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Influence of combined application of P fertilizer and lime on *Mucuna flagellipes* nodulation, growth and yield

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Field studies were carried out in the Teaching and Research farm of Cross River University of Technology, Obubra, Nigeria in 2016 and 2017 cropping seasons to determine the effects of lime and phosphorus on the nodulation of *Mucuna flagellipes.* The experimental design was a 3 × 4 factorial of three lime rates: 0, 1 and 2 t $CaCO_3$/ha and four P rates: 0, 20, 40 and 60 kg P/ha laid out in a randomized complete block design with three replications. Lime at 2 t/ha significantly reduced soil acidity, improved growth and yield of *M. flagllipes*. The highest number of leaves and nodule per plant were obtained at phosphorus rate of 60 kg/ha. The combined used of 2 t/ha lime and 60 kg/ha P resulted in the highest leaf area index, dry matter of plant fractions (leaf, stem and nodule) per plant. A combination of 40 kg/ha and 1.0 t/ha lime produced the highest seed yield (3.768 and 3.567 t/ha) per hectare in 2016 and 2017. Results indicated improvement in soil nutrients after harvest. Farmers can use 2 t/ha lime, 40 kg/ha P or 1 t/ha lime combined with 40 kg/ha P to cultivate *M. flagellipes* an indigenous legume readily available in Nigeria in place of expensive nitrogenous commercial fertilizers for improved biological nitrogen fixation seed yield and sustainable soil fertility management.

Key words: *Mucuna flagellipes*, nodulation, lime, P-fertilizer, nodulation, yield.

INTRODUCTION

*Mucuna flagellipe*s (Vogel ex Hook) belongs to the family Fabaceae and sub-family Papilioniodeae (Asiegbu and Agba, 2008). It is a perennial, lesser known legume, indigenous to Nigeria. The crop has high economic importance in pharmaceutical, cosmetics, domestic and other uses. In pharmaceutical industry, extract from the seed could be used as a binder in the formulation of ephedrine hydrochloric tablet (Eyuiche, 2010). The leaves are used to formulate local hair dye (Okoro, 2007). The seed is rich in protein, fats, carbohydrate and minerals and is widely consumed in soup preparation where it performs the basic function of thickener and condiments (Odedele, 2011). In spite of these economic importances of *M. flagellipes*, the crop is only grown at a sub-subsistence level as a compound crop. There is no report on its nodulation and biological nitrogen fixation ability of the crop.

Nitrogen is a unique element and the most common limiting element for plant growth, biomass production, agricultural productivity and is one of the most expensive

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Table 1. Meteorological data of the study sites during 2016 and 2017 cropping seasons.

Weather parameter	April		May		June		July		August		Sept		October		November		December		Total		Mean	
	2016	2017	2016	2017	2016	2017	2016	2017	2016	2017	2016	2017	2016	2017	2016	2017	2016	2017	2016	2017	2016	2017
Minimum	25.3	24.8	24.2	24.2	23.4	23.3	22.1	22.4	24.3	24.6	23.1	22.5	22.4	22.3	21.1	20.2	19.3	20.2	205.2	227.0	22.82	25.22
Maximum	33.4	33.7	32.3	32.8	30.7	31.4	29.4	30.3	32.2	32.4	30.2	31.3	30.6	30.5	29.1	29.4	28.4	28.4	276.3	280.2	30.71	31.13
Relative humidity (%)	81.5	79.9	83.1	82.5	84.6	85.2	86.2	87.3	78.4	76.7	80.8	81.3	83.2	78.8	75.4	77.4	66.3	70.3	719.5	258.4	79.94	79.9
Rain fall (mm)	203.6	196.4	312.8	275.8	403.5	361.7	502.8	48.8	243.7	275.7	327.4	308.7	215.3	278.5	121.4	102.4	49.8	38.8	2380.3	2325.4	264.47	258.4

Source: Department of Agronomy Metrological Unit. Cross River University of Technology, Obubra, Cross River State, Nigeria.

to purchase as fertilizer (Bejandi et al., 2012). In Nigeria, especially in Cross River State, commercial nitrogen fertilizers are scarce, expensive and most peasant farmers cannot afford it.

However, *M. flagellipes* is an indigenous legume with high potential of nodulation and biological nitrogen fixation for sustainable soil fertility management that can be readily available to a large population of Nigerian poor farmers. Information is presently lacking on the nodulation and biological nitrogen fixation capacity of *M. flagellipes* in Cross River, South-South, Nigeria. Therefore, this study was conducted to determine the appropriate rate of either lime, phosphorus or combined application of lime and phosphorus required for optimum nodulation, biological nitrogen fixation, growth, yield and sustainable improve soil fertility management in South-South, Nigeria.

MATERIALS AND METHODS

Two years field experiments were carried out in the Teaching and Research farm, Department of Agronomy, Cross River University of Technology, Obubra, Cross River State, South-South, Nigeria in 2016 and 2017 cropping seasons to evaluate the influence of combined phosphorus and lime on nodulation, biological nitrogen fixation, growth and yield of *M. flagellipes*. Obubra is located at latitude 05° 59'N and longitude 08° 15" E (Cross River Agricultural Development Project (CRADP), 1992).

Total monthly rainfall in the experimental sites was high all through from May to October and the highest rainfall was observed in the months of July in 2016 and 2017, while December recorded the lowest rainfall (Table 1). The month of April in 2016 and 2017 had the highest atmospheric temperatures and was the lowest in the month of December. Air relative humidity followed the same trend as the rainfall in the two cropping seasons

The site used for the experiment was under two years grass fallow when it was cleared. Seed bed was well prepared by ploughing and harrowing in 5th April, 2016 and 2017. Soil samples were collected with steel auger to a depth of 0 to 20 cm from thirty representative locations before planting (6th April, 2016 and 2017) and after harvesting in 15th December (2016 and 2017) of the *M. flagellipes*. These soil samples collected before planting were bulked together from where a sub-sample was obtained for laboratory analysis to determine the physical and chemical characteristics of the site, using standard laboratory methods. While the soil samples collected after harvesting were not bulked together. They were analyzed separately on per plot or per treatment basis to determine the nutrient status of the experimental field after harvesting.

The soil of the study sites before planting *M. flagellipes* was sandy loam, low in organic matter with low pH but high in aluminium and acidic (Table 2).

The experimental design was a 3 × 4 factorial laid out in a randomized complete block design (RCBD). Treatments comprised three lime rates of 0.0, 1.0, and 2.0 t/ha of $CaCO_3$ and four phosphorus rates of 0, 20, 40 and 60 kg P/ha. There were a total of twelve treatment combinations which were randomly laid out in the field within each of the three blocks. There were three replications with 12 plots in each block. The dimension of each plot measured 4 × 3 m with area of 12 m^2.

Lime was applied into the appropriate plots at two weeks before planting on 7th April, 2016 and 2017 before the final pulverizing of the soil. *M. flagellipes* seeds were soaked in water at room temperature for 24 h before planting at the spacing of 1.0×0.6 m on 26th April, 2016 and 2017 cropping seasons.

Single super phosphate fertilizer carrier of phosphorus was applied to the appropriate plots on 20th June, 2016 and 2017 by ring banding.

Cultural practices

Weeding was done manually by hoeing four times in each year (2016 and 2017) to keep the plots as weed free as possible. Basal dressing with100 kg K/ha muriate of potash was applied to all plots.

Data collection

Data collected on plant height (cm) was determined by measuring the length of the plant from the soil level to the topmost leaf using a measuring tape; number of leaves per plant was determined by taking a visual count of the green leaves.

Leaf area index (LAI)

LAI was estimated from leaf area. Leaf area was measured by random selection of 15 plants from the middle row and

Table 2. Soil physical and chemical properties of the experimental sites before planting and after harvesting of *Mucunaflagellipes* in 2016 and 2017 cropping seasons.

Physical property	Before planting		After harvesting	
	2016	2017	2016	2017
Mechanical property				
Coarse sand (%)	16.4	15.7	16.4	16.5
Fine sand (%)	68.5	66.8	67.7	66.7
Silt (%)	5.5	5.7	5.6	5.8
Clay (%)	18.3	17.8	18.4	17.6
Textural class	Sandy loam	Sandy loam	Sandy loam	Sandy loam
Chemical property				
pH in water	5.01	5.02	5.14	5.16
pH in KCl	4.02	4.03	4.13	4.14
Organic carbon (%)	0.84	0.84	0.92	0.93
Organic matter (%)	1.33	1.34	1.48	1.49
Nitrogen (%)	0.09	0.08	0.11	0.12
Available phosphorus (Cmol/kg)	6.8	6.9	6.9	6.9
Base saturation (%)	99.67	64.4	65.3	65.6
Exchangeable cation (cmol/kg)				
Potassium	0.14	0.14	0.17	0.18
Magnesium	1.8	1.9	2.02	2.14
Calcium	2.9	2.9	3.21	3.23
Sodium	0.09	0.09	0.12	0.12
Exchangeable acidity (Ea; Cmol/kg)				
Aluminium	1.8	1.9	1.71	1.65
Hydrogen	2.4	2.5	1.83`	1.78
Cation exchange capacity (%)	8.56	8.62	8.73	9.73

taken to the laboratory where the leaf area was measured using the leaf area meter (Model-MK-2). From the measured leaf area, leaf area index was determined based on the relationship as stated by Shortal and Liebbardt (2000).

$$LAI = Y \times N \times A_1 \times (A_P)^{-1}$$

where LAI=leaf area index, Y=population of plants per plot, N=Average number of leaves per plant, A1=Average area per leaf, and AP=Area of plot.

The destructively sampled plants were separated into fractions (leaves, stem and nodule) and put in a paper envelopes and oven dried at 80°C to a constant weight for three days for the dried matter determination of leaves, stem and nodules per plant in both 2016 and 2017 seasons, respectively.

Crop growth rate analysis

Analysis of nodules growth rate was evaluated at three stages of 75 days after planting (DAP), 90 DAP and 164 DAP for the two seasons through destructive sampling of one plant per plot using the growth analysis techniques described by Shortal and Liebbardt (2000):

Crop Growth Rate (CGR) = $W_2 - W_1 / SA (t_2 - t_1)$ g/m^2/day where W_1 and W_2 = dry weight of nodule at beginning and end of the interval of growth period. t_1 and t_2 = sampling time 1 and 2, SA = the area occupied by the plant at sampling.

Data were taken on such observations as pests and disease incidents and on weather.

Harvesting

Harvesting was done on December 10th, 2016 and 2017. Yield data were collected at harvest. Each plant was harvested separately. Number of pods and seeds per plant was obtained by visual counting of pods and seeds per plant, seeds yield per plant and per hectare were recorded using electronic weighing balance.

Statistical analysis

All data collected were statistically analyzed using the analysis of variance (ANOVA) procedure for factorial experiment in randomized complete block design as out lined by Gomez and Gomez (1984). Separation of treatment means for statistical significant difference was done using Fishers least significance difference (F-LSD) at 5% probability level as described by Obi (2002).

Table 3. Effects of lime on the soil pH at 4, 8 and 12 weeks after lime application in 2016 and 2017 cropping seasons.

Lime treatment (t $CaCO_{3//}$ha)	Weeks after application (WAA)					
	4 WAA		8 WAA		12 WAA	
	pH in water	pH in KCl	pH in water	pH in KCl	pH in water	pH in KCl
2016 Cropping Season						
0	5.01	4.01	5.19	4.18	5.04	4.05
1	5.09	4.06	5.20	4.21	5.93	5.72
2	5.12	4.08	5..42	4.32	6.45	5.91
Mean	5.07	4.05	5.27	4.24	5.81	5.22
LSD(0.05)	0.002	0.001	0.002	0.001	0.002	0.001
2017 Cropping Season						
0	5.03	4.02	5.19	4.18	5.05	4.06
1	5.08	4.07	5.52	4.21	5.65	5.67
2	5.14	4.09	5..83	4.32	6.38	5.74
Mean	5.08	4.06	5.51	4.24	5..69	5.16
LSD(0.05)	0.002	0.001	0.002	0.001	0.003	0.002

WAA: Weeks After Lime Application.

Table 4. Effect of Lime and phosphorus application on the dry weight (g) of the seed remains of the germinated *Mucuna* flagellipes seed with progress in seedlings growth.

Phosphorus (kg/ha)	Lime treatment (t $CaCO_3$/ha)							
	0.0	1.0	2.0	Means	0.0	1.0	2.0	Means
	2016 Cropping Season				2017 Cropping Season			
At 45 Days After planting								
0	0.82	0.69	0.39	0.63	0.81	0.67	0.41	0.63
20	0.63	0.74	0.45	0.69	0.62	0.71	0.43	0.57
40	0.71	0.99	0.42	0.79	0.76	0.95	0.87	0.65
60	0.90	0.72	0.55	0.72	0.84	0.78	0.74	0.79
Mean	0.77	0.78	0.49	0.71	0.76	0.78	0,61	0.66
NS	NS	NS	NS	NS	NS	NS	NS	NS
At 60 Days After planting								
0	0.43	0.52	0.54	0.50	0.40	0.57	0.37	0.45
20	0.51	0.55	0.45	0.50	0.53	0.51	0.42	0.47
40	0.42	0.50	0.42	0.45	0.44	0.53	0.41	0.46
60	0.59	0.44	0.55	0.53	0.40	0.47	0.34	0.40
Means	0.49	0.50	0.49	0.49	0.44	0.52	0.39	0.45
NS	NS	NS	NS	NS	NS	NS	NS	NS

NS: Non significant at 5% probability level.

RESULTS

Liming significantly increased soil pH at each increment of lime rate (Table 3). The increase in soil pH per unit of lime indicated that liming effects was the highest with 2.0 t/ha at 8 and 12 weeks after application. Application of phosphorus did not at any time influence the soil pH significantly. There were significant interaction effects of applying 20 kg/ha of phosphorus and liming at 2 t/ha on soil pH after 8 weeks of measuring the pH in water and at both 4 and 8 weeks after liming.

In the present study, it was observed that *M. flgellipes* seed did not decay immediately after germination as shown in Table 4.

Result of destructive sampling of *M. flgellipes* at the early stage of growth (40-60 DAP) showed that the

Table 5. Effect of phosphorus and lime application on plant height (Main vine length cm), number of leaves, leaf area index (LAI) leaf dry weight (g) per plant at 50% flowering of *Mucuna flagellipes* in 2016 and 2017 cropping seasons.

Phosphorus (kg/ha)	Lime Treatments (t $CaCO_3$/ha)							
	0.0	1.0	2.0	Means	0.0	1.0	2.0	Means
	2016 Cropping Season				2017 Cropping Season			
Number of leaves per plant								
0	32.11	41.23	48.34	40.56	30.23	39.14	45.22	38.20
20	37.42	57.76	61.23	52.13	35.31	47.23	60.33	40.63
40	46.13	68.42	70.16	61.57	44.14	65.31	71.24	60.23
60	51.22	75.31	85.23	70.58	49.32	74.22	82.13	68.56
Means	41.72	60.54	65.25	56.21	39.75	56.47	63.73	51.90
LSD(0.05) Lime	1.11	-	-	-	1.21	-	-	-
LSD(0.05) P	2.22	-	-	-	2.51	-	-	-
LSD(0.05) Lime × p	4.02	-	-	-	3.63	-	-	-
Leaf Area Index (LAI)								
0	1.0131	1.1231	1.3105	1.1489	1.0142	1.1251	1.4102	1.1832
20	1.3121	2.2351	2.8321	2.1264	1.2453	2.3014	2.6124	1.7197
40	1.6213	3.7516	3.8974	3.0901	1.5714	3.5121	4.2058	3.0964
60	2.0343	4.8597	5.9685	4.2875	2.0765	4.5133	5.8987	4.1628
Means	1.4952	2.5101	3.501	2.6632	1.4769	2.8630	3.5318	2.5405
LSD(0.05) Lime	0.01	-	-	-	0.01	-	-	-
LSD(0.05) P	0.02	-	-	-	0.02	-	-	-
LSD(0.05) Lime × p	0.03	-	-	-	0.03	-	-	-
Leaf dry weight per plant (g)								
0	27.54	35.37	39.65	34.19	25.76	35.43	41.32	34.17
20	39.78	54.86	78.49	48.83	36.82	60.59	82.15	59.85
40	57.94	136.45	164.37	119.59	53.65	141.33	158.77	117.92
60	63.46	203.28	275.32	180.69	59.89	217.42	269.66	182.32
Means	47.18	107.47	139.45	98.82	44.03	11.37	137.98	64.46
LSD(0.05) Lime	3.12	-	-	-	3.01	-	-	-
LSD(0.05) P	5.23	-	-	-	4.52	-	-	-
LSD(0.05) Lime × p	7.35	-	-	-	6.23	-	-	-
Plant Height (Main Vine length cm)								
0	112.85	136.64	153.41	-	109.76	128.36	161.25	-
20	162.36	227.75	244.63	-	159.56	205.68	237.46	-
40	175.54	314.45	324.37	-	158.84	234.89	312.58	-
60	183.19	343.56	378.59	-	179.54	329.26	363.29	-
Means	-	-	-	-	-	-	-	-
LSD(0.05) Lime	5.12	-	-	-	4.31	-	-	-
LSD(0.05) P	8.24	-	-	-	7.12	-	-	-
LSD(0.05) Lime × p	11.33	-	-	-	10.23	-	-	-

remains of the germinated seedling delayed to decay. It took up to 60 days before it finally decay completely (Table 4). During the same period, the application of lime and phosphorus did not have significant effects on the weight of the remains of germinated *M. flgellipes* seed.

The application of lime or phosphorus significantly increased the numbers of leaves produced in *M. flagellipes* (Table 5). Number of leaves per plant increased significantly with increment of either phosphorus or liming rate with 60 kg/ha and 2.0 t/ha of lime recording the highest number of leaves per plant. In both 2016 and 2017 cropping seasons, the effects of lime and phosphorus on leaf area index (LAI) and leaf dry matter weight per plant closely follow the same

Table 6. Effect of lime and phosphorus application on number of nodules per plant in *Mucuna flagellipes* in 2016 and 2017 cropping seasons.

Phosphorus (kg/ha)	Lime Treatments (t $CaCO_3$/ha)							
	0.0	1.0	2.0	Means	0.0	1.0	2.0	Means
	2016 Cropping Season				2017 Cropping Season			
At 45 Days After planting								
0	-	-	-	-	-	-	-	-
20	-	-	-	-	-	-	-	-
40	-	-	-	-	-	-	-	-
60	-++	-	-	-	-	-	-	-
Means	-	-	-	-	-	-	-	-
At 75 Days After planting								
0	2.7	2.4	3.0	3.2	1.1	2.3	1.3	1.2
20	27	4.3	4.7	3.5	2.3	3.4	4.2	1.8
40	3.3	4.3	4.0	3.6	2.4	4.3	4.4	1.9
60	3.0	4.3	4.0	3.7	2.4	4.4	4.4	2.1
Means	2.9	3.8	3.9	3.5	2.1	3.1	3.3	1.7
LSD(0.05) Lime	0.01	-	-	-	0.01	-	-	-
LSD(0.05) P	0.01	-	-	-	0.01	-	-	-
LSD(0.05) Lime × p	0.02	-	-	-	0.02	-	-	-
At 90 Days After planting								
0	3.1	3.4	3.5	3.3	3.1	4.2	4.3	3.8
20	4.2	6.7	6.3	5.7	4.2	5.1	6.2	5.2
40	5.3	7.3	8.3	7.0	5.3	7.2	8.3	6.9
60	6.2	8.7	8.3	7.7	6.4	8.2	8.5	7.7
Means	4.4	6.2	7.2	5.3	4.5	5.5	6.3	5.9
LSD(0.05) Lime	0.1	-	-	-	0.1	-	-	-
LSD(0.05) P	0.2	-	-	-	0.2	-	-	-
LSD(0.05) Lime × p	0.3	-	-	-	0.3	-	-	-
At 164 Days After planting								
0	5.0	13.3	15.0	11.1	5.1	10.2	13.1	9.5
20	23.0	26.7	33.0	27.3	16.1	19.0	24.3	19.8
40	28.0	29.3	35.7	34.3	20.3	23.3	28.2	23.9
60	29.3	32.7	45.0	34.3	24.0	29.4	32.3	28.6
Means	21.3	25.2	32.2	26.3	16.4	20.2	24.5	20.4
LSD(0.05) Lime	0.2	-	-	-	0.2	-	-	-
LSD(0.05) P	0.4	-	-	-	0.3	-	-	-
LSD(0.05) Lime × p	0.6	-	-	-	0.4	-	-	-

++ = No Nodules formed at 45 and 60 Days after planting. NS= Non significant at 5% probability level.

trend as the number of leaves per plant with plots treated with a combination of 2 t/ha lime and 60 kg/ha phosphorus producing the highest LAI value of 5.9658 and 5.8948 leaf dry weight of 275.32 and 269.42 g per plant in 2016 and 2017 seasons, respectively.

There were no nodules formed early in the life of *M. flagellipes* seedlings up to 60 DAP (Table 6). Nodulation began at 75 DAP when phosphorus at 60 kg/ha and all cases of liming with 2 t/ha produced significantly more numbers of nodules per plant than the 1.0 t/ha of lime. There was profuse nodulation at 164 DAP, nodule number increased with incremental application of phosphorus at the rate of 60 kg P/ha. Similarly, nodule number per plant increase significantly with incremental lime treatment. A combination of 40 to 60 kg P/ha with lime at 2.0 t/ha gave the highest nodule numbers per plant in both crops seasons.

The effects of phosphorus and lime on nodule dry

Table 7. Effect of lime and phosphorus application on nodule dry matter yield per plant (g) in *Mucuna flagellipes* in the 2016 and 2017 cropping seasons.

Phosphorus (kg/ha)	Lime Treatments (t $CaCO_3$/ha)							
	0.0	1.0	2.0	Means	0.0	1.0	2.0	Means
	2016 Cropping Season				2017 Cropping Season			
At 75 Days after planting								
0	0.01	0.02	0.02	0.01	0.01	0.01	0.01	0.01
20	0.01	0.02	0.01	0.01	0.01	0.02	0.02	0.02
40	0.02	0.02	0.02	0.02	0.01	0.02	0.02	0.02
60	0.01	0.03	0.04	0.03	0.01	0.02	0.03	0.02
Means	0.01	0.02	0.02	0.02	0.01	0.02	0.02	0.02
LSD(0.05) Lime	NS	-	-	-	NS	-	-	-
LSD(0.05) P	NS	-	-	-	NS	-	-	-
LSD(0.05) Lime × p	NS	-	-	-	NS	-	-	-
At 90 Days after planting								
0	0.40	0.53	0.61	0.51	0.31	0.42	0.54	0.42
20	0.51	0.61	0.71	0.61	0.42	0.47	0.62	0.50
40	0.60	0.63	0.78	0.67	0.48	0.50	0.69	0.56
60	0.67	0.65	0.68	0.68	0.51	0.56	0.71	0.59
Means	0.55	0.61	0.70	0.61	0.43	0.49	0.64	0.52
LSD(0.05) Lime	0.01	-	-	-	0.01	-	-	-
LSD(0.05) P	0.02	-	-	-	0.02	-	-	-
LSD(0.05) Lime × p	0.03	-	-	-	0.03	-	-	-
At 165Days after planting								
0	1.80	2.27	2.61	2.02	1.14	1.46	2.08	1.68
20	3.12	3.33	4.40	3.61	2.32	2.89	3.17	2.20
40	4.75	6.48	10.33	7.19	3.16	5.96	9.98	6.37
60	5.37	6.67	12.09	8.04	3.85	6.48	11.79	7.37
Means	3.60	4.64	7.36	5.22	2.62	4.20	6.76	4.41
LSD(0.05) Lime	0.4	-	-	-	0.3	-	-	-
LSD(0.05) P	0.3	-	-	-	0.4	-	-	-
LSD(0.05) Lime × p	0.6	-	-	-	0.6	-	-	-

NS= Non significant at 5% probability level.

weight followed similar trends as the nodule number (Table 7). Nodules dry weight per plant were the highest at the same combination rates of phosphorus and lime obtained above for nodule number per plant during the two seasons.

Phosphorus application always increased the nodule growth rate dry weight as compare with where no phosphorus was applied (Table 8.).

The nodule growth rate was more than doubled between 90 and 164 DAP compared with nodule growth rate recorded early in the life of the crop at 75 to 90 DAP in the two cropping seasons. All cases of combined application of lime and phosphorus gave a greater nodule dry weight production rate compared with where either lime or phosphorus alone was applied. The highest nodule dry weight growth rate of 0.998 g/m^2/day in 2016 and 0.895 g/m^2/day in 2017 was recorded with combine application of phosphorus at 40 kg P/ha and lime at 2.0 t/ha between.

Harvest and yield results

The results further indicated that phosphorus fertilizer significantly enhanced *M. flagellipes* yield in the two cropping seasons (Table 9). The use of either phosphorus or lime produced more vigorous plants having significantly more number of pods, seeds and weight than where phosphorus or lime was not applied. The seed yield per plant increased significantly with each progressive increase in phosphorus rate and reached a threshold at 40 kg/ha, beyond which there was a

Table 8. Effect of phosphorus and lime application on nodule growth rate (g/m^2/day) in *Mucuna flagellipes* in the 2016 main crop and 2017 cropping seasons.

Phosphorus (kg/ha)	Lime Treatments (t $CaCO_3$/ha)							
	0.0	1.0	2.0	Means	0.0	1.0	2.0	Means
	2016 Cropping Season				2017 Cropping Season			
At 75-90 Days After planting								
0	0.003	0.04	0.004	0.004	0.002	0.003	0.004	0.003
20	0.006	0.006	0.007	0.006	0.004	0.005	0.006	0.005
40	0.007	0.007	0.008	0.007	0.006	0.007	0.008	0.007
60	0.007	0.008	0.008	0.008	0.007	0.008	0.008	0.008
Means	0.006	0.006	0.007	0.008	0.005	0.006	0.007	0.006
LSD(0.05) Lime	0.001	-	-	-	0.001	-	-	-
LSD(0.05) P	0.001	-	-	-	0.001	-	-	-
LSD(0.05) Lime × p	0’002	-	-	-	0.002	-	-	-
At 90- 164 Days After planting								
0	0.312	0.453	0.476	0.414	0.234	0.336	0.454	0.343
20	0.651	0.768	0.774	0.731	0.316	0.467	0.575	0.453
40	0.785	0.867	0.998	0.879	0.137	0.549	0.895	0.541
60	0.793	0.932	0.743	0.908	0.558	0.598	0.759	0.638
Means	0.635	0.75*5	0.808	0.733	0.389	0.488	0.606	0.494
LSD(0.05) Lime	0.01	-	-	-	0.01	-	-	-
LSD(0.05) P	0.02	-	-	-	0.02	-	-	-
LSD(0.05) Lime × p	0.03	-	-	-	0.03	-	-	-

significant decline in seed per plant. There were evidence, a significant interaction, where a combined application of 2.0 t/ha lime and 40 kg/ha phosphorus produced higher pod and seed yield per plant and per hectare to other rates of lime and phosphorus combinations or where either lime or phosphorus were applied alone (Table 9). Thus, the highest *M. flagellipes* seed yield of 3.768 and 3.567 t/ha.

Results of the soil analysis after harvesting of *M. flagellipes* showed that the application of lime always resulted in higher accumulation of organic matter, nitrogen, phosphorus, calcium and magnesium in the soil of the treated plots than the plots not treated with lime (Table 10). Similarly, successive increase in phosphorus application resulted in progressive increased in soil phosphorus, organic matter, nitrogen and potassium accumulation. The combined application of lime at 2.0 t/ha with phosphorus at 40 P kg/ha always gave the highest calcium and phosphorus as compared with where either lime or phosphorus was applied alone.

DISCUSSION

Lime application increased soil pH and reduced soil exchangeable acidity after harvesting as compared to before planting and where lime was not applied. The increase in soil pH under lime treatment was due to addition of $CaCO_3$ which reacts with water leading to production of OH^- ions which forms $Al(OH)_3$ and H_2O thus raising the soil pH and decreasing exchangeable acidity. Elsewhere, studies conducted by Benvindo (2014) and Nekesa et al. (2011) indicated that lime application lead to increased soil pH and decreased soil exchangeable acidity.

M. flagellipes growth and yield characteristics in 2016 and 2017 were significantly better with the use of phosphorus and lime than the control where phosphorus and lime were not applied. There were no significant differences in the effects of the seasons on the performance of all the growth and yield attributes determined in the study. The lack of performance differences in all the growth and yield attributes determined in the two growing seasons may likely be due to the fact that the same rates of lime and phosphorus as well as similar field experiment conditions were used in both 2016 and 2017.

The observed significant performance in growth and yield attributes with lime and phosphorus treatment was due to the effects of liming that reduced the soil acidity increased availability of phosphorus and other essential nutrients required by *M. flagellipes.* This facilitates nodulation by *M. flagellipes* that benefited from rhizobium biological nitrogen fixation produced. This increased availability of nitrogen that promoted profuse number of leaves per plant and plant height. Nitrogen which is the

Table 9. Effect of phosphorus and lime application on number of pods seed and yield perplant and per hectare of *Mucuna flagellipes* in 2016 and 2017 cropping seasons.

Phosphorus (kg/ha)	Lime Treatments (t $CaCO_3$/ha)							
	0.0	1.0	2.0	Means	0.0	1.0	2.0	Means
	2016 Cropping Season				2017 Cropping Season			
Number of pods per plant								
0	14.12	16.11	18.31	-	13.23	15.12	19.31	-
20	17.23	20.34	33.22	-	18.34	23.21	33.13	-
40	19.32	31.23	51.41	-	22.11	34.32	60.24	-
60	21.14	42.14	47.31	-	23.23	47.14	49.32	-
Means	-	-	-	-	-	-	-	-
LSD(0.05) Lime	1.11	-	-	-	1.21	-	-	-
LSD(0.05) P	2.22	-	-	-	2.51	-	-	-
LSD(0.05) Lime × p	4.02	-	-	-	3.63	-	-	-
Seed weight per plant (g)								
0	36.73	41.63	52.36	43.57	34.38	44.27	50.15	-
20	42.45	59.43	63.40	53.09	44.74	62.56	68.73	-
40	56.39	226.54	108.17	130.37	62.16	238.84	113.34	-
60	65.52	87.59	78.38	77.16	68.43	79.73	80.82	-
Means	50.27	-	-	-	-	-	-	-
LSD(0.05) Lime	-	-	-	-	-	-	-	-
LSD(0.05) P	-	-	-	-	-	-	-	-
LSD(0.05) Lime × p	-	-	-	-	-	-	-	-
Seed per hectare (t/ha)								
0	0.231	0.245	0.268	0.248	0.226	0.251	0.274	0.250
20	0.523	0.896	1.324	0.981	0.573	0.914	1.383	0.9567
40	0.823	3.768	2.675	2.4187	0.716	3.567	2.291	2.1913
60	0.635	1.021	1.567	1.116	0.742	1.542	1.013	1.0990
Means	0.553	1.2273	1.0668	-	0.5643	1.5641	1.2402	-
LSD(0.05) Lime	-	-	-	-	-	-	-	-
LSD(0.05) P	-	-	-	-	-	-	-	-
LSD(0.05) Lime × p	-	-	-	-	-	-	-	-
Seed yield per hectare (t/ha)								
0	-	-	-	-	-	-	-	-
20	-	-	-	-	-	-	-	-
40	-	-	-	-	-	-	-	-
60	-	-	-	-	-	-	-	-
Means	-	-	-	-	-	-	-	-
LSD(0.05) Lime	5.12	-	-	-	4.31	-	-	-
LSD(0.05) P	8.24	-	-	-	7.12	-	-	-
LSD(0.05) Lime × p	11.33	-	-	-	10.23	-	-	-

major product of biological nitrogen fixation is associated with high photosynthetic activities, vigorous vegetative growth (leaf number, LAI and plant height) (Mesfin et al., 2014).

The greater dry matter of plant fraction (stem leaf and nodules) occurred in *M. flagellipes* with higher phosphorus fertilizer rate up to the 60 kg/ha. The applied phosphorus provided the needed nutrient and enhanced photosynthetic activities that result to the production of more dry matter in *Mucuna flagellipes* plant fractions. These findings corroborated with the report of Bekere et al. (2012) that observed significant increases in dry matter accumulation in leaves and stem of *(Glycine max*) with progressive increase in phosphorus rates.

Table 10. Effect of phosphorus and lime application on soil organic matter, nitrogen, phosphorus, calcium and potassium after harvest of *Mucuna flagellipes.*

Phosphorus (kg/ha)	Lime Treatments (t $CaCO_3$/ha)							
	0.0	1.0	2.0	Means	0.0	1.0	2.0	Means
	2016 Cropping Season				2017 Cropping Season			
Organic Matter (%)								
0	1.56	1.74	1.86	1.75	1.47	1.73	1.85	1.68
20	1.68	1.87	1.93	1.91	1.65	1.88	1.91	1.81
40	1.83	1.97	2.01	1.98	1.80	1.95	2.04	1.93
60	1.92	2.06	2.13	1.88	1.94	2.07	2.15	2.05
Means	1.72	1.83	1.94	1.83	1.72	1.91	1.99	1.87
LSD(0.05) Lime	0.002	-	-	-	0.002	-	-	-
LSD(0.05) P	0.001	-	-	-	0.001	-	-	-
LSD(0.05) Lime × p	0.003	-	-	-	0.003	-	-	-
Total Nitrogen (%)								
0	0.01	0.03	0.06	0.03	0.01	0.03	0.05	0.03
20	0.03	0.05	0.07	0.05	0.03	0.04	0.06	0.04
40	0.08	0.12	0.56	0.05	0.07	0.15	0.57	0.26
60	0.09	1.02	1.02	1.05	0.08	1.03	1.05	0.72
Means	0.05	0.31	0.44	0.35	0.05	0.06	0.18	0.27
LSD(0.05) Lime	0.02	-	-	-	0.02	-	-	-
LSD(0.05) P	0.01	-	-	-	0.01	-	-	-
LSD(0.05) Lime × p	0.03	-	-	-	0.03	-	-	-
Total Phosphorus (ppm)								
0	7.1	7.6	7.8	7.5	6.8	7.4	7.6	7.27
20	8.4	8.9	9.1	8.8	8.2	8.7	9.4	8.76
40	8.6	9.2	9.5	10.1	8.7	9.4	9.7	9.27
60	8,9	10.1	11.2	10.1	8.9	10.2	11.5	10.2
Means	8.3	9.2	9.4	9.1	8.15	8.93	7.13	8.86
LSD(0.05) Lime	0.002	-	-	-	0.002	-	-	-
LSD(0.05) P	0.001	-	-	-	0.001	-	-	-
LSD(0.05) Lime × p	0.003	-	-	-	0.003	-	-	-
Potassium(meg g/100 g soil)								
0	0.14	0.15	0.17	0.15	0.12	0.16	0.18	0.15
20	0.16	0.18	0.19	0.18	0.15	0.17	0.19	0.17
40	0.17	0.21	0.23	0.20	0.16	0.22	0.24	0.21
60	0.18	0.25	0.30	0.24	0.19	0.24	0.33	0.25
Means	0.16	0.20	0.22	0.19	0.16	0.20	0.24	0.20
LSD(0.05) Lime	0.001	-	-	-	-	-	-	-
LSD(0.05) P	0.002	-	-	-	-	-	-	-
LSD(0.05) Lime × p	0.003	-	-	-	-	-	-	-
Calcium (Meg/100 g soil)								
0	1.00	1.53	1.96	1.50	0.98	1.39	1.95	0.96
20	1.04	1.73	2.50	1.70	1.06	1.75	2.41	1.74
40	1.07	1.84	2.75	1.94	1.08	1.87	2.62	1.87
60	1.09	1.98	2.75	1.94	1.11	2.11	2.58	1.93
Means	1.30	1.77	1.39	1.74	1.41	1.78	2.39	1.63
LSD(0.05) Lime	0.002	-	-	-	0.002	-	-	-
LSD(0.05) P	0.001	-	-	-	0.001	-	-	-

Table 10. Contd.

LSD(0.05) Lime × p	0.003	-	-	-	0.003	-	-	-
Magnesium (Meg/100 g soil)								
0	0.82	0.86	0.89	0.86	0.79	0.84	0.86	0.83
20	0.84	0.89	0.92	0.88	0.83	0.87	0.91	0.87
40	0.87	0.94	0.95	0.98	0.84	0.92	0.93	0.20
60	0.89	0.96	0.98	0.94	0.87	0.97	0.99	0.94
Means	0.86	0.91	0.95	0.90	0.84	0.90	0.92-	0.89
LSD(0.05) Lime	0.002	-	-	-	0.002	-	-	-
LSD(0.05) P	0.001	-	-	-	0.001	-	-	-
LSD(0.05) Lime × p	0.003	-	-	-	0.003	-	-	-

The observed delay in nodulation by *M. flagellipes* that took up to 75 days after planting before the formation of nodules could probably be due to the large size of the seed cotyledons (Agba 2001). The *M. flagellipes* seedlings could have depended on the food reserves deposited in the large cotyledons (with dry weight 0.45-0.55 g) at 60 days after planting as one of its major sources of nutrient at the early stage of growth and development. Asiegbu (2008) also reported delayed in nodule formation in *M. flagellipes* for up to 75 days after planting and attributed the delay to large size of seed cotyledon of *M. flagellipes* that took long time of up to 60 days before it completely decayed.

The greater nodule dry weight and growth rate obtained in phosphorus treated than the untreated *M. flagellipes* plots could be related to the increased valaibility of soil phosphorus that promoted profuse production of nodules that facilitate symbiotic rhizobia activities that resulted in higher nitrogen fixation. Moreover, this also suggested that indigenous rhizobium BNF activities were highly favoured due to phosphorus application. This agrees with the previous findings by Bereke and Hailemanam (2012); Bekere et al., (2013) that application of phosphorus in most leguminous crops is associated positively with nodulation and biological nitrogen fixation which result to increase in nodule dry weight and yield in soybean (*Glysine max* L). Increased nodule dry weight with phosphorus application has been reported by Abdula (2013) in Chickpea (*Cicer arietinum* L).

Biomass (leaf, stem and nodule dry weight) and yield components (number of pods and seed) per plant were also high in phosphorus and lime treated plots in the two cropping seasons. Phosphorus at 40 kg/ha gave higher pod and seed yield per hectare.

Result further indicated that the combined used of 1.0 t/ha of lime and 40 kg/ha phosphorus seemed most satisfactory in obtaining the highest seed yield of *M. flagellipes* of 3.768 and 3.367 tons/ha in both 2016 and 2017 cropping seasons. The observed high seed yield per hectare associated with high number of pods, dry weight of nodules leaves and stem show that plants which produced more vigorous nodules tend to have higher plant growth which results in increased yield components and seed yield. This may also indicate the positive effects of lime and phosphorus growth, nodulation biological nitrogen fixation and yield of *M. flagellipes.*

These findings were in accordance with those of Mesfin (2014) who found that a combined application of lime and phosphorus produced higher seed yield than where either lime or phosphorus was applied alone in Haricot Bean.

The pronounced increased in accumulation organic matter, nitrogen, phosphorus, potassium, calcium and magnesium in the soil after harvesting *M. flagellipes* noted in the present study indicated that the symbiosis of *M. flagellipes* with soil indigenous rhizobium was effective. Furthermore, the application of lime and phosphorus as expected to enhance conducive conditions for soil flora and fauna especially nodulation, rhizobium activities, and BNF resulted in beneficial effects. Thus, increasing the soil nutrients and promoted *M. flagellipes* growth, nodulation BNF, yield and added more sustainable fertility to cultivated soil as revealed by this study.

Conclusion

Based on the result of this study, *M. flagellipes* has high potential for nodulation, biological nitrogen fixation to improve sustainable soil fertility status. Therefore, the crop should be incorporated into the regular farming system by cultivating it with the application of either only lime at 1.0 to 2.0 $CaCO_3$/ha or phosphorus at 40 or 60 kg/ha or with a combine application of 1.0 t/ha of lime and 40 kg/ha of phosphorus for optimum nodulation, biological nitrogen fixation, improve sustainable soil fertility status and seed yield. This technique could thus be used as a cheap source of cultivating *M. flgellipes* using low rates of phosphorus and lime by poor rural smallholder farmers who cannot afford expensive large

quantities of mineral fertilizers for sustainable soil fertility and increase plant yield. To better understand the nodulation, biological nitrogen fixation of *M. flgellipes* as influence by combined lime and phosphorus, further studies should be carried out on effects of rhizobium inoculation, phosphorus and lime application on biological nitrogen fixation, growth and yield of *M. flgellipes* in both greenhouse and field condition.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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