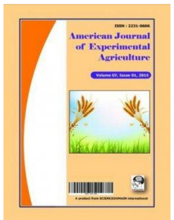

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Response of Maize Planted after Two Legumes to Four Rates of Phosphate Rock

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Authors' contributions

This work was carried out in collaboration between all authors. Author JNO designed the study, wrote the protocol and wrote the first draft of the manuscript. Authors TOF and SOA reviewed all drafts of the manuscript and managed the analyses of the study. Author SAO performed the statistical analysis. All authors read and approved the manuscript.

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ABSTRACT

A field experiment was conducted to study the combined effect of legume growth (in terms of agronomic P use efficiency from Phosphate rock (PR) and sources of nitrogen (N) from legumes and subsequent organic matter additions (green manure incorporation) on the growth and yield of maize. Four rates of PR (0, 40, 50 and 60 kg ha^{-1} P) were applied to two legume types: mucuna (*Mucuna pruriens)* and cowpea (*Vigna unguiculata*) and incorporated before sowing maize in a randomised complete block design replicated three times at the Teaching and Research farm of the Federal University of Agriculture, Abeokuta, Nigeria. Mucuna gave a significantly ($p<0.05$) higher percent N and dry weight (kg ha^{-1}) compared to cowpea. The interaction of cowpea × 40 kg ha^{-1} PR gave a significantly higher value in Agronomic efficiency of applied Phosphorus (AE_P) and Partial factor productivity of Phosphorus (PFP_P), respectively. The increase in the AE_P and PFP_P by cowpea in the interactions could be that cowpea dissolved phosphorus from rock Phosphorus (P)

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better compared to mucuna by the combination of P release into soil solution following the mineralisation of organic P additions via cowpea. The interaction of mucuna × 50 kg ha^{-1} rock P significantly increased fresh cob weight of maize. Sustainable maize production can be achieved with combination of rock phosphate at 50 kg ha^{-1} and mucuna.

Keywords: Legumes; N sources; rock P; maize; yield; P use efficiency.

1. INTRODUCTION

Maize (*Zea mays* L.) requires adequate supply of nutrients, particularly nitrogen, essential for good vegetative growth and grain development. The quantity of nitrogen required depends on the pre-planting vegetation, organic matter content, tillage method and light intensity [1,2]. Its availability in sufficient quantity throughout the growing season is essential for optimum growth of maize. It mediates the utilization of phosphorus, potassium and other elements in plants [3]. The optimal amount of these elements cannot be utilized if nitrogen is deficient, which can result in reduced maize yield. Limited use of nitrogen has resulted in the problem faced in maize production, in spite of the increase in land areas under maize production, yield is still low. Some of the major causes of low yield are declining soil fertility, insufficient use of fertilizers resulting in severe nutrient depletion of soils [4]. Global mobilization of P roughly tripled compared to its natural flow, and global food production is now highly dependent on the continuing use of phosphate [5]. P surpluses and deficits are found in developing countries including a large area of P deficit soils (largely in the tropics) for which addition of P represents the only way to increase agricultural productivity and income.

Phosphorus is another important nutrient required to increase maize yield. Consequently, lack of phosphorus is as important as the lack of nitrogen in limiting maize performance. The availability of phosphorus to plant is highly constrained by inorganic chemical reactions and the release of phosphate exceeds inorganic phosphate (excluding P contained in rocks) in most soils and the turnover of organic P pools prove a large portion of the P taken by plants [6].

Due to the decline in maize production, small holder sub-humid cropping systems of Africa present the need to develop more sustainable production systems [7].

Leguminous crops are generally selected for use as green manure because the major objective of manuring is to increase the nitrogen supply in the soil. The incorporation of legumes as green manure in cropping systems may improve the utilisation of PR and therefore influence the dynamics and availability of P. The most promising agronomic approach in organic cropping systems appears to be the integration of legume green manures into the cropping rotation, which can mobilise P from sparingly soluble PR or fractions that are not available to the following crop [8]. This not only positively affect soil properties and increases nitrogen (N) supply, but also increases P supply to the main crop [9,10]. The portion of green manure nitrogen available to a following crop is usually about 40% to 60% of the total amount contained in the legume. Properly grown green manure may contain 1-2% nitrogen, 0.5-0.75% phosphorus and 3-5% potassium [11]. The breakdown of green manures in soil influences mineral nutrient availability in another way. During decomposition of organic matter, carbonic and other organic acids are formed as a by-product of microbial activity. The organic acids react with insoluble mineral rocks and phosphates releasing phosphates and exchangeable nutrients. The contribution of cowpea to the soil is made available to the soil and subsequent crop planted [12] and the contribution is about 58.97 kg if the crop is turned over. Some cowpea varieties have been discovered to increase phosphorus in the soil; they take up the soil P and make it available to the following crop [13]. Mucunas' primary agronomic importance is soil fertility maintenance, soil protection and weed suppression [14]. It can increase phosphorus availability after application of rock phosphate by transplanting the organic form through the xylem into the shoot [15].

The phosphate content of rock phosphate is at least 20%. Applying P from regionally available phosphate rock (PR) to nitrogen fixing legumes may be an affordable technology to resource-challenged farmers to produce a large amount of N rich biomass and at the same time enriching the soil. Despite studies on legumes and rock P; little information is available on sources of N from green manure and levels of rock P on maize. This study investigated effects of N sources (green manure) and rates of rock phosphate on growth and yield of maize and efficacy of green manure in term of agronomic P use efficiency.

2. MATERIALS AND METHODS

A field experiment was conducted at the Teaching and Research farm of the Federal University of Agriculture, Abeokuta, Nigeria between July to October, 2010. The area lies within the Southern derived Savannah (latitude 7º12'N and longitude 3º23'E) agro-ecological zone of South western Nigeria. The rainfall pattern is bimodal with an average rainfall and temperature of 1166 mm and 21ºC respectively. The amount of rainfall decreased (Table 1) from July (322.9 mm) to October (172.3 mm) while temperature increased from July (25.9ºC) to October (27.3ºC).

A 2 × 4 factorial experiment was laid out in a randomised complete block design replicated three times. The factors were legumes: mucuna (*Mucuna pruriens)* and cowpea (*Vigna unguiculata*) and application rates of rock phosphate (0, 40, 50 and 60 kg ha^{-1}). The land was ploughed and harrowed before marking out into plots. Each plot measured 3 m x 4 m. Composite soil samples were collected using 5 mm soil auger at a depth of 0 – 20 cm for pre-planting soil analysis. The particle size analysis was done by pipette method [16]; soil pH in water was determined using soil: water ratio of 1:2 by a pH meter with a glass electrode. Organic matter was determined using the Walkey & Black method [17]. Total N in the soil was determined by Kjedahl digestion and N determined colourimetrically [18]. Exchangeable bases in the samples were extracted in IM NH_40AC at pH 7.0. Ca and Mg in the extract were read by atomic absorption spectrophotometer (AAS). Na and K were analyzed by using flame photometry. Available phosphorous was determined by Bray-1 extraction and determined colourimetrically by the molybdenum blue procedure [19].

The legumes (mucuna and cowpea) were planted in July 1st, 2010 at a spacing of 50 cm x 50 cm at three seeds per hole. Rock phosphate (0, 40, 50 and 60 kg ha^{-1}) was applied at 4 weeks after planting (WAP) to the legumes. At 6 WAP, data on fresh weight, dry matter and number of nodules per plant were collected on legumes in a net plot size of 4 m^2 before incorporation into the soil and left for one week to decompose. The %N of each plant treatment was analysed. Partial Factor Productivity (PFP_P) and Agronomic Efficiency (AE_P) of phosphorus were estimated using the difference method [20]. The analysis of the rock phosphate showed that the amount of P was 13.78 mg kg^{-1}. Three seeds of widely grown early maturing hybrid maize variety Oba Super 2 was planted in August 13, 2010. The seeds were treated with apron plus before sowing. The spacing was 75 cm x 50 cm, seeds were thinned to two per hole. Weeding was controlled manually at 2 and 5 WAP. Data collected on growth and yield parameters of maize included: plant height (cm), stem girth (cm), leaf number/plant, leaf area (cm^2), cob length (cm), cob girth (cm), number of grains/cob and fresh cob weight (t ha^{-1}). Data collected were subjected to Analysis of Variance (ANOVA) and treatment means compared using Duncan Multiple Range Test (DMRT) at 5% probability level.

3. RESULTS AND DISCUSSION

The physico-chemical properties of the soil are shown in Table 2. The soil is loamy sand, alkaline and very low in organic matter, Total N and CEC. Most of the nutrients in this soil were low and below the critical level [21], making it necessary for the application of soil amendment in the form of legumes and phosphate rock.

Table 3 shows the percent N and average P use efficiency terms for maize in legumes and rock P. The percent N showed significant differences in legume types, rock P and interaction of legumes and rock P. Mucuna gave a significantly higher % N compared to cowpea. This could be attributed to higher number of nodules/plant produced by mucuna relative to cowpea. The level of % N was lowest at 60 kg ha^{-1} rock P. This was significantly different from other levels of rock P. The 50 kg ha^{-1} rock P gave a significantly higher value in % N. The interaction of cowpea × 50 kg ha^{-1} rock P gave a significantly different value in % N compared to other interactions.

The AE_P was significantly different with 60 kg ha^{-1} rock P giving a higher significant value. Cowpea × 40 kg ha^{-1} rock P interaction gave a significantly higher value in AE_P and PFP_P. The increase in AE_P and PFP_P by cowpea could be that cowpea dissolved phosphorus from rock P better than mucuna by the combination of P released into soil solution following the mineralisation of organic P additions via cowpea [13]. The addition of rock P at 40 kg ha^{-1} significantly increased the PFP_P. The PFP_P decreased with increase in the level of rock P. This could be due to high rate of P accumulation present in the soil [22], and the recovery of the applied P during the growth of maize.

Table 1. Meteorological data of the site during the period of the experiment

Month	Rainfall (mm)	Temperature (ºC)	Relative humidity (%)
July	322.9	25.9	87.7
August	266.6	26.1	85.9
September	257.6	26.7	85.9
October	172.3	27.3	81.7
Total	1,019.4	106	

Source: Department of Agro meteorological and Water Management, Federal University of Agriculture, Abeokuta

Table 2. The physico-chemical properties of soil before planting

Soil properties	Amount
pH 1:1 (H_2O)	7.06
Organic C (%)	0.26
Soil organic matter (%)	0.45
Total N (%)	0.03
Available P (mg kg-^{1})	29.77
Exchangeable cations (cmol kg-^{1})	
Ca	1.29
Mg	0.04
Na	1.46
K	0.58
Particle size (%)	
Sand	84.8
Silt	7.6
Clay	7.6
Textural class	Loamy sand

Significant differences were observed between the legumes in fresh and dry weights and number of nodules (Table 4). Mucuna was significantly ($P<0.05$) superior to cowpea in the three parameters. Interactions of mucuna × rock P had higher values in fresh and dry weight (kg ha^{-1}) and were significantly different from interactions of cowpea × rock P.

Table 5 shows the effect of legumes and rock P on growth of maize. Mucuna had higher significant value in number of leaves/plant while in stem girth and leaf area, cowpea had higher significant values different from mucuna. The significantly higher number of leaves/plant produced by maize in mucuna plot could be attributed to the higher percent N and number of nodules/plant. Nitrogen is an essential element for growth in maize and fresh weight (biomass) of mucuna incorporated into soil could have increased nutrients and organic matter for maize growth. The interactions of legume × rock P showed significant differences in all the growth parameters of maize. Cowpea × 60 kg ha^{-1} rock P significantly increased plant height, stem girth and leaf area compared to mucuna × 40 kg ha^{-1} rock P. Mucuna x rock P interactions gave higher number of leaves/plant though this was not significantly different from cowpea × rock P interactions except in mucuna × 0 kg ha^{-1} rock P and cowpea × 40 kg ha^{-1} rock P.

Table 3. Percent N and average P use efficiency terms for maize in legumes and rock P

Treatments	% N	AE_P (kg kg^{-1})	PFP_P (kg kg^{-1})
Legumes			
Mucuna(M)	4.80a	-	-
Cowpea(C)	4.57b	-	-
SE±	0.83		
Rock P (kg ha^{-1})			
0	5.08b	-	-
40	4.60c	-24.75b	480.50a
50	5.22a	-61.80c	342.40b
60	3.85d	13.50a	350.30b
SE±	0.06	16.87	7.33
Legume × Rock P			
M × 0	4.95c	-	-
M × 40	4.24d	8.25e	616.50a
M × 50	5.01c	40.00d	526.60b
M × 60	5.01c	-194.50f	211.00e
C × 0	5.20b	-	-
C × 40	4.97c	227.50a	628.00a
C × 50	5.43a	72.00c	392.40d
C × 60	2.69e	138.17b	405.17c
SE±	0.04	90.65	92.68

Means followed by the same letter in a column are not significantly different (P = 0.05)

Fresh cob weight (t ha^{-1}) of maize was increased by level of rock P at 60 t ha^{-1} (Table 6). Yield parameters such as cob girth, number of grains/cob and fresh cob weight had significant differences in legume × rock P. Mucuna × 50 kg ha^{-1} rock P significantly increased cob girth and fresh cob weight of maize compared to cowpea × 50 kg ha^{-1}. [15] reported that mucuna increased phosphorus availability after application of rock P and phosphorus is an important nutrient required to increase maize yield. The result of lack of phosphorus is as important as the lack of nitrogen in limiting the performance of maize. Mucuna supplied sufficient amount of N with the addition of 50 kg ha^{-1} rock P to increase the yield of fresh cob weight of maize [6].

Table 4. Effects of legumes and rock P on fresh weight, dry weight and number of nodules of legumes

Treatments	Fresh weight (kg ha^{-1})	Dry weight (kg ha^{-1})	Number of nodules/plant
Legumes			
Mucuna(M)	349,800a	81,700a	7.00a
Cowpea(C)	223,325b	22,725b	3.50b
SE±	17.62	4.20	1.43
Rock P (kg ha^{-1})			
0	294,150	50,150	4.33b
40	302,075	50,325	6.00ab
50	277,900	52,200	5.50ab
60	302,075	56,175	5.16ab
SE±	ns	ns	1.01
Legume × Rock P			
M × 0	365,825ab	83,875a	2.00c
M × 40	333,250ab	79,950a	4.00ab
M × 50	314,175b	78,025a	4.33b
M × 60	385,825a	84,950a	3.66bc
C × 0	222,500c	16,425b	6.66a
C × 40	222,500c	20,725b	8.00a
C × 50	230,000c	26,350b	6.66a
C × 60	218,325c	27,425b	6.66a
SE±	8.81	2.10	0.71

Means followed by the same letter in a column are not significantly different (P = 0.05)
ns- not significant

Table 5. Effects of legumes and rock P on growth of maize

Treatments	Plant height (cm)	Stem girth (cm)	Number of leaves/plant	Leaf area (cm^2)
Legumes				
Mucuna(M)	127.50	8.85b	14.03a	625.85b
Cowpea(C)	132.71	9.78a	13.78b	836.93a
SE±	ns	1.19	0.22	141.36
Rock P (kg ha^{-1})				
0	134.77	9.30	13.96	732.27
40	121.17	8.88	13.90	697.50
50	128.00	9.36	13.90	722.33
60	136.50	9.71	13.86	827.17
SE±	ns	ns	ns	ns
Legume × Rock P				
M × 0	139.67ab	9.26b	14.13a	668.07bc
M × 40	117.33b	8.70b	14.00ab	579.33c
M × 50	132.00ab	9.20b	14.00ab	658.67bc
M × 60	121.00ab	8.23b	14.00ab	705.33bc
C × 0	129.87ab	9.33b	13.88ab	796.67ab
C × 40	125.00ab	9.06b	13.73b	815.67ab
C × 50	124.00ab	9.53ab	13.80ab	786.00abc
C × 60	152.00a	11.20a	13.80ab	949.00a
SE±	10.77	0.60	0.11	70.68

Means followed by the same letter in a column are not significantly different (P = 0.05)
ns- not significant

Table 6. Effects of legumes and rock P on yield of maize

Treatments	Cob length (cm)	Cob girth (cm)	Number of grains/cob	Fresh cob weight (t ha^{-1})
Legumes				
Mucuna(M)	15.23	13.12	385.00	23.22
Cowpea(C)	14.83	12.41	336.00	21.09
SE±	ns	ns	ns	ns
Rock P (kg ha^{-1})				
0	15.30	13.00	350.00	20.21ab
40	15.00	12.41	388.00	19.22ab
50	14.00	12.66	346.00	17.12b
60	15.83	13.00	357.00	21.02ab
SE±	ns	ns	ns	0.004
Legume × Rock P				
M × 0	15.93	13.33ab	362.00ab	24.33ab
M × 40	15.33	12.83ab	449.33a	24.66ab
M × 50	14.66	13.66a	375.00ab	26.33a
M × 60	15.00	12.66ab	354.67ab	12.66ab
C × 0	14.66	12.66ab	339.33ab	16.02b
C × 40	14.66	12.00ab	328.33ab	25.12ab
C × 50	13.33	11.66b	317.67b	19.62ab
C × 60	16.66	13.33ab	359.33ab	24.31ab
SE±	ns	0.62	42.61	0.003

Means followed by the same letter in a column are not significantly different (P = 0.05)
ns- not significant

4. CONCLUSION

It is concluded that cowpea dissolved phosphorus from rock P better than mucuna and sustainable maize production in small-holder farms can be achieved with the combination of mucuna and rock P at 50 kg ha^{-1}.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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