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Differences in the Liming Potential of Some Fertilizer Materials in a Tropical Acid Alfisol

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Abstract: Reduction of acidity level is of immense importance in sustaining productivity of majority of tropical soils; yet liming raises production cost besides the possibility of environmental contamination. In evaluating the lime effectiveness of some organic, organo-mineral and inorganic phosphorus (P) fertilizers, investigations were conducted to determine changes in pH and P availability in a Typic Paleustalf incubated with P fertilizers at various periods (7, 14 and 21 days) relative to conventional lime application. Each treatment was thoroughly mixed with 50 g soil and moistened to 60% field capacity with distilled water. Only lime was used in the first experiment while the second involved 15 sole and combined applications of lime (2 t ha^{-1}) and P (88 kg P ha^{-1}); the P fertilizer sources being Crystalliser, CRYS (a blend of Sokoto rock phosphate, SRP and talc), Single Super Phosphate (SSP) and Organic Fertilizer (OF) in addition to control. Treatments were replicated three times in Completely Randomised Design (CRD). Liming at 2.0 t ha^{-1} was optimum, soil pH being 6.1-6.6. Soil amendment increased pH to between 5.5 and 7.5 compared with the average of 5.2 for the control. At the end of a 3-week incubation period, untreated soil remained acidic (pH = 4.8) while reductions in acidity (pH 5.2-7.4) were recorded for the amended samples. Liming at 2 t ha^{-1} also resulted in maximum P-release of 17.33, 16.76 and 15.09 mg P kg^{-1} after 1, 2 and 3 weeks of incubation, respectively while the untreated soils had the least available P at all incubation periods. Lime (applied alone) and lime + P treatments gave the highest soil pH values of 7.0-7.2 after 7 days of incubation. Soil pH decreased gradually with incubation periods in all treatments with control becoming more acidic. Sole and combined applications of the P sources led to higher pH values of 5.5 for organic fertilizer (O.F), rock phosphate, CRYS (5.0) and single super phosphate; SSP (5.0), while CRYS + SSP, CRYS + OF and OF + SSP gave 5.8, 5.6 and 5.7, respectively compared with control (5.2). Relative Agronomic Efficiency (RAE)/Lime Effectiveness (LE) based on soil pH was indicative of the ameliorating ability of OF while higher amount of CRYS would be required to reduce soil acidity. Liming and fertilizer application increased soil pH and enhanced P release, respectively. The application of OF and CRYS could prove multipurpose (by its lime effectiveness and P releasing property) especially to farmers in developing countries challenged by acid soils and limited by high cost of soil management.

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 (Fageria *et al.*, 1991). 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 (Okigbo, 1997) 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 our intensely cultivated soils (Mbagwu, 2003). Cropping soils without fertilizer use under a continuous intensified farming system facilitates

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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 (Bolan *et al.*, 1991) and acid rain (Raij, 1991) 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 soil, 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 fertilizer- 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 (between September and December, 2005) at the Plant Nutrition Unit of the Agronomy Department, University of Ibadan, Nigeria using loamy sand Alfisol collected from International Institute for Tropical Agriculture (IITA) substation in Ikenne, Nigeria. Analysis of the soil prior to the conduct of the experiments revealed its characteristics to be: pH (H_2O) = 4.7, organic carbon = 10.9 g kg^{-1}, total N = 9.4 g kg^{-1}, available P = 2.91 mg kg^{-1}, exchangeable Ca, Mg, Na and K = 0.38, 0.09, 0.29 and 0.48 cmol 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 (Soil Survey Staff, 1994) formed on sandstones (Akinrinde, 1987).

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, 1, 2, 3 and 4 t ha^{-1} Ca $(OH)_2$. The treatments were replicated 3 times in Completely Randomised Design (CRD) to give a total of 5×3×3 (lime application levels * incubation periods * 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 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 2 t ha^{-1}, which was obtained as the optimum liming rate in the first experiment while P-fertilizers were applied at 88 kg ha^{-1}. Soil pH and available P were subsequently determined to know the effectiveness of these 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.

RAE or LE = Soil pH (with test liming material)-soil pH (with control)/Soil pH (with conventional lime)-soil pH (with control) × 100%

RESULTS AND DISCUSSION

Soil pH increased with increase in lime application levels (Table 1) but declined with increasing incubation periods. Lime application at 4 t ha^{-1} led to the highest soil pH (7.5) followed by 3 t ha^{-1} (7.2) after 1 week-incubation period. There was no significant difference in pH of soils incubated for various periods when limed at 4 t ha^{-1} but soils incubated for 7 days with 3 t ha^{-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 2 t ha^{-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 1.0 t ha^{-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 the treated soils after 7, 14 and 21 days of incubation was significantly higher than for the un-amended soils (4.7) (Table 1). Liming at 1.0 t ha^{-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

Table 1: Soil pH and available phosphorus (P) contents after 7, 14 and 21 day-incubation periods with different levels of lime

	Incubation period (days)					
	7		14		21	
$Ca(OH)_2$ Applied (t ha^{-1})	pH	Available P (mg kg^{-1})	pH	Available P (mg kg^{-1})	pH	Available P (mg kg^{-1})
0	4.99e	7.09c	4.60d	7.15b	4.50e	4.24b
1	5.66d	10.79bc	5.54c	9.41b	5.50d	9.94a
2	6.14c	17.33a	6.65b	16.76a	6.46c	15.09a
3	7.20b	16.19ab	7.19a	14.48a	7.18b	15.61a
4	7.53a	13.01abc	7.53a	13.53a	7.54a	11.42a

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

Table 2: 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

	Incubation period (Days)					
	7		14		21	
Treatment	pH	Available P (mg kg^{-1})	pH	Available P (mg kg^{-1})	pH	AvailableP (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 (OF)	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
±SE	0.26	0.29	0.29	3.03	2.98	2.80

SE, Standard Error

indicative of acid conditions. This is evident from the available P contents of soils incubated at 1.0 t ha^{-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 2.0 t ha^{-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 (Tisdale *et al*., 1996).

Table 1 further reveals that soil available P (at most of the lime application levels) decreased with incubation time. The untreated soils had the least available P at all the incubation levels while 2.0 t ha^{-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 2.0 t ha^{-1} resulted in soil pH 6.1-6.6, which permitted the highest available P contents of the incubated soils. However, liming at 3.0 or 4.0 t ha^{-1} increased soil pH to above 7 causing the soil to be low in available P content compared with the values at 2.0 t ha^{-1}. Fageria *et al*. (1995) 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 2. 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 (Kotur, 1991). 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/P-fertilizer 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 Follet *et al*. (1981). 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.* (1991) 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.* (2000). FAO (2004) and Edwards (1991) 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 (Opara-Nadi *et al.*, 2000) that 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 (Akinrinde *et al.*, 1999; Siddaramappa *et al.*, 1991) while subsequent decrease could have been caused by P fixation (Saranganath *et al.*, 1977). 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 study of Minhas and Tripathi (1986) and Marwaha and Kanwar (1981) 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 its slow release by CRYS (which is largely a rock phosphate, RP) as well as the mineralization of the organic fertilizer (Akinrinde *et al.*, 2000; Reddy *et al.*, 1996). In a similar study, Akinrinde *et al.*, (2000) reported gradual increase in H_2O extracted 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 (Agegnehu and Taye, 2004).

Relative Agronomic Efficiencies (RAEs) or Lime Effectiveness (LE) of tested soil amendments (phosphorus fertilizer sources) relative to conventional lime: Table 3 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

Table 3: Soil pH and Relative Agronomic Efficiencies (RAEs) of lime and phosphorus fertilizer treatments at 7, 14 and 21 day-incubation periods

	Incubation period (Days)					
	7		14		21	
Treatment	pH	RAE (%)	pH	RAE (%)	pH	RAE (%)
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 (OF)	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+OF	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+OF	5.69	20.72	5.24	13.96	5.03	8.40
OF+SSP	5.73	22.79	5.05	5.40	5.00	7.14
CRYS+OF+SSP	5.55	13.47	4.91	-0.90	4.91	3.36
L+CRYS+OF	7.71	125.38	7.55	118.01	7.47	110.92
L+SSP+OF	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+OF+CRYS+SSP	7.58	118.65	7.41	111.71	7.41	108.40

subsequent decreases 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 (Opara-Nadi *et al.*, 2000).

CONCLUSIONS

Lime application rate at 2 t ha^{-1} gave soil pH values favourable for crop production and this also permitted the highest release of available P. This indicates that liming at 2.0 t ha^{-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 CRYS and OF treated soil samples, P availability during residual cropping is likely unlike in the case of SSP, which suffered fixation. Also, P fertilizer combinations such as OF+SSP, CRYS+OF+SSP and L+CRYS+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 CRYS and OF required for sustainable crop production would assist the farmer especially those working with acid soils.

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