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Lime-Manure Agronomic Effects in Droughty Low-Fertility Tropical Soils Largely Reflect P-Bioavailability Changes

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Abstract

Increasing bioavailable forms of phosphorus (P) in acid tropical soils could promote their productivity. Liming and manuring ameliorate soil acidity and enhance P mineralization and hence bioavailability. The study evaluated the effects of synthetic lime (0, 2.5 and 5 t ha^{-1}) and poultry-droppings manure (0, 25 and 50 t ha^{-1}) in acid sandy-loam Ultisols on soybean growth, and explored the relationships among its growth indices, plant P content, soil available P and soil pH. The experiment was executed under glasshouse conditions with crop growth data collected weekly during 2-6 weeks after sowing, while plant P content, soil available P and soil pH were determined at the end of the six-week growth phase. Treatment had more pronounced effects on soybean plant height than leaf area and number of leaves, with the highest values generally in 2.5 t ha^{-1} lime plus 50 t ha^{-1} manure. Soybean plants were about three times taller in this treatment than the control. Main effects showed tendency for better growth in potted soils limed at 2.5 t ha^{-1} over 0 and 5 t ha^{-1}, and consistently highest values in those manured at 50 t ha^{-1} compared to 0 and 25 t ha^{-1}. Plant height and leaf area depended on soil available P ($R^2 = 0.76^{**}$) and plant P ($R^2 = 0.88^{**}$) contents, respectively, both of which depended on soil pH ($r = 0.80^{*}$ and 0.74^{*}, respectively). Moderate liming (2.5 t ha^{-1}) and ample manuring (50 t ha^{-1}) could enhance soybean early-stage morphological growth in readily leached, low-fertility tropical soils. These increases are largely a reflection of acidity-ameliorating effect of such soil amendments on P-bioavailability and hence uptake.

Key words : Acid tropical soils, synthetic lime, nutrient-rich manure, soil available P, plant nutrition.

Highly weathered tropical soils are known to be naturally acidic and of low fertility status (Caires *et al*., 2008; Fageria *et al*., 2011; Ubi *et al*., 2017). These acidic soils with high levels of rainfall over years are leached of basic ions (Ubi *et al*., 2017). Heavy rainfall is one major cause of basic cations removal over a long period of time through leaching. Leaching increases acidity as leached soils are left with toxic and insoluble compounds of iron (Fe) and aluminium (Al) in soil (Zhang *et al*., 2016). Acidic soils have high amount of Fe and Al oxides with high specific surface area (Achat *et al*., 2010). These oxides have high appetite for phosphate which can sometimes become almost insatiable (Bueis *et al*., 2019). Oxides of Fe and Al are the main sorbents of phosphate responsible for phosphorus (P) sorption in acidic soils and thus its bio-unavailability in these soils (Turrión *et al*.; Achat *et al*., 2010; Bueis *et al*., 2019). Poor availability of P is a major limiting constraint for crop production in acidic soils (Wang *et al*., 2010).

Tropical soils are also of low fertility with low soil organic matter (SOM) content due to high mineralization rate. The SOM influences the physical, chemical, and biological characteristics of the soil (Adiaha, 2017; Sandirakirana and Arifin, 2021). Low SOM content implies a decrease in the ability of soil to hold and make

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available nutrients essential for plant growth (Ejesa, 2021). Decomposition process of SOM releases inorganic P, a form accessible by plants (Gichangi, 2019). Soil content of SOM influences the activities of soil microbes that are responsible transformation of organic P into inorganic P (Allison and Vitousek, 2005; Bueis *et al*., 2019). The SOM is a major constituent of soil sorption complex which is responsible for the binding of ions in the soil and thus plays a critical role in P sorption (Debicka *et al*., 2016). The SOM can complex Fe and Al ions responsible for P precipitation as insoluble Fe and Al phosphates, reducing P retention in soils (Haynes and Mokolobate, 2001). Organic acids originating from organic matter decomposition enhance the solubility of calcium phosphates, and these organic molecules are adsorbed by Fe and Al oxides, blocking P sorption sites (Bueis *et al*., 2019). Also, SOM increases the ability of soil to resist the natural tendency of becoming acidic (Ejersa, 2021). Depletion of SOM affects P bioavailability and thus limit crop productivity in these acid low-fertility soils.

Liming is common management practice in most agricultural systems used to mitigate soil acidification and thus enhance crop productivity in such soils (Mkhonza *et al*., 2020). The application of lime brings about desirable soil pH, decreases toxicity of Fe and Al, increases calcium and magnesium supplies as well as enhances the availability of P (Mkhonza *et al*., 2020). Increased soil pH, resulting from lime application, increases microbial activity (Rousk *et al*., 2020; Paradelo *et al*., 2015). This in turn enhances decomposition of soil organic matter (Garbuio *et al*., 2011; Grover *et al*., 2017). Lime application increases the availability of nutrients, which would otherwise be strongly limited by low soil pH (Rastija *et al*., 2014), improving nutrient uptake (Takala, 2019; Mkhonza *et al*., 2020). Lime application increases P availability by decreasing the amount of Fe and Al ions and P fixation on their oxides (Mkhonza *et al*., 2020). Liming creates a favourable root environment for plants as a result of these different effects it has on soils.

Manure can be a valuable, relatively inexpensive source of P and other essential plant nutrients (Han *et al*., 2008; Saleem *et al*., 2017; Wajid *et al*., 2020). Availability of P from animal manures can be as high as 70% (Han *et al*., 2008). Mineralization process involved when manure is added to soils enhances nutrient availability following the transformation of nutrient elements from organic to inorganic forms (Saleem *et al*., 2017). Negatively charged SOM complexes cations such as Fe and Al in acid soils and calcium (Ca) in calcareous soils (Haynes and Mokolobate, 2001), thereby inhibiting their crystallization and their role in P sorption and/or precipitation in soils (Haynes and Mokolobate, 2001; Brady and Weil, 2008). Presence of organic acids in manure could inhibit phosphate adsorption through adsorption site competition (Borggaard *et al*., 2005). Therefore, crop production can benefit from the application of manures through increased P bioavailability (Haynes and Mokolobate, 2001; He *et al*., 2008; Adiaha, 2017).

Some researchers suggest the use of good source of P in combination with liming for increased crop productivity (Workneh *et al*., 2013; Temasgen *et al*., 2017; Ameyu, 2019; Opala, 2020; Tshiabukole *et al*., 2022). The complimentary effect will ensure that P from manure source will not be adsorbed by Fe and Al oxides under acidic conditions. Therefore, the objectives of this research were to (i) evaluate the effects of synthetic lime and poultry-droppings manure in acid sandy-loam Ultisols on soybean growth, and (ii) to explore the relationships among its growth indices, plant P content, soil available P and soil pH.

Materials and methods

Soil of the study : The research was conducted using soil from the University of Nigeria Teaching & Research Farm (06°52 N, 07°24 E; elevation of about 447 m asl) at Nsukka, southeastern Nigeria. The climate is humid tropical, with mean annual rainfall of 1600 mm and minimum and maximum temperatures of 21 and 31 °C, respectively. The soil, deeply weathered reddish brown coarse-textured Ultisols, is underlain by false-bedded sandstone. Soil surface in this area is excessively 'porous' and well-drained and hence often droughty (Obalum and Obi, 2014). The soil's occurrence in a high-rainfall zone and its 'porous' attribute, makes it highly leached of basic cations as evident in its being strongly acid (Obalum *et al*., 2011).

Procurement of study materials : Topsoil (0-20 cm) was collected from the Greenhouse area of the University of Nigeria Teaching & Research Farm. These soil samples were allowed to air-dry in the glasshouse and later crushed and sieved using 2-mm sieve. This was to remove all unwanted materials from the soil samples before potting. Quicklime (CaO-88%) and treated soybean seeds were sourced from the local market in Nsukka. Poultry-droppings manure was sourced from Animal Science Section of the Farm. This was crushed and sieved to allow for proper mixing while potting.

Experimental design : The research was a glasshouse study. The experiment was executed as a completely randomized design (CRD) having nine treatments replicated thrice. Ceramic pots of approximate capacity 2.25 L were used for this study. Treatments consisted of factorial combination of three rates (0, 2.5 and 5.0 t ha^{-1}) of quicklime and three rates (0, 25 and 50 t ha^{-1}) of poultry-droppings manure. These treatments were mixed with 2.5 kg air-dry topsoil. Assuming a soil bulk density of 1,500 kg m^{-3}, the application rates translated into 0, 2.5 and 5.0 g per pot for quicklime and 0, 25 and 50 g per pot for poultry-droppings manure. Theses application rates are represented as L_0, $L_{2.5}$, $L_{5.0}$ and PD_0, PD_{25}, PD_{50} for lime and manure rates respectively. The three replications of these treatments gave a total of 27 potted soils for the study. The potted soils were watered to field capacity and left overnight before sowing soybean. Two seeds were sown per potted soil and later thinned to one seedling per potted soil.

Agronomic data collection : Plant growth data were collected weekly from second week until the sixth week after sowing (WAS). Growth parameters measured included plant height, leaf area and number of leaves. Plant height, the vertical distance from the soil level in the pot to the tip of the seedling, was measured using a meter rule. To determine leaf area, the lengths (L) and widths (W) of two broadest leaves were measured and the average taken to estimate leaf area as 0.31 LW. Samples of plant leaf were also collected for analysis P content. This was done at six weeks as this is stage of vegetative growth when mature leaves could be sampled for plant nutrient analysis (Stammer and Mallarino, 2018). The leaf samples were air-dried for three weeks before this analysis.

Laboratory analyses : Soil samples were air-dried to constant weight, crushed and passed through a 2-mm mesh sieve before analyses. Soil pH was determined in deionised water in 1:2.5 soil-water suspensions (McLean, 1982), and the values measured potentiometrically using a Beckman's zeromatic glass electrode pH metre. Available P was extracted with Bray 2 solution; thereafter, the values were measured colorimetrically using the method described by Olsen and Sommers (1982). Plant P content was analyzed by digesting 0.5 g of plant samples with 20 ml each of nitric acid and perchloric acid, after which the digest was washed with distilled water and later extraction was done using Bray 2 solution (Olsen and Sommers, 1982).

Data analyses : The data generated from this study were analysed using GenStat and SPSS software. First, analysis of variance was used to test for differences in treatments of the study using GenStat. Where significant differences existed, mean separation was done by the Fisher's least significant difference (F-LSD) procedure at 5% level of probability ($p < 0.05$). Correlation and regression analyses were carried out using SPSS. This was to examine the relationships among soil pH in water, soil available P, growth indices of soybean and plant P content of soybean.

Results and Discussion

Effects of lime and manure rates on growth parameters : The effects of lime and manure rates on plant height, leaf area and number of leaves of soybean are shown (Table 1a, b and c, respectively). Generally, plant height differed among treatments. The data show a trend of highest values in treatment $L_{2.5}$ + $PD_{5}0$. Leaf area, however, differed among treatments only at 3 and 4 WAS. The trend observed in leaf area was same as for plant height; highest values were consistently observed in treatment $L_{2.5}$ + PD_{50}. Number of leaves differed among treatments at 4, 5 and 6 WAS. Highest values for this parameter were observed in treatment $L_{2.5}$, PD_{50} at 2 and 3 WAS, while treatment $L_{2.5}$ + PD_{25} showed highest values at the later growth stages being 4, 5 and 6 WAS. For all growth parameters measured in this research, lowest values were generally observed in treatment L_0 + PD_0.

Plant height was influenced by lime rate all

Table 1a. Effects of lime and poultry-droppings manure application to the coarse-textured acid soil on plant height (cm) of soybean

	2 WAS				3 WAS				4 WAS			
	Manure rates											
Lime rates	P_0	P_{25}	P_{50}	Mean	P_0	P_{25}	P_{50}	Mean	P_0	P_{25}	P_{50}	Mean
L_0	16.90	12.33	20.67	16.63	31.00	21.50	46.25	32.92	37.70	31.00	73.30	47.30
$L_{2.5}$	14.33	19.50	21.33	18.39	39.80	62.00	59.17	53.66	53.70	97.00	103.50	84.70
$L_{5.0}$	23.33	19.67	19.50	20.83	43.17	43.17	47.69	44.67	68.70	74.70	75.70	73.00
Mean	18.19	17.17	20.50		37.99	42.22	51.03		53.30	67.60	84.20	
F-LSD (0.05)	2.85†				7.92†				13.41†			
	1.64§,				4.57§,				7.74§,			
	1.64¶				4.57¶				7.74¶			

	5 WAS				6 WAS			
	P_0	P_{25}	P_{50}	Mean	P_0	P_{25}	P_{50}	Mean
L_0	43.00	50.30	103.00	65.40	59.80	85.60	135.00	93.40
$L_{2.5}$	62.30	109.70	137.20	103.10	111.80	93.00	208.00	137.60
$L_{5.0}$	90.00	110.00	101.80	100.60	96.20	137.00	150.70	128.00
Mean	65.10	90.00	114.00		89.20	105.10	164.60	
F-LSD (0.05)	20.31†				33.07†			
	11.73§,				19.09§,			
	11.73¶				19.09¶			

$L_{0,\ 2.5,\ 5.0}$ - lime at 0, 2.5, 5 t ha^{-1}, respectively; $PD_{0,\ 25,\ 50}$ - poultry manure droppings at 0, 25, 50 t ha^{-1}, respectively; WAS - weeks after sowing; †, §, ¶ LSD for interaction, manure rate and lime rate effects, respectively

through the growth phase of soybean. Generally, all through the growth period, lime rate of 2.5 t ha^{-1} gave the tallest plants. Plant height also differed among manure rates all through the growth period. Manure applied at 50 t ha^{-1} gave tallest plants while 0 t ha^{-1} gave shortest plants. The effects of lime showed that leaf area differed among lime rates except at 6 WAS. Treatments $L_{2.5}$ and L_0 consistently gave highest and lowest values, respectively. Leaf area was influenced by manure rate. Consistently, manure applied at 50 t ha^{-1} gave highest values while 0 t ha^{-1} gave lowest values. All through the growth period, number of leaves differed among lime and manure rates. The trend was the same as observed in the other parameters, liming at 2.5 t ha^{-1} showed most effect on number of leaves consistently. Also, applying manure at 50 t ha^{-1} influenced number of leaves most.

General trend for treatments with lime and manure to have better effect on growth parameters was observed in this research. This is to say that the complimentary effect of liming and manuring in acid low-fertility soils could be of great benefit in plant growth. Liming created favorable root environment by ensuring desirable soil pH, decreasing the toxicity of Fe and Al, and enhancing the availability macronutrients. It also improves soil biological activity and mineralization of organic compounds, thereby improving nutrient uptake (Saleem *et al*., 2017; Takala, 2019). Also, the addition of manures increases microbial activity that ensures the biochemical transformations and mineralization of plant nutrients (Saleem *et*

Table 1b. Effects of lime and poultry-droppings manure application to the coarse-textured acid soil on mean leaf area (cm^2) of soybean

	2 WAS				**3 WAS**				**4 WAS**			
	Manure rates											
Lime rates	P_0	P_{25}	P_{50}	**Mean**	P_0	P_{25}	P_{50}	**Mean**	P_0	P_{25}	P_{50}	**Mean**
L_0	4.47	5.88	9.52	6.62	9.49	5.95	18.67	11.37	9.78	10.34	21.45	13.86
$L_{2.5}$	6.59	7.54	9.55	7.89	10.09	8.28	21.41	13.26	11.59	15.07	21.70	16.12
$L_{5.0}$	5.85	7.39	9.68	7.64	8.25	9.52	17.20	11.66	9.03	15.41	18.50	14.31
Mean	5.63	6.93	9.58		9.28	7.92	19.09		10.13	13.61	20.55	
F-LSD (0.05)	NS†				1.93†				2.75†			
	0.94§,				1.11§,				1.59§,			
	0.94¶				1.11¶				1.59¶			

	5 WAS				**6 WAS**			
	P_0	P_{25}	P_{50}	**Mean**	P_0	P_{25}	P_{50}	**Mean**
L_0	9.82	12.51	20.12	14.15	9.21	12.78	15.53	12.51
$L_{2.5}$	12.58	19.27	23.08	18.31	10.97	14.50	26.86	17.45
$L_{5.0}$	11.41	19.09	22.32	17.61	8.57	16.34	19.97	14.96
Mean	11.27	16.96	21.84		9.58	14.54	20.79	
F-LSD (0.05)	NS†				NS†			
	1.94§,				4.11§,			
	1.94¶				NS¶			

$L_{0,\ 2.5,\ 5.0}$ - lime at 0, 2.5, 5 t ha^{-1}, respectively; $PD_{0,\ 25,\ 50}$ - poultry manure droppings at 0, 25, 50 t ha^{-1}, respectively; WAS - weeks after sowing; †, §, ¶ LSD for interaction, manure rate and lime rate effects, respectively

al., 2017). Liming ensured nutrient elements made available from the manure were accessible for plant uptake due to its effect of decreased acidity. Researchers have reported that appropriate combination of lime and fertilizers could improve plant growth as well as yield (Ameyu, 2019; Nnadi *et al.*, 2020). Also, there was tendency for treatment $L_{2.5}$ + PD_{50} to show the most effect on growth parameters. This suggests that moderate lime application in combination with ample poultry droppings manure application was best for increased plant growth. Treatment $L_{5.0}$ + PD_{50} performing below the said treatment indicates the negative effect of over liming on plant growth.

Soil pH and available P and plant P content as affected by treatment : At the end of 6-week period, values for soil pH, available P and plant P content were determined (Table 2). Soil pH, available P and plant P differed among treatments with $L_{2.5}$ + PD_{50} showing the highest values for available P and plant P content. Generally, it was observed that soil pH, available P and plant P increased as rate of lime and PD increased. The increase in pH with an increase in lime rate can be associated with a decrease in hydrogen ions by its neutralization effect and an increase in hydroxide ions following lime application (Bolan *et al.*, 2003; Antoniadis *et al.*, 2015; Li *et al.*, 2019). Increasing soil pH with increase in PD in this study could be attributed to the release of cations by the organic matter due to mineralization. The presence of increased cations counters acidity effect and decreases exchangeable Al in soils amended with manure. Addition of manure has been reported to

Table 1c. Effects of lime and poultry-droppings manure application to the coarse-textured acid soil on number of leaves per soybean plant

	2 WAS				3 WAS				4 WAS			
	Manure rates											
Lime rates	P_0	P_{25}	P_{50}	Mean	P_0	P_{25}	P_{50}	Mean	P_0	P_{25}	P_{50}	Mean
L_0	7	4	9	7	13	13	19	15	17	17	25	20
$L_{2.5}$	10	10	12	10	19	16	22	19	17	31	28	25
$L_{5.0}$	10	10	11	10	16	15	22	18	17	20	26	21
Mean	9	8	10		15	16	21		17	23	27	
F-LSD (0.05)	NS† 1.29§, 1.29¶				NS† 1.62§, 1.62¶				4.45† 2.57§, 2.57¶			

	5 WAS				6 WAS			
	P_0	P_{25}	P_{50}	Mean	P_0	P_{25}	P_{50}	Mean
L_0	15	22	31	23	23	21	47	30
$L_{2.5}$	23	54	32	36	25	63	47	45
$L_{5.0}$	19	20	35	25	25	31	50	35
Mean	19	32	32		24	38	48	
F-LSD (0.05)	4.15† 2.40§, 2.40¶				14.16† 8.17§, 8.17¶			

$L_{0,\ 2.5,\ 5.0}$ - lime at 0, 2.5, 5 t ha^{-1}, respectively; $PD_{0,\ 25,\ 50}$ - poultry manure droppings at 0, 25, 50 t ha^{-1}, respectively; WAS - weeks after sowing; †, §, ¶ LSD for interaction, manure rate and lime rate effects, respectively

increase soil pH (Soremi *et al*., 2017; Ogunezi *et al*., 2019; Okebalama *et al*., 2020; Chukwuma *et al*., 2023; Ndzeshala *et al*., 2023; Onah *et al*., 2023)

Available P increased with increase in lime rate as the addition of lime decreases the binding of P to Fe and Al. Liming causes the precipitation of Fe and Al as insoluble compounds (Antoniadis *et al*., 2015). In addition, Fe and Al oxides become more negatively charged with an increase in pH contributing to an increase in available P (Opala, 2017). Increase in availability of P with increase in PD can be attributed to the mineralization of organic P in poultry manure. It could also be that negatively charged organic molecule adsorbed or complexed ions such as Al and Fe in acid soils (Haynes and Mokolobate, 2001; Brady and Weil, 2008). This could inhibit their crystallization and decrease their role in P sorption and/or precipitation. Organic acids from organic matter could inhibit phosphate adsorption through adsorption site competition (Borggaard *et al*., 2005). Organic molecules adhering to sorbing surfaces can mask fixation sites and prevent them from interacting with phosphorus ions in solution (Brady and Weil, 2008). The phenomenon of increases in soil available P as a result of manure application has been severally reported in the study area (Ogunezi *et al*., 2019; Obalum *et al*., 2020; Okebalama *et al*., 2020; Umeugokwe *et al*., 2021; Chukwuma *et al*., 2023; Ndzeshala *et al*., 2023; Onah *et al*., 2023)

Plant P increase with an increase in lime rate could be explained by increase in availability of essential elements including P, making it available for plant uptake. Liming can also influence uptake of nutrients by plants through its indirect effect on the soil microbial activity by creating favourable conditions for microbial activities caused by increased pH (Cheng *et al*., 2013). Increase in plant P content due PD addition is attributed to increased availability of P as a result of organic matter mineralization. Manure is known to be a reservoir of essential macro nutrients and the nutrients are released upon decomposition and mineralization (Ogunezi *et al*., 2019; Nnadi *et al*., 2021). Improved availability soil nutrient contents caused by poultry manure addition has been reported to have increased nutrient uptake and hence their concentrations in plant tissues (Ewulo *et al*., 2008; Ogunezi *et al*., 2019).

Relationships among soil pH, available P, plant P content and growth indices of soybean : The coefficients of the correlation among soil pH in water, available P, plant P content and growth indices of soybean are presented (Table 3). The data show that soil pH had significant ($p < 0.05$) positive relationship with available P, plant P content, plant height and leaf area. However, the relationship was not significant for number of leaves. The relationships between available P and plant P content as well as the growth indices were significant ($p < 0.05$) positive ones. The relationships observed between plant P content

Table 2. Mean-weighted values for soil pH, available P, plant P content and above-soil dry matter for the different treatments

Treatment	pH_{water}	AvP	% PltP (mg kg^{-1})
$L_0 + PD_0$	5.8	5.60	0.12
$L_0 + PD_{25}$	6.8	20.52	0.16
$L_0 + PD_{50}$	7.1	29.85	0.32
$L_{2.5} + PD_0$	6.6	7.46	0.14
$L_{2.5} + PD_{25}$	7.0	22.38	0.16
$L_{2.5} + PD_{50}$	7.3	48.50	0.33
$L_{5.0} + PD_0$	6.7	9.33	0.15
$L_{5.0} + PD_{25}$	7.2	27.98	0.19
$L_{5.0} + PD_{50}$	7.4	27.98	0.28
F-LSD (0.05)	0.06	0.16	0.01

$L_{0,\ 2.5,\ 5.0}$ - lime at 0, 2.5, 5 t ha^{-1} respectively; $PD_{0,\ 25,\ 50}$ - poultry manure droppings at 0, 25, 50 t ha^{-1} respectively; AvP - available phosphorus; PltP - plant P content and growth indices were also significant ($p < 0.05$) positive ones for plant height as well as leaf area. However, there was a non-significant relationship between plant P content and number of leaves of the soybean plants.

Furthermore, the correlation among growth indices were significantly ($p < 0.05$) positive in all cases. Growth indices were regressed on soil pH, available P and plant P content (Table 4). Plant height was significantly ($p < 0.05$) predicted by available P with R^2 and SEE values of 0.76 and11.94, respectively. Leaf area was significantly ($p < 0.05$) predicted by plant P content with R^2 and SEE values of 0.88 and 1.90, respectively. Number of leaves was also significantly ($p < 0.05$) predicted by available P with R^2 and SEE values of 0.48 and 5.20, respectively.

Table 3. Matrix of coefficients of Pearson's correlations among soil pH in water, available P, plant P content and growth indices of soybean (n = 9) showing the r values

	pH_{water}	AvP	PltP	PHt	LA	NOL
pH_{water}	-					
AvP	0.80*	-				
Plt P	0.74*	0.86**	-			
PHt	0.83**	0.87**	0.79*	-		
LA	0.71*	0.90**	0.94**	0.86**	-	
NOL	0.64	0.70*	0.64	0.73*	0.74	-

AvP - available phosphorus; PltP - plant P content; PHt - plant height; LA - leaf area; NOL - number of leaves

Table 4. Results of multiple linear regression of soybean growth indices on available P and plant P content (n = 9)

Regression models	R^2	Adj. R^2	SEE
Leaf area = 1.456 + 57.863 PltP	0.876	0.858	1.901
No. of leaves = 14.304 + 0.349 AvP	0.488	0.415	5.200
Plant height = 36.613 + 1.470 AvP	0.762	0.728	1.938

Regressions are significant at $p < 0.05$; Plant P - plant P content; AvP - available phosphorus; SEE - standard error of the estimate

The significant relationships generally observed among soil pH, available P, plant P content and growth indices in this research were expected as pH affects P availability in soils, its uptake by plants and hence the growth of plants. Some researchers reported that P concentrations in plants were directly related to the extractable P from soil (Bolan *et al*., 2003). Practices that mitigate acidity and low fertility in acidic soils enhance bioavailability of P which can be indicative in the increased plant uptake of P and consequently the increase in plant growth.

Conclusion

Application of lime and poultry droppings manure in acid low-fertility soils enhanced the availability of phosphorus. Increase in soil available P led to increases in plant P content which translated into improved soybean growth. The findings of this research showed that the combined effects of lime and poultry droppings manure was beneficial to plant production. Growth indices varied among lime and poultry-droppings manure rates. Moderate use of synthetic lime and ample poultry-droppings manuring enhanced soybean morphological growth better than other lime-manure options used in this study. These increases in growth are a reflection of effect of lime and poultry-droppings manure on P bioavailability.

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