

LIME EFFECTIVENESS OF SOME FERTILIZERS IN A TROPICAL ACID ALFISOL

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ABSTRACT

Liming increases production costs and environmentally unfriendly. Effectiveness of crystalliser (CRYS), single super phosphate (SSP) and organic fertilizer (OF) for liming was evaluated by determining pH and phosphorus- (P)-availability in an acid alfisol incubated with the amendments, $\text{Ca}(\text{OH})_2$ being reference. Treatments were replicated thrice in completely randomised design. Un-amended soil remained acidic (pH 4.8) but liming raised pH (6.1-6.6), enhancing maximum (15.09-17.33 mg kg⁻¹) P-release (un-amended having 4.24-7.09 mg P kg⁻¹). Lime (L) and L+P treatments resulted in maximum pH increases (7.0-7.2), decreasing with incubation. Fertilizer treatments also raised pH (5.0-5.5 for OF, CRYS or SSP; 5.6-5.8 for CRYS +SSP, CRYS+OF and OF+SSP) relative to control (5.2). Acid soil infertility-ameliorating potential of CRYS and OF was revealed. They could be used multi-purposely as lime and P fertilizers by poor-resource farmers challenged by acid soil infertility factors.

KEY WORDS: acid typic paleustalf, lime effectiveness, organic and inorganic phosphorus fertilizer, relative agronomic efficiency.

INTRODUCTION

A large proportion of soil resource found in the humid tropics is acidic and deficient in phosphorus (P). This may not be unrelated to the leaching of basic cations coupled with poor management practices characteristic of the region. The occurrence of high levels of aluminium (Al) and iron (Fe) in soil usually give rise to low pH and P release. Wherever Fe and Al imbalances exist, a corresponding P stress occurs. With high rate of P fertilizer additions, soil sorption sites are satisfied and P level increase to sufficiency for crop production [11]. This is of particular importance because of the role of P in plant nutrition; enhancing nitrogen (N) absorption, influencing pod and seed formation in legumes and contributing significantly in plant energy processes.

The subject of soil addition or amendment to improve soil fertility and correct soil acidity is recently enjoying research attention; partly because of limited use of costly inputs like fertilizers, lime - soil amendments [22] occasioned by the inability of poor resource farmers to purchase these materials. Where available, application of inorganic fertilizer without soil test, on the long run, can increase soil acidity. It is also due to side effects of inorganic fertilizer on intensely cultivated soils [20]. Cropping soils without fertilizer use under a continuous intensified farming system facilitates nutrient depletion while soil degradation sets in. Another extreme of excess P fertilizer use could result in ground water pollution. In all cases, the sustainability of the soil resource is jeopardized.

Conventional lime still remains the major means of ameliorating soil acidity; yet most farmers find it difficult to purchase it coupled with the sub soil acidity associated with inadequate liming practice. Basically, inputs into the soil -inorganic fertilizer application and biological nitrogen fixation [7] and acid rain [24] have been labelled as causes of soil acidity. In like manner, soil additives capable of increasing soil pH could be exploited for correcting the twin problem of low pH and P deficiency. When rock phosphate (RP) is added to acid soils, P availability could be increased due to P supply abilities of these materials. With Ca and Mg constituent, RP assumes a significant role as a potential tool for sustaining soil productivity by reducing its acidity level. With this, it is important to consider the liming abilities of Ca-containing fertilizers - RP, SSP and organic fertilizer in addition to their P supplying property.

As such, this study sought to investigate the lime effectiveness of some P fertilizers (organic and inorganic) in an acid alfisol in relation to their ability to raise soil pH and enhance P release for sustainable soil productivity.

MATERIALS AND METHODS

Two laboratory incubation studies were conducted using loamy sand Alfisol collected from International Institute for Tropical Agriculture (IITA) substation in Ikenne, Nigeria. Analysis of the soil, prior to incubation, revealed its characteristics to be: pH (H₂O)=4.7, organic matter=18.9g kg⁻¹, total N=9.4g kg⁻¹, available P =2.91mg kg⁻¹, exchangeable Ca, Mg, Na and K = 0.38, 0.09, 0.29 and 0.48 c mol kg⁻¹, respectively. Soil physical properties determination gave sand = 918 g kg⁻¹, clay =14.0 g kg⁻¹ and silt=68.0 g kg⁻¹. Thus, it was an acid loam sand alfisol -Typic Paleustalf [28] formed on sandstones [3].

In the first laboratory investigation, 50 g samples of the experimental soil were contained in 45 custom laboratory cups and incubated for 7, 14 and 21 days with 0, 25, 50, 75 and 100 mg Ca (OH)₂ kg⁻¹ [equivalent to 0, 34.25, 68.5, 102.75 and 137.00 mg CaCO₃ kg⁻¹] Calcium hydroxide (slaked / hydrated lime) is calcium oxide (quicklime) slaked with water. It was used in this study in order to enhance solubility.

The treatments were replicated 3 times in completely randomised design (CRD) to give a total of 5 x 3 x 3 (lime application levels x incubation periods x replicates) experimental units. The soil samples were moistened to 60 % field capacity (FC) during the incubation periods and 15 samples were analysed for pH and available P determination at the end of each period. The quantities of Ca (OH)₂ applied were subsequently plotted against pH values for the estimation of optimum liming rate for the soil.

The second laboratory experiment involved the use of the same amount of soil and incubation periods as in the first. However, the following 16 sole and combined treatments were replicated three times in CRD: control (C), lime (L), single super phosphate (SSP), crystalliser (CRYS -blend of Sokoto RP and talc), organic waste-fertilizer (OF), L+SSP, L+CRYS, L+OF, CRYS+SSP, CRYS+OF, OF + SSP, CRYS+OF+SSP, L+CRYS+OF, L+SSP+OF, L+CRYS+SSP and L+OF+CRYS+SSP. Lime was applied at 50 mg kg⁻¹, which was obtained as the optimum liming rate in the first experiment while P-fertilizers were applied at 44 mg P kg⁻¹. The nutrient composition of each soil amendment used is provided in Table 1. Soil pH and available P were subsequently determined to know the effectiveness of the treatments in correcting soil acidity and releasing P with time. The relative agronomic efficiencies (RAEs) of the amendments were then estimated to indicate their lime effectiveness (LE) relative to conventional lime. The RAE or LE was computed as the ratio of soil pH with a specific/test soil amendment minus soil pH of control/untreated soil and

soil pH obtained with conventional lime treatment minus soil pH of control/untreated soil i.e.

$$\text{RAE or LE} = \frac{\text{Soil pH (with test liming material)} - \text{soil pH (with control)}}{\text{Soil pH (with conventional lime)} - \text{soil pH (with control)}} \times 100 \%$$

Laboratory analysis of soil samples

Soil pH was determined in a 1:2 soil/water using glass electrode pH meter, N by micro Kjeldahl [16] and available P by Bray -1-P method [9]. Exchangeable cations were determined by IN NH_4OAC pH 7.0 extraction, organic C by wet dichromate method [30] while micronutrients were extracted by use of acidified NaHCO_3 extractant [15]. The respective concentrations in filtrates were read on atomic absorption spectrophotometer (AAS). The soil particle sizes were analysed by hydrometer method [8] and read on textural triangle.

Data Analysis

Data collected were subjected to analysis of variance (ANOVA) using Sigma Stat computer software. Subsequently, Duncan Multiple Range Test (DMRT) was used to indicate differences in the effects of the lime application rates in the first experiment while standard deviation (\pm SE) was used in the second experiment to establish variations in the effectiveness of the soil amendments.

RESULTS AND DISCUSSION

Soil pH increased with increase in lime application levels

(Table 2) but declined with increasing incubation periods. Lime application at 100 mg kg^{-1} led to the highest soil pH (7.5) followed by 75 mg kg^{-1} (7.2) after 1 week-incubation period. There was no significant difference in pH of soils incubated for various periods when limed at 100 mg kg^{-1} but soils incubated for 7 days with 75 mg kg^{-1} lime were different from those incubated for 14 days but were not different from those of 21 days. The same trend occurred for soils incubated with 50 mg kg^{-1} of lime, which resulted in soil pH 6.1 (after 7 days) with an increase to 6.6 after 14 days of incubation and subsequent decrease to 6.4 after 21 days. At 25.0 mg kg^{-1} liming rate, a slight soil pH decrease (5.6 to 5.5) was associated with increase in incubation period from 7 to 14 days while the values after 14 and 21 days were similar. However, the average pH of 5.5 for 7, 14, and 21 days of incubation was significantly higher than for the un-amended soils (4.7) (Table 2). Liming at 25.0 mg kg^{-1} represented one extreme (inadequacy) of lime application that did not completely ameliorate soil acidity, as pH values of 5.4-5.6 were still indicative of acid conditions. This is evident from the available P contents of soils incubated at 25.0 mg kg^{-1} that was not significantly different from control values at 7 and 14-day incubation periods, suggesting the inefficacy of low rates of lime application. The optimum liming rate for the experimental soil could be accepted to be 50.0 mg kg^{-1} , which raised soil pH to about 6.5 known to ensure the availability of a broad range of essential nutrients (P inclusive) to crops [29].

Table 2 further reveals that soil available P (at most of the

Table 1. Nutrient composition of the soil amendments used.

Fertilizer Nutrient	Nutrient Composition (%)			
	Lime [Ca(OH) ₂]	Organic fertilizer (O.F)	Crystallizer (CRYS)	Single super phosphate (SSP)
Total P ₂ O ₅	-	0.55	36.00	18.00
CaO	51.00	0.36	44.23	-
CaCO ₃	-	-	79.00	-
MgO	-	0.13	0.95	-
N ₂ O	-	2.30	0.11	-
K ₂ O	-	0.47	0.05	-
Fe ₂ O ₃	-	0.36	2.19	-
Al ₂ O ₃	-	-	1.79	-
SiO ₂	-	-	21.35	-
Zn	-	0.019	-	-
Mn	-	0.034	-	-
Cu	-	0.003	-	-

Source: Akinrinde *et al.*, [5]

Table 2. Soil pH and available phosphorus (P) contents after 7, 14 and 21 day – incubation periods with different levels of lime

Ca(OH) ₂ applied (mg kg ⁻¹ soil)	Incubation period (days)					
	7		14		21	
	pH	Available P (mg kg ⁻¹)	pH	Available P (mg kg ⁻¹)	pH	Available P (mg kg ⁻¹)
0	4.99 e	7.09 c	4.60 d	7.15 b	4.50 e	4.24 b
25	5.66 d	10.79 bc	5.54 c	9.41 b	5.50 d	9.94 a
50	6.14 c	17.33 a	6.65 b	16.76 a	6.46 c	15.09 a
75	7.20 b	16.19 ab	7.19 a	14.48 a	7.18 b	15.61 a
100	7.53 a	13.01 abc	7.53 a	13.53 a	7.54 a	11.42 a

Values with the same letter (s) along columns are not significantly different at p=0.05 by Duncan multiple range test.

lime application levels) decreased with incubation time. The untreated soils had the least available P at all the incubation levels while 50.0 mg kg⁻¹ treatment resulted in maximum P – release of 17.33, 16.76 and 15.09 mg kg⁻¹ after 1, 2, and 3 weeks of incubation, respectively. Optimal liming at 50.0 mg kg⁻¹ resulted in soil pH 6.1-6.6, which permitted the highest available P contents of the incubated soils. However, liming at 75.0 or 100.0 mg kg⁻¹ increased soil pH to above 7, causing low soil available P-content compared with the values at 50.0 mg kg⁻¹. Fageria et al., [12] explained that when high rates of lime are applied, available P is significantly reduced.

The summary of pH for soils sampled during the second incubation study is presented in Table 3. In the case of soil amendments involving lime, a range of 7.5-7.7 was recorded, but decreasing with increasing incubation time such that a range of 6.8-7.4 was attained by the last sampling period (21 days). This is an indication of lime depletion through adsorption by soil colloids with time, hence the need for regular lime application [17]. Lime (applied alone) and lime + P source treatments gave the highest soil pH of 7.0-7.2 after 7 days of incubation. For lime and lime combinations (L, L+CRYS, L+OF, L+CRYS+SSP etc), pH increases above the control were observed up to the third week of incubation indicating a tendency for some liming materials to have a long term effect as reported by Follett et al., [13]. The pH of control soils became more acidic with time, while the amounts of available P recovered following incubation were higher than those of the original soil. The pre-incubated/original soil could have been high in total P but low in available

P.

For treatments without lime (CRYS, OF, OF+CRYS, OF+CRYS+SSP etc), appreciable increases in soil pH and available P greater than for the control were obtained. This is in line with the explanation of Wright et al., [31] that increase in soil pH could be attributed to consumption of protons during acidulation of rock phosphate and subsequent neutralization of bases released. These treatments (OF and CRYS) involved materials that supplied fertilizer P in addition to P release through their liming ability as explained by Lelei et al., (18). FAO [14] and Edwards [10] reported that RP and organic fertilizer possess some liming ability. Sole and combined applications of the P fertilizer sources led to higher pH values of 5.5 for OF and CRYS while CRYS +SSP, CRYS+OF and OF+SSP gave 5.8, 5.6 and 5.7, respectively compared with control (5.2). SSP treated soils, however, resulted in pH 5.0 that is lower than for the control. This is an indication of the relative liming abilities of the materials. Combinations involving SSP also gave high soil pH values and the highest available P contents. After one week of incubation, the highest available P concentration was obtained from SSP (47.23 mg kg⁻¹), CRYS+SSP (48.89 mg kg⁻¹) and CRYS+OF+SSP (39.32 mg kg⁻¹) while least available P concentrations were obtained from control (11.75 mg kg⁻¹) and sole lime (12.47 mg kg⁻¹) incubated soils. Same trend was obtained at the third week of incubation.

The low soil pH of SSP after 7 days of incubation relative to control supports the result of previous work [23] that

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Table 3. The influence of lime, phosphorus (P) fertilizer and their combinations on the pH and available P contents of soils incubated for 7, 14 and 21 days.

Treatment	Incubation period (Days)					
	7		14		21	
	pH	Available-P (mg kg ⁻¹)	pH	Available-P (mg kg ⁻¹)	pH	Available-P (mg kg ⁻¹)
Control	5.29	11.75	4.93	11.02	4.83	12.40
Lime (L)	7.22	12.47	7.15	13.05	7.21	13.42
Crystalliser (CRYS)	5.52	21.18	5.06	19.58	5.10	25.90
Organic Fertilizer (O.F)	5.53	38.88	5.25	42.00	4.74	42.44
Single super (SSP)	5.04	47.23	5.36	40.41	5.20	45.34
L+SSP	7.56	32.21	7.23	42.51	7.13	29.81
L+CRYS	7.75	18.50	7.20	17.77	6.82	17.99
L+OF	7.67	25.24	7.49	26.26	7.18	4.52
CRYS+SSP	5.82	34.96	4.87	35.18	4.94	30.90
CRYS+OF	5.69	48.89	5.24	46.50	5.03	44.25
OF+SSP	5.73	20.40	5.05	29.02	5.00	32.13
CRYS+OF+SSP	5.55	15.38	4.91	15.38	4.91	17.19
L+CRYS+OF	7.71	30.83	7.55	25.90	7.47	23.94
L+SSP+OF	7.48	39.32	7.54	46.43	7.34	45.27
L+CRYS+SSP	7.57	29.23	7.46	26.19	7.29	19.44
L+OF+CRYS+SSP	7.58	31.34	7.41	27.13	7.41	24.44
± S.E.	0.26	3.03	0.29	2.98	0.29	2.80

± S.E, Standard deviation.

inorganic fertilizer treatments either maintained same or decreased soil pH compared with control. The high available P contents associated with this inorganic P source are attributed to the fact that it is water-soluble [2,27] while subsequent decrease could have been caused by P fixation [26]. CRYS, OF, CRYS +OF, OF+SSP, L+CRYS+OF and CRYS+OF+SSP soil amendments similarly increased available P throughout the incubation periods in consonance with the work of Minhas and Tripathi, [21] and Marwaha and Kanwar, [19] that RP (e.g. crystalliser) in combination with SSP or farmyard

manure (OF) can be as effective as SSP. With increasing incubation period, control, L+SSP, L+OF, CRYS+OF and CRYS+OF+SSP treatments had the overall tendency to decrease soil available P concentrations while there was a steady increase in available P with respect to OF, CRYS, OF+SSP, L+CRYS+OF and CRYS+OF+SSP. The increases in available P of the latter treatments throughout the incubation period could be due to the slow release of CRYS (which is largely a rock phosphate, RP) as well as the mineralization of the organic fertilizer [4,25]. In a similar study, Akinrinde et al., [4] reported gradual

Table 4. Soil pH and relative agronomic efficiencies (RAE) of lime and phosphorus fertilizer treatments at 7, 14 and 21 day-incubation periods.

Treatment	Incubation period (Days)					
	7		14		21	
	pH	RAE / LE (%)	pH	RAE / LE (%)	pH	RAE / LE (%)
Control (C)	5.29	-	4.93	-	4.83	-
Lime (L)	7.22	100	7.15	100	7.21	100
Crystalliser (CRYS)	5.52	11.91	5.06	5.85	5.10	11.34
Organic Fertilizer (O.F)	5.53	12.43	5.25	14.41	5.22	20.20
Single super phosphate (SSP)	5.14	-12.93	5.36	43.00	5.20	15.54
L+SSP	7.56	117.61	7.23	103.60	7.13	96.63
L+CRYS	7.75	127.46	7.20	102.25	6.82	83.61
L+O.F	7.67	123.31	7.49	115.31	7.18	98.73
CRYS+SSP	5.82	27.46	4.87	-2.70	4.94	4.62
CRYS+O.F	5.69	20.72	5.24	13.96	5.03	8.40
O.F+SSP	5.73	22.79	5.05	5.40	5.00	7.14
CRYS+O.F+SSP	5.55	13.47	4.91	-0.90	4.91	3.36
L+CRYS+O.F	7.71	125.38	7.55	118.01	7.47	110.92
L+SSP+O.F	7.48	113.47	7.54	117.56	7.34	105.46
L+CRYS+SSP	7.57	118.13	7.46	113.96	7.29	103.36
L+O.F+CRYS+SSP	7.58	118.65	7.41	111.71	7.41	108.40

RAE / LE = Relative Agronomic Efficiency / Lime Effectiveness = Soil pH (with test liming material) – soil pH (with control) / Soil pH (with conventional lime) – soil pH (with control) x 100 %.

increase in H₂O –P from 3.06 – 9.70 mg P kg⁻¹ after 5 weeks of incubation for soil samples treated with organic fertilizer. They concluded that OF decreased P fixation and promoted P availability. Furthermore, RP supplied Ca while P – availability was ensured by the release of organic acids (during mineralization of organic fertilizer) which frees Al and Fe bound phosphates from sorption sites [1].

A comparison of results of first and second experiments (Tables 2 and 3, respectively) indicates that control treatment in the latter produced more available P (11.02 – 12.40 mg kg⁻¹) than in the former (4.24 – 7.15 mg kg⁻¹). Furthermore, the 50 mg Ca(OH)₂ kg⁻¹ application

increased P availability in the former and had no effect in the latter. These observations seem to be due to the fact that the experiments were conducted independently and wide changes in the environmental/ambient conditions (particularly relative humidity) during the different periods might have contributed immensely to differences in the respective “wet and dry” cycles. Akinrinde and Obigbesan [6] opined that release of soil nutrients used to be more under wet condition than under wet and dry condition. This implies that higher quantities of soil nutrients would be released with frequent wetting than with less frequent wetting. To elucidate these phenomenons, the two series of experiments could be

conducted simultaneously in future studies.

Relative Agronomic Efficiencies (RAEs) or Lime effectiveness (LE) of tested soil amendments (phosphorus fertilizer sources) relative to Conventional Lime

Data in Table 4 clearly shows that soil samples amended with lime (alone or in combination with P fertilizer sources) recorded the highest pH values of 7 and above. This also translated to higher RAE or LE values above 100 %, indicating additional effect from the P sources. However, the subsequent decreases in with incubation periods confirm the reduction of the lime effectiveness with time as the materials react with soil colloids. Despite the low RAE in respect of the different P sources, their potencies for improving soil pH are obvious considering that further mineralization could occur with time and subsequent additions would increase the cation reserve of the soil. However, the negative value obtained from SSP is an indication that it cannot be relied upon as a liming material [23].

CONCLUSION

Lime application rate at 50 mg kg⁻¹ gave soil pH values favourable for crop production and this also permitted the highest release of available P. This indicates that liming at 50.0 mg kg⁻¹ is required to ameliorate the acid condition of the experimental soil and over liming should be avoided as it could precipitate P deficiency again. Lime treatment combinations resulted in high pH values of about 7. The P fertilizer sources and their combinations also gave appreciable increases in soil pH, indicating their liming characteristics. Since P release was sustained for sole CRY5 and OF treated soil samples, P availability during residual cropping is likely unlike SSP, which suffered fixation. Also, P fertilizer combinations such as OF+SSP, CRY5+OF+SSP and L+CRY5+SSP could favour residual cropping. It is hoped that this would greatly cut cost for the poor resourced farmer who would just require one P fertilizer application depending on crop grown. Information on amount of CRY5 and OF required for sustainable crop production would assist the farmer especially those working with acid soils.

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