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Potential Detrimental Effects from Liming Highly Weathered Soils to Neutrality[1]

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Liming has been an integral part of the cultural practices developed for the intensive agricultural use of acid soils in temperate regions. For many years the use of legumes to supply N for the other crops was a key component of cropping systems. Maximum growth of legumes, such as clovers and alfalfa, was obtained on well limed soils with pH 6.5 to 7.0. Yields of subsequent non-legume crops were best at pH 6.5 to 7.0 due to the higher amounts of N fixed by the preceding legume. From these kinds of experiments the conclusion was reached that pH 6.5 to 7.0 was optimum for growth of corn, small grain and forages.

When agronomists who were trained in the temperate regions worked with soils in the tropics they attempted to transfer information obtained on liming of Mollisols and Alfisols to the highly weathered, acid Ultisols and Oxisols. In many instances liming of soils in the tropics to pH 7 did not give the kind of response obtained with soils in temperate regions and often resulted in no response or decreased yields. In this paper, some of the reasons are discussed why crop yields on the highly weathered, acid soils of the tropics and the southeastern United States may be decreased when limed to pH 7 and above.

Chemical and Mineralogical Properties.

The silicate clays of highly weathered acid soils are coated with hydroxy-Al and hydroxy-Fe which are proton donors (or OH acceptors) and are responsible for much of the apparent pH-dependent charge of soils (Coleman and Thomas, 1967). Anions are also adsorbed by the hydroxy-Al and hydroxy-Fe ions. Thus the Al and Fe coated clays generally regulate the availability of nutrients in the Ultisols and Oxisols.

Kaolinite is generally the predominant clay mineral in the highly weathered acid soils. Because of the acid conditions and high rainfall these soils contain a low reserve of weatherable minerals. In contrast, Mollisols and many Alfisols formed from young, glacial derived materials have a relatively large reserve of weatherable minerals. The predominant clays are montmorillonite, illite and vermiculite which generally have no coatings of hydroxy-Al and hydroxy-Fe. Thus, the clay minerals and nutrient reserve of Ultisols and Oxisols are quite different from those of Mollisols and many Alfisols. Therefore, the effects of liming to pH 7 may be expected to be different for highly weathered soils as compared with the less weathered soils.

Effect of Liming on Physical Properties.

The red soils of the Tropics (Oxisols) generally are well aggregated and have excellent structural properties (Hardy, 1933). Iron oxide compounds which coat the clays are responsible for the stable aggregates formed in red soils (Lutz, 1936). It often has been reported that liming causes a deterioration of the structure of soils in the Tropics. The theory is advanced that liming reduces the positive charge of iron oxide developed at low pH and in this manner reduces the aggregation of clays (Nye, 1966). Schuffelen and Middleburg (1954) presented data for a lateritic soil from Java in which liming a soil of pH 4 to pH 6.5 resulted in a 90% decrease in the percolation rate. The theory was advanced that the peptizing effect of hydroxyl ions competes too strongly with the coagulating effect of Ca ions and causes a deterioration of the structure. However, the soil they worked with contained 2.2 meq Na/100g which was 25% of the exchangeable cations. Such a high Na saturation is not typical of Ultisols and Oxisols and extrapolation of these results to other soils in the Tropics is questionable. Venema (1941) who also worked in Java found that liming a red lateritic soil from pH 6 to pH 7.5 reduced the permeability only 10%.

Lutz (1935) found that the colloids of the Davidson soil, which contains predominantly kaolinitic clay and has a high iron oxide content, flocculated irrespective of the cation saturation. Liming, therefore, did not negate the aggregating effect of the iron oxide. The cation saturation of the colloids, however, did affect the permeability of a Davidson clay membrane (Table 1). The permeability was less for the Ca saturated clay than for the H saturated clay which probably was predominately Al saturated. The Ca saturated clay had a pH of 7.1.

TABLE 1.—EFFECT OF CATION SATURATION ON PERMEABILITY OF A DAVIDSON CLAY MEMBRANE (LUTZ, 1935).

Saturating Cation	Permeability ml H_2O/hr
H	100
Ca	78
Na	62

Percolation of water through the B horizon of a Cecil clay loam (Ultisol) was decreased by liming (Peele, 1936) (Table 2). Liming also increased the percentage of aggregates with a diameter of less than 0.02 mm, which could only occur with a decrease in percentage of larger aggregates. Liming did not affect the flocculation of the colloidal material but it did influence the degree of aggregation and stability of the granules.

In a review, Harris et al. (1966) stated that the stabilization of surface soil aggregates is also influenced by organic binding substances which are microbially produced. They pointed out that liming often stimulates microbial activity and in this way may have a beneficial effect on the structure of certain soils. Aggregates formed by microbial polysaccharides were more stable in acid than in alkaline soils (Martin and Aldrich, 1955). It was hypothesized

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TABLE 2.—THE EFFECT OF LIMING THE B HORIZON OF A CECIL CLAY LOAM ON PERCOLATION AND SIZE OF AGGREGATES (PEELE, 1936).

Lime tons/acre	Percolation ml/hr	Aggregates less than 0.02 mm diameter %
0	51.5	6
1	41.5	20
2	30.5	36

that either the acid form of the polysaccharides was more resistant to attack by soil organisms or that fungi which predominate in very acid soils do not decompose the organic substances as fast as do bacteria and actinomycetes.

Liming of acid soils in which Fe promotes aggregation does not destroy flocculation of the soils. However, it does seem to result in formation of smaller aggregates and reduces the stability of microbially formed aggregates to degradation. The result is a decrease in permeability of the soils and consequently increases the erosion hazard.

Plant Growth and Nutrient Availability as Influenced by Liming to pH 7. Growth. Responses have been obtained to relatively low rates of lime when acid Ultisols and Oxisols have a pH of 5 or less. Higher rates of lime which bring the soil pH to near neutrality often depress yields. Monteith and Sherman (1963) found that sudan grass grown on acid latosols of Hawaii responded to lime applications which brought the pH to 5.5. However, yields were drastically reduced when the soils were limed to pH 7 (Table 3). Lime rates greater than that required to neutralize exchangeable Al reduced growth of trudan on Oxisols in Natal (Reeve and Sumner, 1970) (Table 4). Maximum yields of corn grain and stover on a Humic Latosol were obtained when the soil was limed to give a pH range 5.8 to 6.4 (Younge and Plucknett, 1964). Yields were reduced when the soils were limed above pH 6.4. Liming an acid sandy Ultisol in North Carolina to pH 7 reduced soybean growth 36% as compared with that at pH 5.7 (Mann, 1930). However, soybean growth was increased almost 90% by raising the pH from 4 to 5.7.

TABLE 3.—EFFECT OF LIMING A FERRUGINOUS LATOSOL ON THE GROWTH OF SUDAN GRASS (MONTEITH AND SHERMAN, 1963).

Lime tons/acre	Soil pH	Dry Matter Tops	Dry Matter Roots
		g/pot	
0	4.6	85.8	13.9
2.5	5.6	93.3	14.5
10.0	7.0	53.6	7.0

TABLE 4.—GROWTH OF TRUDAN ON EIGHT OXISOLS AS INFLUENCED BY LIMING (REEVE AND SUMNER, 1970).

Lime tons/acre	pH	Exch. Al Index meq/100g	Dry weight g/pot
0	4.5	0.8	1.7
1	5.0	<0.1	3.8
2	5.5	<0.1	3.4
3	5.9	<0.1	3.0

These examples illustrate that lime rates which only raise the pH to levels which neutralize the exchangeable Al generally give an increase in plant growth. However, liming acid Ultisols and Oxisols to pH 7 results in nutrient disorders which drastically reduce crop growth.

Effect on phosphorus availability. Studies with acid soils have shown that in some instances plant growth was decreased and plants exhibited P deficiencies when the soils were limed above pH 7 (Pierre and Browning, 1935). No reduction in growth was obtained with liming to pH 7 on those soils which did not respond to P fertilization. Growth of corn was considerably less at pH 7 as compared with pH 5.8 with normal rates of P fertilization (Table 5). Extremely high rates of P were required at pH 7 to increase plant growth.

TABLE 5.—EFFECT OF SOIL pH AND SUPERPHOSPHATE ON GROWTH OF CORN ON DEKALB SILT LOAM (PIERRE AND BROWNING, 1935).

Superphosphate lbs/acre	Dry Matter pH 5.8	Dry Matter pH 7.0
	g/pot	
0	9.7	2.7
500	28.7	8.7
2500	43.5	34.5

Fox et al. (1964) found that liming an aluminous ferruginous latosol to pH 6.1 increased the uptake of fertilizer P but liming to pH 7 markedly decreased P uptake by sorghum and DESMODIUM INTORTUM (Table 6). They did not get this marked decrease at pH 7 with a humic ferruginous latosol. A possible explanation for these results could be the strength of P adsorption by the soils. Where P is bound quite strongly a high concentration of Ca ions could reduce the P in soil solution to a very low level by formation of calcium phosphates. On the other hand where P is not bound very tightly a sufficient concentration of P could be maintained.

TABLE 6.—PHOSPHORUS UPTAKE BY SORGHUM AND DESMODIUM INTORTUM GROWN AT SEVERAL pH LEVELS ON TWO LATOSOLS (FOX ET AL., 1964).

Soil pH	Phosphorus uptake: sorghum	Phosphorus uptake: desmodium intortum
	Aluminous Ferruginous Latosol micrograms/pot	
5.3	377	1053
5.5	886	1041
6.1	1407	1674
7.0	171	12
	Humic Ferruginous Latosol	
5.0	777	480
5.6	872	1409
7.2	1493	1370

Pratt el al. (1969) found that within a morphological group of Brazilian soils there was a relationship between P fixation and free iron oxide content.

Latosols fixed less P per given percentage of iron oxide than did the Red-yellow podozols. They suggested that one reason might be a difference in the crystallinity of the iron oxide. Phosphorus adsorption would be less with increased crystallinity of the iron oxide.

Rates of lime which neutralize exchangeable Al result in more efficient uptake of P from Ultisols and Oxisols (Fox et al., 1964; Woodruff and Kamprath, 1965; Reeve and Sumner, 1970). However, lime rates which raise the pH to 7 will probably cause a marked decrease in P availability particularly where P is adsorbed very strongly.

Effect on boron availability. Lime induced B deficiency probably does not occur very often below pH 6.5. Naftel (1937) found that B deficiencies occurred in hairy vetch when a Norfolk loamy sand was limed to pH 7.3. As the pH was further increased growth of hairy vetch continued to decrease (Table 7). Addition of B increased growth at pH 5.5 and 6.4 and prevented the decrease in yield as the pH was raised above 7.

TABLE 7.—THE GROWTH OF HAIRY VETCH ON A NORFOLK LOAMY SAND AS INFLUENCED BY pH LEVEL AND BORON, IRON AND MANGANESE FERTILIZATION (NAFTEL, 1937).

Soil pH	Dry Matter		
	check	B	Fe&Mn
		g/pot	
5.50	4.90	6.50	6.15
6.40	6.75	7.70	6.40
7.28	4.90	—	—
7.66	4.20	7.65	3.85
7.86	2.25	7.86	3.10

In field studies with tobacco no response to B fertilization was obtained at pH levels ranging from 4.9 to 6.0. A response was only obtained on a soil with a pH of 7.0 (Hutcheson and Woltz, 1956).

The uptake of B was much greater at pH 5.2 than at pH 7.4 in a Norfolk sandy loam even though the content of water soluble B was the same (Wear and Patterson, 1962). This suggests that the rate of replenishment of B in the soil solution is much slower at the higher pH. Okazaki and Chao (1968) found that less of the added B was desorbed from Hawaiian soils when they had been limed.

Boron retention of soils at pH 6 was found to be correlated with free iron oxide content and with Al extracted with 1. ON KCl (pH 2) (Sims and Bingham, 1968b). The adsorption of B by hydroxy-Al and hydroxy-Fe increased sharply as the pH increased (Sims and Bingham, 1968a). Maximum retention of B by hydroxy-Al and hydroxy-Fe occurred at pH 7 and 8.5 respectively. The retentive capacity of the hydroxy-Al was approximately 10 times that of the hydroxy-Fe.

Liming of soils containing hydroxy-Al and hydroxy-Fe coated clays to pH 7 and above greatly increases the adsorption of B and thereby reduces its availability. This mechanism of B adsorption would be important in Ultisols and Oxisols but would not be of much importance in Mollisols and many Alfisols.

Effect on Mn availability. Lime induced Mn deficiencies generally occur when low Mn soils with pH 5 and less are limed above pH 6.2. Mehlich (1957) found that manganese sulfate titrated with calcium hydroxide formed a precipitate at pH 8.5 but in the presence of Al and Fe^{+3} salts, Mn started to precipitate at pH 5.8. When a White Store soil was saturated with Al and Fe^{+3} 100 and 80%, respectively, of the added Mn was exchanged with NH_4 at pH 6, but only 52 to 57%, respectively, was exchanged at pH 7.

The presence of Fe results in precipitation of some Mn at Eh-pH values lower than those generally necessary to precipitate Mn (Collins and Buol, 1970). The removal of Mn is thought to be due to both occlusion and sorption by the Fe precipitate. Acidification of the precipitated Fe-Mn mixtures only brought a small part of the Mn back into solution.

Soybean growth on a Dunbar fine sandy loam in North Carolina was increased markedly when limed from pH 4 to pH 5.7 (Table 8) (Mann, 1930). However, liming to pH 6.4 and above decreased growth and the plant Mn content. This suggests that the available soil Mn level was markedly decreased. Studies by Sanchez and Kamprath (1959) verify this point. They found that the exchangeable Mn level of acid Bladen and Norfolk soils was reduced more than one-half when they were limed to pH 6.7 and 7.1, respectively. It can be generally concluded that liming soils, which have a pH of 5 or less and contain appreciable amounts of Al and Fe, may cause Mn deficiencies when the pH is raised above 6.2.

TABLE 8.—THE EFFECT OF LIMING A DUNBAR FINE SANDY LOAM ON THE GROWTH AND MANGANESE CONCENTRATION OF SOYBEANS (MANN, 1930).

Lime tons/acre	pH	Dry Matter g/pot	Plant Mn ppm
0	4.0	7.34	99
0.50	4.7	8.41	56
0.75	5.0	10.26	41
1.0	5.3	10.01	30
1.5	5.7	13.47	25
2.0	6.4	10.64	24
2.5	7.0	8.61	21

Availability of Zn. In a study using Norfolk soils Peech (1941) found that approximately 60% of the added Zn was recovered by extraction with *N* NaCl, at pH 5, 30% at pH 6 and less than 10% at pH 7. A number of studies have shown that plant uptake of Zn is decreased by liming. Zn deficiency of citrus grown on sandy Norfolk soil was readily induced by liming above pH 6 (Camp and Reuther, 1937). The Zn content of sorghum was sharply decreased by addition of 1 ton lime/acre to a Norfolk soil with an initial pH of 5.6 (Wear, 1956). It can be concluded from the above results that liming of soils with a low native supply of Zn to pH 7 will reduce the availability of Zn and very likely will induce Zn deficiencies particularly under intensive cropping.

Summary.

The hydroxy-Al and hydroxy-Fe coatings on clays regulates to a large degree the chemical and physical properties of Ultisols and Oxisols. The hydroxy ca-

tions which are OH acceptors are responsible for the pH dependent cation exchange capacity, the adsorption of anions and soil aggregation.

Liming of Ultisols and Oxisols to pH 7 and above often decreases plant growth. Some possible detrimental affects are:

(1) There is a tendency to promote formation of smaller aggregates and thus reduce the rate of infiltration and making the soils more susceptible to erosion.

(2) Phosphorus deficiency is induced in those soils which strongly adsorb P, probably by formation of sparingly soluble calcium phosphates.

(3) Boron adsorption by hydroxy-Al and hydroxy-Fe is greatly increased and thereby reducing the availability of B.

(4) In the presence of Al and Fe compounds, Mn precipitates at lower pH values than when these materials are absent.

(5) Availability of Zn is substantially reduced by liming.

Liming rates for Ultisols and Oxisols should be based on neutralization of exchangeable Al and in some instances reduction of soluble Mn rather than bringing the pH to neutrality. This will lessen the possibility of any detrimental effects of liming on nutrient availability.

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