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Soil Available Nutrients, pH and Yield Variation in Legume - Maize Systems Utilizing Two Phosphorus Sources in Kabete Kenya

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Abstract — **Phosphorus (P) and nitrogen (N) deficiencies have contributed to low maize yields in Kabete, Kenya. A split plot in a randomized complete block experiment was set up at Kabete Field Station, University of Nairobi, during the long (LRS) and short rain seasons (SRS) of 2012. The objective was to investigate effects of legume integration and P fertilizer application on soil pH, available N and P and yields in maize systems. The main plots were sole maize, legume/maize intercrop and legume-maize rotation systems. The sub plots were Minjingu phosphate rock (MPR) and triple superphosphate (TSP) (60 kg P ha^{-1}) application and a control (no P input). In the LRS, pH at seedling was significantly higher in chickpea/maize intercrop control and with TSP (C/M_{CTRL}; C/M_{TSP}), and lupin-maize rotation with TSP (L-M_{TSP}). At flowering, pH was significantly higher in sole maize control and with MPR (M_{CTRL}; M_{MPR}), chickpea/maize intercrop with MPR (C/M_{MPR}) and lupin/maize intercrop with MPR and TSP (L/M_{MPR}; L/M_{TSP}). At harvest, M_{MPR}, C/M_{TSP} and C/M_{MPR} had significantly higher pH. During the SRS, pH was significantly higher in M_{MPR}, C/M_{MPR}, L/M_{MPR} and L-M_{MPR} at seedling, M_{TSP}, M_{MPR}, L/M_{MPR}, L-M_{CTRL} and L-M_{MPR} at flowering and C-M_{MPR} at harvest. In the LRS available P was significantly higher in M_{CTRL}, C/M_{CTRL} and C-M_{CTRL} at seedling, L-M_{CTRL} during flowering and L/M_{CTRL} at harvest. In the SRS, available P was significantly higher in M_{TSP}, M_{CTRL}, C/M_{CTRL}, L/M_{CTRL}, L/M_{TSP}, C-M_{TSP} and L-M_{TSP} at seedling, C-M_{TSP} at flowering and M_{CTRL} and C-M_{CTRL} at harvest. During the LRS nitrate-N was significantly higher in L/M_{TSP} at seedling, L/M_{CTRL} and C-M_{TSP} at flowering and L/M_{MPR}, L/M_{CTRL}, L-M_{MPR} and C-M_{CTRL} at harvest. In the SRS, nitrate-N was significantly higher in C-M_{MPR}, L/M_{MPR} and C-M_{MPR} treatments at seedling, flowering and harvest, respectively. In the LRS, ammonium-N was significantly higher in M_{TSP}, M_{MPR}, L/M_{TSP}, L/M_{MPR}, L-M_{CTRL}, L-M_{TSP}, L/M_{CTRL}, L-M_{MPR}, C-M_{MPR}, C/M_{TSP} and C/M_{MPR} at seedling, L/M_{TSP} at flowering and C-M_{CTRL}, C/M_{CTRL} and C/M_{MPR} at harvest. In the SRS, ammonium-N was significantly higher in C/M_{CTRL} at seedling and flowering, and C/M_{MPR} at harvest Maize grain yields were significantly higher in L/M_{TSP}, L/M_{MPR} and C/M_{MPR} in the LRS and L-M_{MPR} and L/M_{TSP} in the SRS. Application of either TSP or MPR in legume-maize systems enhanced nutrient availability and maize yields. The intercropping system with MPR use may be more preferable because of dual harvest from same field.**

Keywords — **Intercropping, Minjingu Phosphate Rock, Nitisol, Nitrogen, Triple Superphosphate.**

I. Introduction

Agricultural production in sub-Saharan Africa is curtailed by the predominance of fragile ecosystems and low natural soil fertility [1]. The production of maize (*Zea mays* L.), Kenya's primary staple [2], in small holder farms of Kabete sub-County is constrained by nitrogen (N) and phosphorus (P) deficiencies[3], the two most critical macronutrients in crop production [4,5]. N is a component of organic molecules such as amino acids, proteins and nucleic acids and promotes vigorous vegetative growth [6,7]. Phosphorus stimulates root development, increases stalk and stem strength and improves flower formation and seed production. It also promotes more uniform and earlier crop maturity, increases N-fixing capacity of legumes, improves crop quality and increases resistance to plant diseases [8].

The deficiencies of N and P in small holder farms of Kabete are aggravated by intensive use of soils coupled with irregular mineral fertilizer use due to high costs. On the other hand the quantity of animal manure available in small holder farms is insufficient to meet the nutrient requirement of maize. It is also of variable quality, due to poor handling [9,10].To achieve significant increases in maize production in small holder farms, reversing the trend in N and P depletion and decline in fertility is a priority. This will require feasible cropping oriented innovative technologies, found in the management of the crops [11]. Prior work in Njoro sub-County, Kenya recommended integration of white lupin, with application of MPR, in maize cropping systems for improved soil N and P fertility and yield increases of maize[12,13]. Growing legumes white lupin (*Lupinusalbus*) and chickpea (*Cicer arietinum*) in association with maize with application of Minjingu rock phosphate (MPR) is a feasible technology that can potentially address the soil fertility problems in farmers' fields and increase maize yields, and has not been previously tested in Kabete sub-County.

Minjingu phosphate rock (MPR) deposit from East Africa is a low cost P source with sufficient quantity cum reactivity for direct application [14]. It costs about 50% of processed P fertilizers on elemental basis, rebuilds soil capital P due to its residual effect and has an average effectiveness of about 65% compared to processed fertilizers [15]. The major impediment to its use is its insolubility [14] which may constraint P uptake by plants.

Plants have adapted strategies to enhance insoluble P acquisition and use [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 [16,17]. Chickpea, like lupin, exudes carboxylates from its roots [18] and can mobilize calcium-bound phosphate (Ca-P) for uptake by plants. Additionally, the legumes can supply fixed N to non-legume crops grown in association or rotation with them [19]. Legume roots, rhizodeposits and residues are also important N pools [20, 21].

The aim of this study was therefore to investigate effect of integrating chickpea and white lupin in maize systems with P application on soil pH, available N and P and yields in Kabete, Kenya.

II. Materials and Methods

A. Site Description

A field experiment was conducted at Kabete Field Station (1940 m asl) of the University of Nairobi (latitude 1°15'S and longitude 36°41'E) during the long (LRS) and short rain seasons (SRS) of 2012. The site falls in agro-ecological zone UM3 (Upper Midland) and receives an average annual precipitation of 1000 mm in bimodal distribution (mid-March to May, long rains; October to December, short rains) [22]. The minimum and maximum mean temperatures of the area are 13.7°C and 24.3°C, respectively. The soils are predominantly deep (>180 cm), dark red to dark reddish brown friable clays [23,24] and classified ashumic Nitisols [25,26]. Initial soil properties were: medium pH, available P and total N ; low organic carbon and clay texture (Table I), according to Landon[27] classification of nutrient levels in soil.

B. Experimental Design and Treatments

A randomized complete block design with a split plot arrangement was used. The main plots were cropping systems; (i) monocropping (sole maize), (ii) intercropping (white lupin /maize and chickpea /maize), and (iii) crop rotation (white lupin-maize and chickpea-maize). The sub plots were phosphorous (P) sources; MPR and triple superphosphate (TSP), applied at 60 kg P ha^{-1}, and a control (without P added). Calcium ammonium nitrate (CAN) was top dressed at the rate of 60 kg N ha^{-1} in all plots, a month after planting. Plot sizes measured 3.75 m by 4.8 m with0.5 m and 1 m wide footpaths between plots and blocks, respectively.

C. Agronomic Practices

Land was ploughed manually and crop residues present were removed before application of treatments. MPR and TSP were applied in both the LRS and SRS, by banding and mixed well with soil before seed placement. Maize (*Zea mays* L*;* Hybrid513) was planted at the rate of two seeds per hill at spacing of 75 cm × 30 cm, in respective treatments, and thinned to one plant per hill 28 days after sowing. In the intercropping system, in both seasons, 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 LRS, at spacing of 75 cm × 30 cm. Thinning to one seedling per hill was done four weeks after sowing of legumes. The plots were kept weed free throughout the growing season through hand weeding. Treatments and cropping sequences are shown in Table II.

D. Residue Management

Crop residues obtained after grain harvest in the LRS were chopped (5-20 cm pieces) and incorporated in soil, in plots they were obtained from, during land preparation for planting in the SRS.

E. Soil Sampling and Analyses

Composite soil samples (0-20 cm) were collected before experimental set-up, for characterization of initial physical and chemical properties (Table I). Subsequent samplings (0-20 cm) were carried out at maize seedling, 50% flowering and harvesting stages, for mineral N, available P and pH determinations.

Immediately after sampling, the soil samples were kept in polythene bags, sealed and placed in portable cool boxes. Soil samples for available N (NO_3^--N and NH_4^+-N) analysis were refrigerated and analysed within 24 h using method described by Okalebo et al. [28]. For other soil analyses, samples were air dried by placing them in a shallow tray in a well ventilated area.

Air-dried samples, sieved through a 2 mm mesh, were analyzed for pH (Soil: H_20; 1:2.5), total nitrogen (Kjeldahl method), available P (double acid method) and organic C (Walkley-Black method), as described by Okaleboet al. [28]. Exchangeable bases (K, Ca and Mg) were extracted with 1.0 M-ammonium acetate at pH 7. K was measured by Flame Emission Spectrophotometry, whereas Ca and Mg were measured by Atomic Absorption Spectrophotometry [29]. Soil texture was determined using the hydrometer method [30]. Undisturbed core samples were used for bulk density determination [31].

F. Yield determination

At physiological maturity, the above ground portions of the maize plant were harvested, from two central rows of each plot, and divided into stover (stalk and leaves) and cobs. Fresh weight of stover was determined immediately in the field using a weighing balance. Sub-samples were oven dried (65° C) for 72 hours.

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

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

*Classification by Landon [27].

Table II: Treatments and cropping sequence in LRS and SRS of 2012

Cropping System	Phosphorous Source	Cropping Sequence LRS	SRS
Monocrop	MPR	Maize	Maize
	TSP	Maize	Maize
	Control	Maize	Maize
Rotation	MPR	Lupin	Maize
	TSP	Lupin	Maize
	Control	Lupin	Maize
	MPR	Chickpea	Maize
	TSP	Chickpea	Maize
	Control	Chickpea	Maize
Intercropping	MPR	Lupin/Maize	Lupin/Maize
	TSP	Lupin/Maize	Lupin/Maize
	Control	Lupin/Maize	Lupin/Maize
	MPR	Chickpea/Maize	Chickpea/Maize
	TSP	Chickpea/Maize	Chickpea/Maize
	Control	Chickpea/Maize	Chickpea/Maize

Key: P =MPR = Minjingu Phosphate Rock, TSP = Triple superphosphate, SRS = Short rain season, LRS = Long rain season, / =intercrop.

Dry weight was determined and used to calculate the total above-ground dry matter (DM) yields. Cobs were sun-dried and threshed to obtain grains and their weight was determined. Grain (adjusted to 13% moisture content) and DM yields were converted to kg ha^{-1} using the formula shown below:

Grain/DM yield (kg ha^{-1}) = kg yield $m^{-2} \times 10{,}000m^2$.

G. Statistical Analysis

Data collected was subjected to analysis of variance (ANOVA) using Gen Stat 15th Edition. Mean separation was done using least significant differences (LSD) at $P \leq 0.05$.

III. Results and Discussion

A. Effect of phosphorus sources and cropping system on soil pH

Soil pH values at crop seedling in the LRS were significantly higher in chickpea/maize intercrop control (no P input), chickpea/maize intercrop with TSP and lupin-maize rotation with TSP applied (C/M_{CTRL}, C/M_{TSP} and L-M_{TSP}) (Table III).

At 50% flowering in the LRS, soil pH values were significantly higher insole maize control and with MPR applied (M_{CTRL}; M_{MPR}), chickpea/maize intercrop with MPR (C/M_{MPR}) and lupin/maize intercrop with MPR and TSP applied (L/M_{MPR}; L/M_{TSP}). Conversely, at flowering stage the least pH values were observed where legumes chickpea and lupin were present solely with use of either TSP or no P input (control) i.e. chickpea-maize rotation control (C-M_{CTRL}) and L-M_{TSP} (Table III). At harvest in the long rains, M_{MPR}, C/M_{TSP} and C/M_{MPR} had significantly higher soil pH values. During the short rains and at all stages of maize growth, soil pH was significantly higher where maize was present and mostly with MPR use i.e. M_{MPR}, C/M_{MPR}, L/M_{MPR} and L-M_{MPR} at seedling stage; M_{TSP}, M_{MPR}, L/M_{MPR}, L-M_{CTRL} and L-M_{MPR} at flowering and C-M_{MPR} at harvest (Table III).

The significantly higher pH values with MPR can partly be attributed to indirect liming effect of MPR, due to its high carbonate content [32]. Similar observations were made by Nekesa et al.[33] in a study on use of MPR as a liming material in acid soils of Western Kenya.

The higher pH values observed where maize was growing either solely or as intercrops, in both the LRS and SRS, may be attributed partly to its exudates [34, 35]. In the experiment on rhizosphere properties of maize genotypes with contrasting phosphorus efficiency, rhizosphere pH was influenced by root types and soil P levels [35]. In plants grown at high soil P levels the mean value of rhizosphere pH was slightly higher than in plants grown in low P soil. This was attributed to greater anion release (OH^-or HCO_3^-) into the plant rhizosphere, to regulate the electrochemical cell equilibrium, due to higher P amounts absorbed by plants [35]. In general, a factor that causes major changes in the rhizosphere pH is an imbalance in the ratio of root-absorbed cations/anions [36].

Table III: Soil pH across maize growth stages during the SRS and LRS of 2012

Cropping System	LRS			SRS		
	Seedling	Flowering	Harvest	Seedling	Flowering	Harvest
M_{CTRL}	6.0^{c}	5.8^{a}	5.6^{cd}	5.7^{de}	6.1^{bcd}	6.1^{cd}
M_{TSP}	5.7^{d}	5.4^{bc}	5.7^{bc}	5.5^{ef}	6.3^{ab}	6.0^{d}
M_{MPR}	6.1^{bc}	5.7^{ab}	5.9^{ab}	6.4^{a}	6.4^{a}	6.1^{cd}
C/M_{CTRL}	6.5^{a}	5.5^{b}	5.8^{bc}	6.0^{bc}	5.7^{e}	6.4^{b}
C/M_{TSP}	6.3^{ab}	5.4^{bc}	5.9^{ab}	5.8^{cd}	6.0^{cd}	6.3^{bc}
C/M_{MPR}	6.1^{bc}	5.7^{ab}	6.1^{a}	6.4^{a}	6.1^{bcd}	6.2^{bcd}
L/M_{CTRL}	6.2^{bc}	5.5^{b}	5.6^{cd}	5.6^{def}	5.9^{de}	6.0^{d}
L/M_{TSP}	6.2^{bc}	5.6^{ab}	5.4^{de}	5.6^{def}	5.9^{de}	6.3^{bc}
L/M_{MPR}	6.1^{bc}	5.6^{ab}	5.7^{bc}	6.3^{a}	6.2^{abc}	6.1^{cd}
$C\text{-}M_{CTRL}$	6.1^{bc}	4.9^{e}	5.4^{de}	5.7^{de}	6.1^{bcd}	6.3^{bc}
$C\text{-}M_{TSP}$	6.1^{bc}	5.2^{cd}	5.3^{e}	5.5^{ef}	6.0^{cd}	6.1^{cd}
$C\text{-}M_{MPR}$	6.2^{bc}	5.5^{b}	5.7^{bc}	6.1^{b}	6.2^{abc}	6.9^{a}
$L\text{-}M_{CTRL}$	6.2^{bc}	5.4^{bc}	5.7^{bc}	5.4^{f}	6.4^{a}	6.2^{bcd}
$L\text{-}M_{TSP}$	6.5^{a}	5.1^{de}	5.8^{bc}	5.5^{ef}	6.0^{cd}	6.0^{d}
$L\text{-}M_{MPR}$	6.2^{bc}	5.4^{bc}	5.8^{bc}	6.2^{ab}	6.3^{ab}	6.1^{cd}

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

The lower pH values in $C\text{-}M_{CTRL}$ and $L\text{-}M_{TSP}$ at 50% flowering in the LRS can be attributed to rhizosphere processes by legumes. For legumes, the flowering stage is normally accompanied by N fixation and exudate secretion and subsequently a lower rhizosphere pH [14,37]. Neumann and Romheld [38] reported than lupin and chickpea caused net acidification of growth medium in response to P deficiency.

A study on field-grown cereals and legumes on acid sandy soils of Sudano- Sahelian West Africa also reported root-induced decreases in soil pH by cowpea [39]. The increases were more pronounced with P application. In their study P was applied annually as broadcast single superphosphate (SSP) at 0 and 13 kg P ha^{-1}, and as rock phosphate at a three years' rate of 39 kg P ha^{-1}. Cu et al.[40]while conducting legume-cereal cropping experiments, showed a lower rhizosphere pH in legumes than cereals, while that of intercropped cereal/legume was intermediate. Similar observations were reported by other workers studying soil phosphorus acquisition in the rhizosphere of intercropped species [41, 42, 43].

B. Effect of phosphorus sources and cropping systems on soil available phosphorus

At maize seedling in the LRS, available soil P was significantly higher in M_{CTRL}, C/M_{CTRL} and $C\text{-}M_{CTRL}$ (Table IV). During flowering in the LRS the available P values were significantly higher in $L\text{-}M_{CTRL}$ and at harvesting stage, in L/M_{CTRL} (Table IV). At seedling in the SRS, soil available P levels were significantly higher in M_{TSP}, M_{CTRL}, C/M_{CTRL}, L/M_{CTRL}, L/M_{TSP}, $C\text{-}M_{TSP}$ and $L\text{-}M_{TSP}$. At flowering in the SRS, $C\text{-}M_{TSP}$ had significantly higher available P values while at harvest, M_{CTRL} and $C\text{-}M_{CTRL}$ (Table IV).

The higher values either with TSP use or no P input (control) at seedling stage in both seasons may be explained by utilization of seed P reserves for their growth. Mineral elements stored in seed reserves meet the nutrient demands of seedlings during their initial development and growth [44]. Maximal growth of cereal seedlings can be sustained by seed P reserves, for several weeks after germination, until the plant has three or more leaves and an extensive root system [45].

During flowering and harvesting stages, available soil P values were significantly higher in control treatment (no P input) signifying plant acquisition of both TSP and MPR (results not shown). 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. For the insoluble MPR [46] the legumes chickpea and lupin enhanced its solubilization and subsequent crop uptake. Chickpea, like lupin, exudes carboxylates from its roots and can mobilize calcium-bound phosphate (Ca-P) for uptake by plants [18].

Table IV: Available soil phosphorous (mg kg^{-1}) across maize growth stages during the SRS and LRS of 2012.

Cropping System	LRS			SRS		
	Seedling	Flowering	Harvest	Seedling	Flowering	Harvest
M_{CTRL}	24.9^{a}	25.6^{bc}	25.2^{b}	34.8^{ab}	27.0^{cd}	50.3^{a}
M_{TSP}	19.2^{bc}	22.6^{cd}	20.2^{c}	31.2^{abc}	33.5^{b}	13.7^{ef}
M_{MPR}	11.8^{ef}	11.6^{f}	16.5^{efg}	15.9^{de}	23.9^{d}	23.3^{cd}
C/M_{CTRL}	21.8^{ab}	21.7^{d}	19.9^{cd}	34.9^{ab}	25.5^{cd}	10.7^{f}
C/M_{TSP}	18.4^{bc}	14.6^{ef}	17.3^{def}	30.0^{c}	35.0^{b}	6.4^{f}
C/M_{MPR}	13.1^{de}	11.3^{fg}	13.2^{ghi}	18.0^{d}	13.5^{e}	22.5^{cd}
L/M_{CTRL}	18.6^{bc}	21.1^{d}	28.7^{a}	35.7^{a}	28.4^{c}	22.3^{cd}
L/M_{TSP}	16.0^{cd}	23.9^{cd}	14.9^{fg}	31.9^{abc}	33.1^{b}	34.3^{b}
L/M_{MPR}	8.8^{f}	8.2^{g}	11.8^{i}	11.3^{e}	13.1^{e}	11.6^{f}
C-M_{CTRL}	25.1^{a}	27.6^{b}	24.6^{b}	30.8^{bc}	24.4^{d}	46.7^{a}
C-M_{TSP}	21.2^{b}	21.2^{d}	18.6^{cde}	31.8^{abc}	39.6^{a}	29.8^{bc}
C-M_{MPR}	17.3^{c}	16.2^{e}	14.7^{fgh}	11.9^{e}	25.3^{cd}	24.8^{cd}
L-M_{CTRL}	21.3^{b}	32.3^{a}	24.5^{b}	30.8^{bc}	28.3^{c}	27.2^{bcd}
L-M_{TSP}	17.3^{c}	25.0^{bc}	19.4^{cd}	34.8^{ab}	35.5^{b}	20.1^{de}
L-M_{MPR}	12.1^{ef}	23.1^{cd}	12.7^{hi}	11.7^{e}	11.4^{e}	11.6^{f}

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

C. Effects of phosphorus sources and cropping systems on soil mineral N

In the LRS, soil nitrate-N levels were significantly higher in L/M_{TSP} at seedling (Table V). At flowering, highest values were recorded in L/M_{CTRL} and C-M_{TSP}. At harvest, the nitrate N values were significantly higher in L/M_{MPR}, L/M_{CTRL}, L-M_{MPR} and C-M_{CTRL}. In the SRS, nitrate-N was significantly higher in C-M_{MPR}, L/M_{MPR} and C-M_{MPR} treatments at seedling, flowering and harvest, respectively.

Ammonium-N levels in the LRS were significantly higher in M_{TSP}, M_{MPR}, L/M_{TSP}, L/M_{MPR}, L-M_{CTRL}, L-M_{TSP}, L/M_{CTRL}, L-M_{MPR}, C/M_{MPR}, C/M_{TSP} and C-M_{MPR} at seedling. At flowering, the values were significantly higher in L/M_{TSP}. Ammonium-N values in soil at harvest were significantly higher in the C-M_{CTRL}, C/M_{CTRL} and C/M_{MPR}(Table V).

During the SRS, C/M_{CTRL} at seedling and flowering, and C/M_{MPR} at harvest, had significantly higher ammonium levels in soil. Mineral-N fluctuated with crop development (Table V).

Higher nitrate N levels at seedling in the LRS in L/M_{TSP} treatment may have been due to flush of nitrates formed at onset of long rains. Nitrate frequently accumulates in tropical soils during onset of rains following a dry season [47].

During flowering, in the LRS, L/M_{CTRL} and C-M_{TSP} had significantly higher nitrate N values and is partly attributable to N fixed by lupin and chickpea[48]. Mahieuet al. [48] and Wichern et al. [49]noted that legumes are able to fix significant amounts of N in soil during their growth. At harvest, higher nitrate N values found in L/M_{MPR}, L/M_{CTRL}, L-M_{MPR} and C-M_{CTRL} could have been as a result of N_2 fixed by legumes, also reported by Zarrinet al. [50] .

In the SRS, the significantly higher nitrate-N observed in C-M_{MPR}, L/M_{MPR} and C-M_{MPR} treatments at seedling, flowering and harvest, respectively was due to N fixed by legumes in addition to mineralization of incorporated residues from the prior season. The presence of MPR, which supplied P, could have facilitated better N fixation capacity. N fixation being an energy intensive process requires large amounts of P and so P fertilization can often enhance amounts of N fixed[51]. This is in addition to increased soil pH by MPR which created favourable conditions for microbial growth especially nitrifyers and actinomycetes [52].

Higher ammonium N with MPR and TSP application in respective treatments can be attributable to stimulation of mineralization of crop residues. Organic N mineralization is stimulated by liming [53] and/or P fertilization [54]. MPR had an indirect liming on soil due to its high carbonate content [32].In a study on N mineralization during incubation, liming and P fertilization enhanced N mineralization [55]. C/M_{MPR} had higher ammonium N values at harvest stage in the SRS and this could be due to mineralization at dry conditions in soil. Similar findings were reported by Anggria et al. [56]. They documented that under dry conditions with aerobic conditions, the ammonification of organic residues was faster than oxidation of ammonium to nitrate and resulted in higher ammonium accumulation.

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Table V: Soil mineral N (µgNg^{-1}) across maize growth stages during the LRS and SRS of 2012.

Cropping system	LRS						SRS					
	Seedling		Flowering		Harvest		Seedling		Flowering		Harvest	
	NO_3^-- N	NH_4^+-N	NO_3^-–N	NH_4^+-N	NO_3^-–N	NH_4^+-N	NO_3^-- N	NH_4^+-N	NO_3^-- N	NH_4^+-N	NO_3^-- N	NH_4^+-N
M_{CTRL}	23.3^{h}	19.^{7bcd}	50.2^{c}	26.8^{hi}	32.6^{bcd}	28.8^{ef}	14.3^{f}	34.7^{g}	13.9^{i}	32.2^{f}	17.4^{f}	42.5^{g}
M_{TSP}	31.4^{c}	23.9^{ab}	46.9^{d}	38.8^{c}	29.4^{cde}	27.7^{efgh}	14.0^{f}	33.5^{hi}	13.4^{j}	33.0^{e}	17.0^{f}	39.0^{i}
M_{MPR}	27.3^{ef}	25.3^{ab}	49.4^{c}	29.3^{fg}	28.7^{cdef}	31.2^{cde}	18.6^{e}	35.9^{f}	17.9^{e}	30.4^{g}	21.8^{e}	46.8^{e}
C/M_{CTRL}	15.8^{j}	14.2^{d}	40.8^{f}	17.4^{l}	22.1^{fgh}	35.8^{ab}	20.1^{d}	52.3^{a}	21.8^{c}	52.8^{a}	23.5^{d}	59.6^{c}
C/M_{TSP}	23.3^{h}	23.0^{ab}	47.2^{cd}	23.5^{k}	25.3^{efgh}	30.7^{cde}	18.6^{e}	39.2^{e}	16.7^{g}	39.6^{b}	23.6^{d}	44.8^{f}
C/M_{MPR}	28.2^{e}	25.7^{a}	55.0^{b}	30.7^{f}	19.2^{h}	37.4^{a}	13.2^{g}	45.9^{b}	22.0^{b}	35.8^{d}	25.8^{c}	63.0^{a}
L/M_{CTRL}	30.8^{c}	25.3^{ab}	59.6^{a}	36.2^{d}	43.1^{a}	21.8^{ij}	8.5^{i}	17.2^{n}	5.9^{n}	11.5^{m}	11.4^{g}	25.5^{m}
L/M_{TSP}	39.4^{a}	24.8^{ab}	46.6^{d}	54.0^{a}	33.4^{bc}	24.8^{hi}	9.3^{i}	27.7^{k}	10.1^{l}	26.4^{j}	10.4^{h}	33.2^{k}
L/M_{MPR}	26.4^{f}	24.9^{ab}	43.7^{e}	27.8^{gh}	38.3^{ab}	25.0^{ghi}	24.1^{b}	25.9^{l}	33.6^{a}	25.0^{k}	17.9^{f}	30.6^{l}
C-M_{CTRL}	20.3^{i}	16.3^{bcd}	46.4^{d}	24.3^{jk}	38.6^{ab}	38.5^{a}	19.6^{d}	45.2^{c}	16.9^{f}	36.4^{d}	25.9^{c}	60.8^{b}
C-M_{TSP}	28.5^{e}	21.0^{bc}	60.6^{a}	35.9^{d}	26.4^{defg}	28.4^{efg}	22.3^{c}	33.8^{h}	20.7^{d}	36.4^{d}	27.7^{b}	36.3^{j}
C-M_{MPR}	29.6^{d}	26.4^{a}	54.2^{b}	32.8^{e}	20.3^{gh}	29.3^{def}	25.6^{a}	30.5^{j}	21.8^{c}	22.6^{l}	32.9^{a}	42.9^{g}
L-M_{CTRL}	26.3^{f}	23.2^{ab}	54.0^{b}	29.4^{fg}	26.6^{cdefg}	19.1^{j}	8.9^{i}	24.3^{m}	10.8^{k}	27.9^{i}	8.9^{i}	24.3^{n}
L-M_{TSP}	34.3^{b}	26.9^{a}	33.2^{g}	41.6^{b}	32.4^{bcd}	27.1^{fgh}	5.6^{j}	33.1^{i}	6.1^{m}	29.6^{h}	6.3^{j}	41.6^{h}
L-M_{MPR}	25.0^{g}	24.3^{ab}	44.5^{d}	25.7^{ij}	37.2^{ab}	33.1^{bc}	11.7^{h}	41.3^{d}	14.0^{h}	38.2^{c}	10.8^{h}	50.7^{d}

Key: LRS – long rain season; SRS = Short rain season; CTRL = Control; TSP = triple superphosphate; MPR = Minjingu phosphate rock. Means in a column followed by the same letter(s) are not significantly different at $P \leq 0.05$ (Fisher's Protected Least Significant Difference Test)

Soil mineral N values fluctuated across crop growth stages because nitrogen accumulation is closely linked to biomass accumulation [50]. Shataet al.[57] further notes that there is greater N acquisition by a non-legume crop intercropped with a legume. Li et al.[58] and Zhang and Li [59] reported decreased soil nitrate-N contents at harvest in maize faba beans intercropping system.

D. Effect of phosphorus source and cropping system on maize yield

In the LRS, maize grain yields were significantly higher in L/M_{TSP}, L/M_{MPR} and C/M_{MPR}(Table VI). In the SRS, significantly higher grain yields were recorded in L-M_{MPR} and L/M_{TSP} treatments (Table VI).

Maize DM yields in the LRS were significantly higher in L/M_{TSP}. In the SRS, DM yields were significantly higher in L/M_{MPR}, C/M_{MPR}, L-M_{MPR} and C-M_{MPR}(Table VI).

The higher grain yield in L/M_{TSP}, M/L_{MPR} and M/C_{MPR} treatments in the LRS can partly be attributed to improvement in N levels in soil by the legumes white lupin and chickpea. Jansen [60] studying white lupin, reported a potential atmospheric nitrogen fixation rate of up to 400 kg N ha^{-1} yr^{-1}. 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 [50].

Higher yields in L-M_{MPR} and L/M_{TSP} in the subsequent season can be attributed to increase in soil nitrogen partly due to N fixation by lupin in addition to mineralization of incorporated residues. Sufficient availability of nitrogen (N) is a prerequisite for high dry matter production and protein yields [61]. In addition, lupin has a high above ground biomass [62] which upon incorporation at harvest, possibly enhanced N supply to maize after decomposition, resulting to higher grain yields.

Legumes lupin and chickpea may have also improved P nutrition for maize through enhancing P release from MPR by acidification of the rhizosphere. Chickpea, like lupin, exudes carboxylates from its roots [63] and could have mobilized calcium-bound phosphate (Ca-P) for uptake by plants. Kamh et al. [64] and Nuruzzaman et al. [65] also reported better growth of wheat after lupin cropping in a pot experiment. Onwonga et al. [12] and Lelei and Onwonga [13] also observed increased yield of maize due to MPR application and integration of white lupin.

Table VI: Maize grain and DM yields (t ha^{-1}) over the SRS and LRS of 2012

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

Key: LRS – long rain season; SRS= Short rain season; CTRL = Control; TSP = triple superphosphate; MPR = Minjingu phosphate rock. Means in a column followed by the same letter(s) are not significantly different at $P \leq 0.05$ (Fisher's Protected Least Significant Difference Test).

IV. Conclusion

Cultivating chickpea or white lupin in intercropping or rotation systems with maize and use of either TSP or MPR improved available N and P and maize yields. The intercropping system with use of cost effective MPR may be preferred by farmers because of harvest of two crops from the same field.

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