Effects of lime and phosphate amendments on Alfisols of the Canary Islands

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The effects of lime ($Ca(OH)_2$) and disodium orthophosphate (Na_2PO_4H) added separately to selected Alfisols of the Acentejo Area (Tenerife, Canary Islands) have been studied. These soils have excessive acidity and a very high amount of exchangeable aluminium. $Ca(OH)_2$ significantly ($P = 0.01$) increased soil pH (at 50% acid neutralization) and available P (at 100–200% acid neutralization), and decreased exchangeable Al (at 12.5% acid neutralization) while the addition of Na_2PO_4H did not significantly affect the available P, exchangeable Al, or the pH of the soil. It is recommended that Alfisols should be treated with lime to neutralize 100–200% of the acid using wetting and drying cycles during equilibration before adding P.

Keywords: Alfisol; Acidity; Aluminium; Amendment

The poor growth shown by many plants on acid soils, particularly those with a pH <5.5 may be attributed to the acidity itself, the deficiency of P and Ca, or the toxicity resulting from the presence of Mn and Al in the soil (Schmehl *et al.*, 1950; Andrew *et al.*, 1973; Foy *et al.*, 1973a; Keisling and Fuqua, 1979). In most cases, the importance of the individual factors cannot readily be determined.

The symptoms of Ca and P deficiencies are frequently confused with Al toxicity (Randall and Vose, 1963; Johnson and Jackson, 1964; Lee, 1971), and the two tend to occur together because when Ca decreases, Al occupies its exchangeable positions. With respect to P, this element is blocked by Al in the plant including the roots.

The soils of the study area, Acentejo region, have high acidity with pH values between 4 and 6 in aqueous suspension. The exchangeable complex has a low content of Ca (26.7%) and high levels of Al (10.7%) (Gutiérrez *et al.*, 1987). All these characteristics seem to indicate that the addition of Ca and P could improve several of the physical and chemical properties of these soils (Gutiérrez *et al.*, *ibid.*; Trujillo *et al.*, 1987) and, therefore, the general fertility of the soil with a possible beneficial effect on yield.

The aim of this study is to report the variation of soil acidity due mainly to exchangeable Al, and available P, with the addition of Ca and P to the soil.

Materials and methods

The seven soils used in this study were volcanic Alfisols (Typic Haplustalf) from the Acentejo region in the north of Tenerife. The aqueous suspension of the samples (1:2.5) had a pH ranging between 4.2 and 4.8 and an exchangeable acidity due to the contribution of (Al + Mn + H) between 14.69 and 19.34 meq $100g^{-1}$.

Two experiments were carried out (1) addition to soil samples of increasing amounts of P as Na_2PO_4H at 0, 50, 100, 150, and 200 ppm; (2) addition to soil samples of sufficient $Ca(OH)_2$ to neutralize a theoretical 0, 12.5, 25, 50, 100, 200, or 300% of the exchangeable acidity. In both experiments, after the amendments were added, three wet-dry cycles over a period of 10 days were completed and samples were incubated moist for an additional 2 weeks at room temperature until a completely dried sample was achieved. After incubation the parameters determined were pH of the aqueous suspension (1:2.5), exchangeable Al (extracted with 1N KCl) (Kamprath, 1970), and available P_2O_5 (Olsen *et al.*, 1954). Both experiments and the chemical analyses were carried out on duplicate samples and the values shown in the tables correspond to the average value. Statistical analysis by variance analysis (*F*-test) and the Duncan Multiple Range Test (DMRT) were done with use of the statistical graphics system of the Statistical Graphics Corporation computer program with $P < 0.01$ as a significant difference.

Results and discussion

Some general characteristics of the soils [pH, O.M., P_2O_5, exchangeable cations (Ca, Mg, Na, K), exchangeable Al extracted in 1N KCl, CEC, and exchangeable acidity (Al + Mn + H)] are given in Table 1.

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Table 1 Chemical properties of the soils

Soil sample number	pH	O.M. (%)	P_2O_5 (%)	Exchangeable cations (meq $100g^{-1}$) Ca	Mg	Na	K	Mn	Al	meq $100g^{-1}$ CEC	Exchangeable acidity
1	4.7	2.58	104	3.51	0.82	0.80	1.68	0.33	1.65	21.5	14.69
2	4.6	4.62	76	5.07	0.76	0.10	1.41	0.16	1.76	23.1	15.76
3	4.6	2.35	149	2.97	0.73	0.12	1.77	0.24	2.54	21.5	15.91
4	4.2	3.01	173	2.68	0.44	0.19	1.49	0.37	3.44	21.0	16.20
5	4.8	4.56	69	6.54	1.00	0.16	0.63	0.18	0.99	25.4	17.07
6	4.8	1.34	69	2.30	0.74	0.10	0.88	0.13	3.30	22.8	18.78
7	4.2	2.68	83	2.06	0.33	0.02	1.35	0.27	5.18	23.1	19.34

Table 2 Effect of P addition as Na_2PO_4H on some soil chemical properties

Soil number	Soil chemical property	ppm P 0	50	100	150	200
1	pH	4.7	4.7	4.7	4.7	4.7
2		4.6	4.7	4.8	4.7	4.8
3		4.6	4.7	4.7	4.7	4.7
4		4.2	4.2	4.3	4.4	4.3
5		4.8	4.9	4.8	4.9	4.9
6		4.8	4.7	4.8	4.7	4.8
7		4.2	4.3	4.4	4.4	4.4
1	1N KCl extractable Al (ppm)	149	153	147	150	153
2		159	193	167	199	184
3		229	245	221	210	208
4		319	326	328	347	335
5		89	98	91	80	102
6		297	270	281	250	257
7		467	454	448	452	416
1	P_2O_5 (ppm)	104	119	147	119	104
2		76	90	90	83	76
3		149	149	173	165	157
4		173	215	173	198	214
5		69	83	76	97	90
6		69	76	62	62	56
7		83	83	83	104	90
1	Ca (meq $100g^{-1}$)	3.51	3.68	3.62	3.75	3.71
2		5.07	3.94	3.97	4.03	5.14
3		2.97	2.86	2.92	2.93	3.60
4		2.68	2.50	2.47	2.45	3.12
5		6.54	7.25	7.27	7.13	7.96
6		2.30	3.51	3.38	3.40	3.40
7		2.06	2.06	2.61	2.06	2.22
1	Mg (meq $100g^{-1}$)	0.82	0.90	0.92	0.88	0.92
2		0.76	0.76	0.77	0.76	0.78
3		0.73	0.65	0.68	0.63	0.64
4		0.44	0.40	0.36	0.44	0.46
5		1.00	0.87	0.86	0.83	0.84
6		0.74	0.74	0.75	0.77	0.72
7		0.33	0.25	0.25	0.30	0.24

Differences between treatments of each soil sample are not significant

Na_2PO_4H addition

The results of the addition of P on some soil properties are set out in Table 2. The variations in the parameters with phosphate addition are not significant. Even available soil P remained practically constant. Therefore, the P added seemed to be fixed by the Fe and Al oxides which are to be found in large amounts in these soils (Fernández Caldas *et al.*, 1982).

$Ca(OH)_2$ addition

The experimental results and statistical analysis for $Ca(OH)_2$ addition are given in Table 3. In all soils, $Ca(OH)_2$ increased the pH, and the pH for neutralization ≥50% was significantly higher than the 0% neutralization, according to DMRT.

The exchangeable Al of all the samples, independent of their original level of acidity, was reduced by between about 10- and 75-fold after a theoretical neutralization of 50% of the acidity (Table 3). The higher the Al in the original soil, the more pronounced was the decrease. Significant reduction of exchangeable Al ($P < 0.01$ by DMRT) could be observed from 12.5% neutralization. It should also be noted that exchangeable Al changed very little from 50 to 300% neutralization. At neutralization >50%, available P increased, and available P of all soils were significantly ($P < 0.01$) greater than the control (0% neutralization) after 200% neutralization had been achieved. This increase is probably a result of changes in the chemical reactivity and to the form in which the aluminium is found.

Liming of an acid soil causes two opposite effects on the available P. Firstly, P adsorption by the amphoteric surfaces decreases when the pH increases and, secondly, when the soils have a very high content of exchangeable Al, hydroxy-Al polymers, which constitute a new P-adsorbing surface in soils (Haynes, 1983), may be precipitated. This situation is not completely clear, but Haynes (1983) observed that when a moistened acid soil with a very high exchangeable Al content was incubated with lime and P, the P adsorption increased. On the contrary, if the limed soil was dried before adding the phosphate, the P adsorption decreased. Apparently, drying significantly changes the surface characteristics of a limed soil. Haynes suggested that Al hydroxides like gibbsite may crystallize as a result of drying. More research on this topic is needed.

Exchangeable Ca content increased significantly ($P < 0.01$) after 25% neutralization in most soils, except for soils 1 and 5 where the increase was significant after 50% neutralization had been reached. The amount of exchangeable Mg for most

Table 3 Effect of calcium addition as $Ca(OH)_2$ on some soil chemical properties

Soil sample number	Soil chemical property	% Neutralization 0	12.5	25	50	75	100	200	300	F	Significance level
1	pH	4.7	4.9	5.1	5.7a	6.3a	6.9a	7.6a	8.4a	85.4	NS
2		4.6	4.9	5.1	5.7a	6.1a	6.5a	7.6a	8.1a	91.9	NS
3		4.6	4.7	5.0	5.7a	6.4a	6.9a	7.8a	8.4a	97.0	NS
4		4.2	4.4	5.1	5.2a	5.8a	6.2a	7.5a	7.8a	94.6	NS
5		4.8	5.1	5.3	5.8a	6.2a	6.3a	7.5a	7.8a	55.9	NS
6		4.8	5.0	5.8	6.0a	6.6	6.9a	7.8a	8.3a	113.3	NS
7		4.2	4.3	5.2	5.3a	5.8a	6.3a	7.8a	8.2a	125.5	NS
1	1N KCl extractable Al (ppm)	149	63a	29a	4a	3a	3a	3a	2a	126.1	NS
2		159	71a	29a	4a	3a	3a	2a	2a	129.9	NS
3		229	136a	63a	24a	14a	6a	6a	6a	187.8	NS
4		319	205a	19a	14a	3a	3a	3a	3a	323.6	NS
5		89	43a	16a	3a	3a	2a	2a	2a	49.9	NS
6		297	102a	38a	4a	3a	3a	2a	2a	435.4	NS
7		467	305a	23a	15a	8a	8a	7a	5a	478.2	NS
1	P_2O_5 (ppm)	104	104	104	119	112	134a	142a	149a	14.8	0.0005
2		76	76	90	90	97	97	104a	174a	30.0	NS
3		149	149	142	149	142	165	189a	189a	14.9	0.0005
4		173	173	173	181	189	189	279a	329a	87.0	NS
5		69	69	83	90	83	83	149a	165a	76.5	NS
6		69	69	76	69	83	83	97a	97a	12.2	0.001
7		83	90	97	97	119a	134a	157a	165a	66.1	NS
1	Ca (meq $100g^{-1}$)	3.51	4.96	6.53	8.55a	11.22a	13.50a	19.80a	25.60a	108.1	NS
2		5.07	6.20	7.67a	9.69a	11.62a	13.14a	20.79a	23.54a	272.4	NS
3		2.97	4.21	5.54a	8.45a	10.66a	13.37a	20.98a	25.29a	245.9	NS
4		2.68	4.68	7.69a	7.79a	9.81a	13.47a	20.77a	25.53a	147.7	NS
5		6.54	6.72	8.16	10.61a	12.60a	14.70a	24.04a	27.22a	192.7	NS
6		2.30	3.29	7.61a	9.15a	11.60a	15.93a	24.92a	29.04a	198.7	NS
7		2.06	4.10	5.01a	8.21a	11.84a	13.69a	22.55a	26.83a	377.0	NS
1	Mg (meq $100g^{-1}$)	0.82	0.85	0.76	0.69	0.60a	0.60a	0.44a	0.30a	21.6	0.0001
2		0.76	0.74	0.72	0.67	0.66	0.57	0.32a	0.30a	20.2	0.0002
3		0.73	0.60	0.57	0.67	0.58	0.55	0.34a	0.20a	13.3	0.0008
4		0.44	0.46	0.43	0.51	0.47	0.43	0.35	0.24a	4.2	0.0308
5		1.00	0.92	0.93	0.93	0.82	0.82	0.64a	0.52a	9.7	0.0020
6		0.74	0.72	0.71	0.68	0.64	0.62	0.34a	0.13a	29.8	NS
7		0.33	0.35	0.36	0.35	0.36	0.11a	0.28a	0.11a	11.4	0.0013

The letter a following a number denotes that the number is significantly ($P = 0.01$) different from the 0% neutralization control in the same row by Duncan's Multiple Range Test

soils (except soil 4) did not decrease significantly until 200% acid neutralization (Table 3).

Based on the results of this study Alfisols should be treated with $Ca(OH)_2$ or $CaCO_3$ and allowed to equilibrate over a suitable time. Wetting and drying cycles should be produced during the liming and equilibration. The amount of $Ca(OH)_2$ required to change a soil with a pH of 3.5 and an exchangeable Al of 280 ppm to a pH of between 5 and 6 and an exchangeable Al of 11 ppm is presented here as an example. The acidity (Al + Mn + H) should be neutralized by 100 to 200%. An average value of 150% requires the addition of 0.657 g of $Ca(OH)_2$ $100g^{-1}$ of soil or 1.80 kg m^{-2} (or its equivalent in $CaCO_3$ or CaO) for a depth of 25 cm and an apparent density of 1.10 g cm^{-3}, the average for this soil depth.

References

Andrew, C.S., Johonson, A.D. and Sandland, R.L. (1973) Effect of aluminium on the growth and chemical composition of some tropical and temperature pasture legumes, *Aust. J. Agric. Res.* **24** 325–339

Fernández Caldas, E., Tejedor Salguero, M.L. and Quantin, P. (1982) *Suelos de regiones volcánicas, Tenerife, Islas Canarias*, Colección Viera y Clavijo IV, Secretariado de Publicaciones de la Universidad de La Laguna, Consejo Superior de Investigaciones Científicas.

Foy, C.D., Fleming, A.L. and Schwartz, J.W. (1973a) Opposite aluminium and manganese tolerances of two wheat varieties, *Agron. J.* **65** 123–126

Gutiérrez, F., Trujillo, I. and Figueruelo, E. (1987) Viñedos Canarios, Zona de Acentejo, II. Características Fisicas, *Anal. Edafología Agrobiología* **XLVI** 7–8

Haynes, R.J. (1983) Effect of lime and phosphate applications on the adsorption of phosphate, sulfate and molybdate by a spodosol, *Soil Sci.* **135** 221–227

Johnson, R.E. and Jackson, W.A. (1964) Calcium uptake and transport by wheat seedlings as affected by aluminium, *Proc. Soil. Sci. Soc. Am.* **28** 381–386

Kamprath, E.J. (1970) Exchangeable aluminium as a criterion for liming leached mineral soils, *Soil Sci. Soc. Am. Proc.* **34** 252–254

Keisling, T.C. and Fuqua, M.C. (1979) Aluminium and manganese toxicity of rose plants grown in East Texas. *Hort. Sci.* **14** 509–510

Olsen, S.R., Cole, C.V., Watanabe, F.S. and Dean, L.A. (1954) Estimation of available phosphorus in soils by extraction with sodium bicarbonate, *U.S. Dep. Agric. Cir.* **939**

Lee, C.R. (1971) Influence of aluminium on plant growth and mineral nutrition of potatoes, *Agron.J.* **63** 604–608
Randall, P.J. and Vose, P.B. (1963) Effect of aluminium on uptake and translocation of phosphorus by perennial ryegrass, *Plant Physiol.* **38** 403–409
Schmehl, W.R., Peech, M. and Bradfield, R. (1950) Causes of poor growth of plants on acid soils and beneficial effects of liming, I. Evolution of factors responsible for acid soil injury, *Soil Sci.* **70** 393–410
Trujillo, I., Figueruelo, E. and Gutierrez, F. (1987) Viñedos Canarios, Zona de Acentejo, III. Características químicas, *Anal. Edafología Agrobiología* **XLVI** 9–10