effect plays a role an important role in the interspecific facilitation between intercropped species (Li et al., 2007). Li et al. (2007) performed a 4-yr field experiment in which maize and faba bean in alternating rows (intercropped) reported a rhizosphere effect of faba bean on maize. Legumes are known for their potential in P solubilization (Badawi et al., 2011). Legumes can enhance PR dissolution through acidification of the rhizosphere and exudation of organic acids (Pypers et al., 2007). Chickpea like lupin, exudes carboxylates from its roots and can thus mobilize calcium-bound phosphate (Veneklaas et al., 2003). White lupin is able to develop proteoid roots that exude large quantities of malate and citrate during P deficiency, increasing the availability of mineral-bound P by solubilizing Ca, Fe and Al phosphates (Neumann et al., 2000) and making P available (Li et al., 2004).

5.0 Conclusion

A higher SAP was obtained with TSP than MPR application in the first season in both experiments. This was because TSP is water soluble and it availed its P more readily than MPR. The latter has low solubility in water. In the subsequent seasons, SAP with MPR application approached that of TSP and exceeded it the LRS 2013. This was as a result of solubilization of MPR by the legumes white lupin and chickpea. Comparison of the two legumes shows that both were competitive in enhancing MPR solubilization. Furthermore, in the subsequent seasons, crop residue decomposition led to release of nutrients as well as organic acids. The acids released by the decomposing residues may have also enhanced MPR solubilization.

Higher SAN was obtained in the first season with the use of TSP in both experiments. The water soluble fertilizer supplied P promoted good root network and subsequently a higher uptake of P by crops occurred.

Uptake of P resulted in proper legume nodulation and in turn higher levels of N fixed and accumulation in soil. In the subsequent seasons, MPR solubilization by legumes, led to increase in SAN as aforementioned. It can be concluded that the performance of MPR was equally competitive as TSP in supply of P.

Cropping system had a significant effect on SAP, SAN and soil pH in both experiments. Of the various cropping systems, intercropping system had the highest SAN levels followed by crop rotation and finally monocropping. Legume-cereal intercropping, has been found to be a productive and sustainable system due to its resource utilization (water, light, nutrients), and its effect on N input from symbiotic nitrogen fixation by the legumes. In the crop rotation system similar effect of legumes on nutrients levels was realized. Crop rotation practices, increase N supply for cereals, thus a cereal crop following the legume can then benefit directly from the enhanced nutrient availability in the soil and acquire nutrients released from the decomposing legume residues. SAP was low in the intercropping and was due to P uptake by plants after MPR solubilization. Higher uptake of P led to proper root development and nodulation and thus N fixation which resulted in to higher levels of SAN. There was lower pH in the intercropping system. The legumes exuded carboxylates from their roots which acidified the rhizosphere and enhanced MPR solubilization thus P was availed in soil.

Monocropping system had the lowest SAN especially with the use of TSP fertilizer. This was as a result of plant P uptake. Thus monocropping systems can cause deterioration of soil health.

The stage of crop growth had a significant effect on SAP, SAN, and soil pH in both experiments. SAP was low at flowering stage and flowering and was due to plant uptake. The legumes were at their peak of growth at flowering and nodulated roots were well developed to exude carboxylates, which solubilized P from MPR for crop uptake. Release of P from MPR positively affected SAN as aforementioned.

Growing legumes in intercropping system with sorghum with application of MPR is recommended for improved chemical properties.

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