

# Effects of Carbon, Nitrogen, Phosphorus, and Biocides on Phosphorus Adsorption in Highly Weathered Soils

Lee, Dowon and Carl F. Jordan\*

*Department of Environmental Planning, Graduate School of Environmental Studies,*

*Seoul National University, Seoul 151-742, Korea*

*Institute of Ecology, University of Georgia, Athens, GA 30602, USA\**

## 탄소, 질소, 인 및 살균제가 고도로 풍화된 토양의 인 흡착에 미치는 영향

이도원 · Carl F. Jordan\*

서울대학교 환경대학원 환경계획학과

*Institute of Ecology, University of Georgia, Athens, GA 30602, USA\**

### ABSTRACT

After two highly weathered soils were treated with glucose, ammonium nitrate, monobasic potassium phosphate and biocides, and incubated for 4 or 6 weeks, adsorption tests were carried out to determine their effect on P adsorption. Glucose addition generally decreased P adsorption. The addition stimulated microbial activity, which might contribute to the reduced adsorption, probably through chelation and anion competition. Consistent tendency was not observed with N treatment. Addition of P initially decreased P adsorption, probably through blockage of adsorption sites. Biocides generally decreased adsorption, probably because the microbes that survived the biocides grew and metabolized rapidly using the remains of the microbes that had been killed. Soil 1 with naturally lower levels of C and higher levels of aluminium adsorbed more P than soil 2.

These results suggest that in highly weathered soils, which are low in available P and high in exchangeable Al, cultivation techniques which increase soil organic matter will also result in higher levels of plant-available P.

**Key words:** Adsorption, Chelation, Microbial activity, Organic matter, Phosphorus, Ultisol.

### INTRODUCTION

Alternative management techniques such as minimum cultivation and agroforestry are becoming more common (National Research Council 1989), especially on highly weathered tropical and subtemperate soils (Wiese 1983).

In minimum cultivation, organic matter input into the soil is often increased. The benefits of increased levels of soil organic matter include: 1) improved soil structure, 2) increased water holding capacity, 3) acting as a source and sink for plant nutrients, and 4) increased cation exchange and buffer capacity (Tate 1987).

In region with low average temperatures where decomposition is slow, minimum tillage may result in an accumulation or "loading" of soil organic matter, with a concomitant immobilization of nutrients. This has been attributed to: 1) greater physical occlusion of soil organic matter (Tiessen *et al.* 1984a), 2) lack of tillage which enhances microbial degradation (Doran *et al.* 1987), and 3) dominance of fungi which have slower nutrient turnover and lower growth efficiency than bacteria (Holland and Coleman 1987, Hendrix *et al.* 1987).

In highly weathered acid soils of warmer climates, aluminum toxicity and phosphorus availability are often greater problems than slow decomposition. Reduced aluminum toxicity (Hargrove and Thomas 1981) and improved phosphorus availability (Lee *et al.* 1990) are two benefits frequently associated with increased soil organic matter in tropical and sub-temperate regions. These effects are extremely important in alleviating plant stresses associated with what are considered to be the leading constraints to agronomic production on soils classified as oxisols and ultisols with aluminum toxicity and phosphorus deficiency (Olson and Engelstad 1972, Stevenson 1986).

Several mechanisms have been suggested to explain how organic matter enhances availability of soil phosphorus to plants. The mechanisms include solubilization by weathering (Johnson *et al.* 1977, Kucey 1983, Tate 1984, Thomas *et al.* 1985, Lopez-Hernandez *et al.* 1986, Nagarajah *et al.* 1968, 1970) and competition by organic ligands for adsorption sites on soil minerals (Sibanda and Young 1989, Traina *et al.* 1986, Young and Bache 1985). Organic matter can also decrease the availability of P through adsorption, but desorption is also important, and the net result of higher soil organic matter may be increased P availability (Harter 1969, Tiessen *et al.* 1984b, Le Mare 1982).

In previous work (Lee *et al.* 1990), we found higher levels of microbial activity caused by higher levels of C in soil resulted in less adsorption of P, as determined by fractionation of soil P. In this work, the objective was to determine the effect of C on P availability using adsorption tests. Other objectives were to evaluate interactions of C with inorganic N and P additions, and with biocides. Initial status of soil N and P may influence the P adsorption/desorption processes (Lee *et al.* 1990). Transformation of N in soil is an important factor influencing P adsorption processes by altering the concentration of the hydrogen ion in soil solution. Nitrification can be coupled to solubilization of iron-phosphate due to chemical reduction of  $Fe^{3+}$  to relatively mobile  $Fe^{2+}$  under reducing conditions (Jansson 1987). Biocides were included in the experiments to compare the influence of fungi vs. bacteria in influencing adsorption/desorption. Combinations of biocides may elucidate interactions of several biotic groups (Ingham *et al.* 1985). Because soil type strongly influences P adsorption and desorption characteristics (Lajtha and Bloomer 1988), we

compared adsorption on two ultisols, one higher in Al and lower in C than the other.

## METHODS

### Soil Types

Soils were taken from the B horizon, below the rooting zone of trees, to minimize organic matter content. Soil 1 was a Madison sandy clay loam, a calvee, kaolinitic, thermic typic hapludult (USDA 1968) collected in Clarke County, Georgia. Sand, silt, and clay were 46.2%, 12.3% and 41.5%, respectively. Extractable Al with KCl was 0.14 cmol/kg soil, total C 5.4 g/kg soil, and N undetectable by CHN analyzer. Water soluble inorganic P was less than 1 ppm. Soil 2 was collected near Marab, Par, in the Amazon Basin of Brazil. It has been classified by the Brazilian system as Podizolico Vermelho Amarelo Alico (Red Yellow Podzolic). This is a type of ultisol in the U.S. Soil Taxonomy (Sanchez 1976). Sand, silt, and clay were 12%, 71%, and 17%, respectively. Extractable Al with KCl was 0.01 cmol/kg soil, total C 15.0 g/kg soil, and N 0.08 g/kg soil by CHN analyzer.

### Experimental Design and Treatment

Twenty grams of soil (oven dry basis) was placed in ten gram glass vials. Soils were treated in three blocks, with two replicates for soil 1, and three replicates for soil 2. For soil 1, N was added to the columns in one block at the rate of 0.1 g  $\text{NH}_4\text{NO}_3\text{-N}$ /kg soil. In a second block, 0.05g  $\text{KH}_2\text{PO}_4\text{-P}$ /kg soil was added. There were no additions of N nor P in the third block.

Within each block there were four treatments: C as 1 gram of glucose-C/kg soil, to stimulate microbial activity; C plus bactericide; C plus fungicide; C plus bactericide plus fungicide. Bactericide was streptomycin, added at a rate of 3 g/kg soil. Fungicide was cycloheximide, added at 1 g/kg soil. There were two control columns that received no additions, two in the N block that received only N, and two in the P block that received only P.

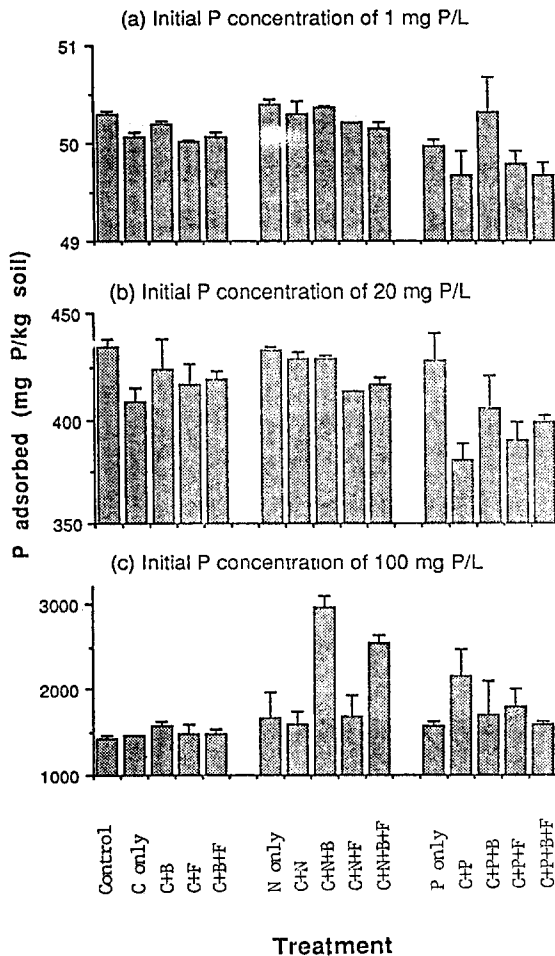
Soil 2 was used as a comparison for soil 1, to determine P adsorption differences in a soil with naturally higher levels of C and lower levels of Al, and to confirm any effects of N addition on P adsorption observed in soil 1. Since the soils differed in other ways too, the comparison is not ideal. Yet it was felt that using soils with naturally different levels of C might yield information not obtainable through experiments in which soil C was manipulated with additions of glucose C. Soil 2 had the following treatments: additions of N; bactericide (B) only; N+B; fungicide (F) only; N+F; B+F; N+B+F; control with no additions. One gram cellulose-C/kg soil was also included as a treatment.

### Incubation

The soil in each vial was adjusted to 43% soil moisture, which represented approximate field capacity. Vials were incubated at 25°C for four weeks for soil 1, and for six weeks for soil 2.

### Phosphorus Adsorption Test

Procedures were a modification of the method described by Fox and Kamprath (1970). After incubation, soil was air-dried, ground, and passed through a 0.5 mm sieve. One-half gram of soil sample was placed in 25ml of a 0.01 M  $\text{CaCl}_2$  solution containing 1, 20, and 100 mg  $\text{KH}_2\text{PO}_4\text{-P}$  /L solution. For soil 2, only P at 20 mg /L concentration was used. The soil and phosphorus mixture was continually shaken end-over-end for 24 hours. Five milliliter of subsample was pipetted from the mixture after 0.5, 3, and 24 hour reaction times. These suspensions were centrifuged for 10 minutes at 10,000 rpm at 0°C, and the super-



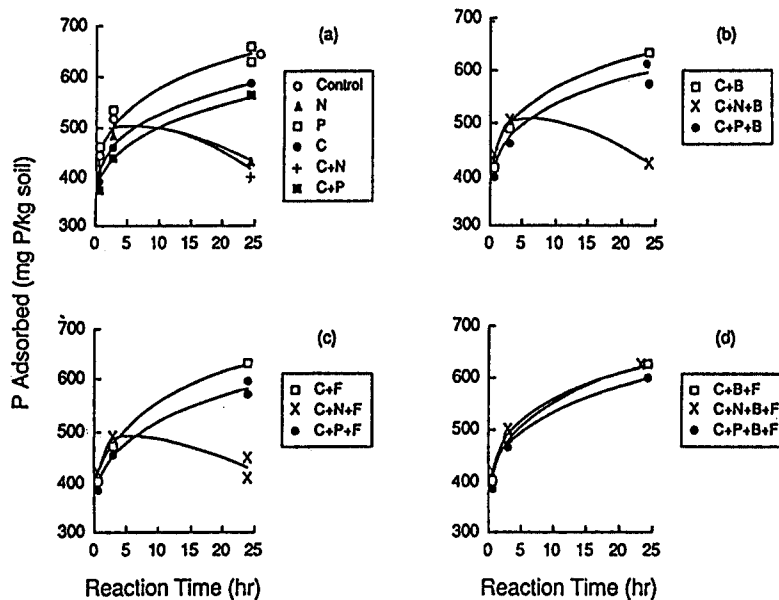
**Fig. 1.** Adsorption of P by soil 1 during 0.5 hr reaction time from solution initially containing three levels of dissolved P. Treatment symbols: C=glucose; N=ammonium nitrate; P=monobasic potassium phosphate; B=bactericide (streptomycin); F=fungicide (cycloheximide).

natant was passed through a Whatman No. 42 filter. The filtrate was stored at 4°C and inorganic P was determined by the molybdenum blue method, adapted for the Technicon Auto Analyzer (Allen *et al.* 1974). Adsorbed P was calculated as the difference between initial and final P concentrations.

## RESULTS AND DISCUSSION

### Effects of Carbon

Adsorption of P after 0.5 hour for the most cases of the 1 and 20 mg /L solution was lower in soil to which C had been added than in the controls, even though there were not statistical analyses for the duplicates (Fig. 1). This tends to confirm the hypothesis that soils with higher levels of organic matter adsorb less P. The result may have been an indirect effect of the glucose addition. Glucose probably stimulated microbial growth, and lowered adsorption may have been partly a result of microbial activity. Organic ligands produced by microbial activity may have reacted with iron and aluminum,



**Fig. 2.** Adsorption of P by soil 1 at three reaction times from solution initially containing 20 mg mono-basic potassium phosphate per liter. Treatment symbols are the same as for Fig. 1. Individual data points are plotted. Where only one point appears for a treatment at a particular reaction time, values were too close to plot separately.

thereby decreasing adsorption sites available for P reactions. Increased microbial biomass also may have been partly responsible. Phosphorus may have been adsorbed directly by microbes, where it would be more readily desorbed than had it been adsorbed to clay minerals.

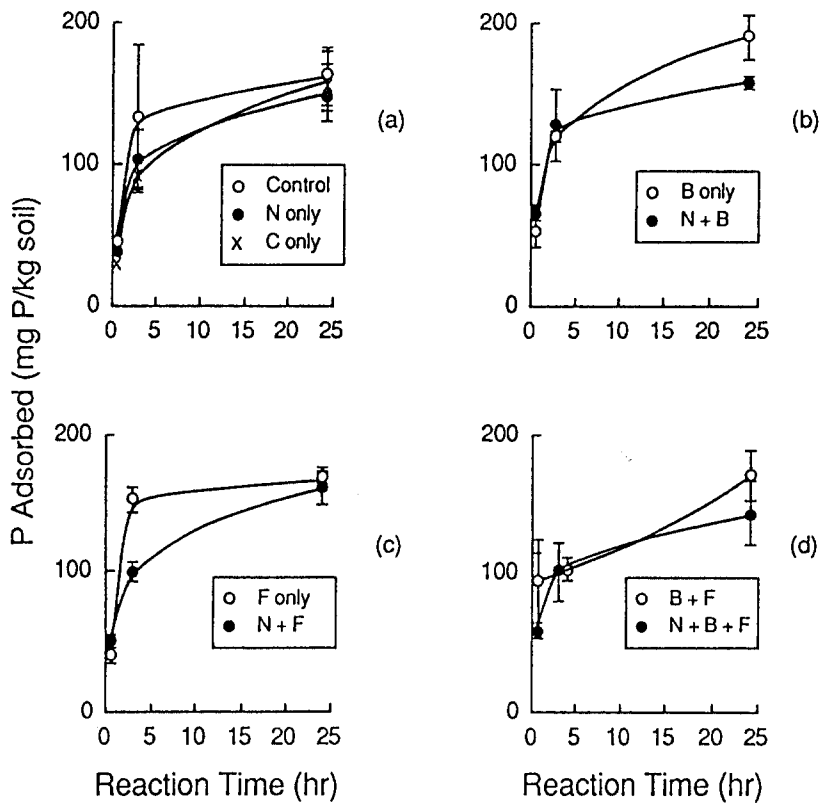
Adsorption by soil 1 (Fig. 2) was higher than by soil 2 (Fig. 3), over all time intervals, for the 20 mg P/L solution. Lower content of aluminum in soil 2 may have caused part of the difference in P adsorption. In general, P adsorption onto soil particles is ascribed to compounds of Al, Fe, and Ca (Lee *et al.* 1990).

An initial P concentration of 100 mg/L resulted in no discernible trend (Fig. 1). For this concentration and 0.5 hour reaction time, the differences due to C were overshadowed by total adsorption.

Beyond 0.5 hour, adsorption of P was less for soil with C added compared to control and to plus-P treatment, for the 20 mg/L solutions (Figs. 2a, 3a), although at 24 hours, differences shown in Fig. 3a are slight. The plus-N treatments are discussed below.

### Effect of N and P

For soil 1 at 0.5 hour, addition of N had very little effect on the adsorption of P compared to the control, but slightly increased adsorption compared to C only and C+N



**Fig. 3.** Adsorption of P by soil 2 at three reaction times from solution initially containing 20 mg mono-basic potassium phosphate per liter. Treatment symbols are the same as for Fig. 1, except C indicates cellulose. Plotted values are mean and standard deviation of three replicates.

(Fig. 1).

However, after 24 hours, addition of N generally resulted in lower P adsorption for the 20 mg P/L solution (Fig. 2a, b, c). In soil 2, addition of N lowered P adsorption, but the effect was clearest at intervals greater than 0.5 hour (Fig. 3). Lowered P adsorption due to N could have resulted from nitrification, or from production of organic acids. Both result from microbes such as nitrifiers and other microscopic heterotrophs.

For solutions of 1 and 20 mg P/L at 0.5 hour reaction time, addition of P reduced adsorption compared to controls, and addition of C+P reduced adsorption compared to C alone in soil 1 (Fig. 1a, b). Previously added P possibly occupied adsorption sites, thereby reducing adsorption.

### Effect of Biocides

If microbial processing of organic carbon would have been reduced by the biocides, P

adsorption might have been enhanced by the treatments of biocides. This seems to have been the result for the C+P+B additions at the 1 and 20 mg P/L level (Fig. 1), but not for the other treatments (Figs. 1, 2 and 3). These results may be explained by the results of Lee *et al.* (1990), using the same soils and biocide levels. They found that bactericide inhibited soil respiration for one day, but actually stimulated over a longer interval, probably due to growth of microbes that survived the biocide treatment. This may also be one of the possible explanations for this study. Addition of bactericide may have resulted in higher levels of biomass, over the course of the incubation.

### **Mechanisms**

Addition of C, N, and P, singly and in combination, decreased P adsorption by the two soils tested. Presumably, C served as an energy source for microbes, while additions of N and P overcame limiting conditions for metabolism. The increased microbial activity may have included processes such as production of organic acids and nitrification which reduced P adsorption. In addition, P presumably blocked P adsorption sites, thus accounting for the initial lowering of P adsorption.

Biocides also apparently increased microbial respiration due to rapid growth of organisms surviving the biocide application (Lee *et al.* 1990). Because soil organic matter increases exchange surfaces in the soil, soil with higher organic matter could have higher P adsorption. However, in the soils tested here, the soil with the higher levels of C (soil 2) had lower adsorption of P.

One reason may be the levels of exchangeable Al in the soils tested. The reaction of P with Al results in a bond which is stronger than the exchange reaction of P in the surface of organic matter. When soil organic matter is higher, more P is adsorbed by organic matter, and less reacts with the Al. This P is readily desorbed again into solution. Decrease in net P adsorption with increased organic matter also can be caused by high rates of oxygen depletion during decomposition of organic matter. Phosphorus release from sediment layers can be enhanced by deoxygenation (Syers *et al.* 1973, Carlton and Wetzel 1988). In our experiment, decomposition of organic matter could have depleted oxygen and created anoxic conditions inside soil aggregates.

An additional factor to explain less P adsorption with higher organic matter is that the organic matter also may have complexed some of the Al, making less available to react with the P. Other characteristics of soil minerals also can influence P adsorption and desorption (Lajtha and Bloomer 1988).

## **CONCLUSION**

For the soils and conditions tested, an increase in organic matter resulted in a net increase in P availability. The mechanisms of action may involve complexation and anion competition, although other factors may also be involved. These results suggest that in

regions where weathered soils high in Al are common, cultivation techniques which maximize soil organic matter may reduce the need for inorganic applications of phosphate and/or lime.

## 적 요

인 흡착에 대한 포도당과 질소, 인, 그리고 살균제의 영향을 밝히기 위해서 고도로 풍화된 두 종류의 토양에 이들 물질을 첨가하고 4주 내지 6주 동안 배양한 다음 인 흡착실험을 수행했다. 탄소 첨가는 인 흡착을 감소시켜다. 유기탄소의 첨가는 미생물 활동을 높이고, 생성물의 킬레이션과 음이온 경쟁으로 토양의 흡착력을 저감시킨 것으로 사료된다. 인 흡착에 대한 질소의 일관된 효과는 관찰되지 않았다. 인의 첨가는 처음에 인 흡착력을 감소시켰는데 이는 배양전에 첨가한 인에 의해 흡착지점이 차지되었기 때문일 것이다. 살균제는 일반적으로 인 흡착을 감소시켰는데 이는 아마도 살아남은 미생물이 죽은 미생물들을 빠르게 분해하여 생성된 물질들이 일으킨 킬레이션에 기인한 것으로 유추된다. 자연적으로 유기탄소 함량이 적고 치환성 알루미늄 함량이 높은 토양에서 인 흡착이 더 높았다. 이 결과는 유효인의 농도가 낮고, 치환성 알루미늄 함량이 높은 풍화된 토양에서 유기물을 증가시키는 경작방법이 식물에 대한 인이용도를 높일 것임을 시사한다.

## ACKNOWLEDGEMENT

We thank A.N. Sharpley, R.L. Potter, G.J. Batmanian, D.S. Cho, and two anonymous Koreans for their constructive criticisms of the manuscript. The research was carried out as part of a study on soil organic matter and P availability, supported in part by U. S. Agency for International Development, and U. S. National Science Foundation.

## LITERATURE CITED

- Allen, S.E., H.M. Grimshaw, J.A. Parkinson and C. Quarby. 1974. *Chemical Analysis of Ecological Materials*. Blackwell, Oxford, 565p.
- Carlton, R.G. and R.G. Wetzel. 1988. Phosphorous flux from lake sediments: effect of epipellic algal oxygen production. *Limnol. Oceanogr.* 33:562-570.
- Doran, J.W. L.N. Mielke and J.F. Power. 1987. Tillage/residue management interaction with the soil environment, organic matter, and nutrient cycling. *INTECOL Bull.* 15:33-39.
- Fox, R.L. and E.J. Kamprath. 1970. Phosphate sorption isotherms for evaluating the phosphate requirements of soils. *Soil Sci. Soc. Amer. Proc.* 34:902-907.
- Hargrove, V.L. and G.W. Thomas. 1981. The effect of organic matter on exchangeable aluminum and plant growth in acid soils. *In Chemistry in the Soil Environment*. Soil Sci. Soc. Am. J. Special Pub. no. 40. pp. 151-166. Soil Sci. Soc. Am. Madison, Wisconsin.



- Harter, R.D. 1969. Phosphorus adsorption sites in soils. *Soil Sci. Soc. Am. Proc.* 33: 630-632
- Hendrix, P.F., D.A. Crossley, Jr., D.C. Coleman, R.W. Parmelee, and M.H. Beare. 1987. Carbon dynamics in soil microbes and fauna in conventional and no-tillage agroecosystems. *INTECOL Bull.* 15:59-63.
- Holland, E.A. and D.C. Coleman 1987 Litter placement effects on microbial and organic matter dynamics in an agroecosystem. *Ecology* 68:425-433.
- Ingham, R.E., J.A. Trjogymow, E.R. Ingham and D.C. Coleman. 1985. Interactions of bacteria, fungi, and their nematode grazers: effects on nutrient cycling and plant growth. *Ecol. Monogr.* 55:119-140.
- Jansson, M. 1987. Anaerobic dissolution of iron-phosphorus complexes in sediment due to the activity of nitrate-reducing bacteria. *Microb. Ecol.* 14:81-89.
- Johnson, D.W., D.W. Cole, S.P. Gessel, M.J. Singer and R.V. Meinden. 1977. Carbonic acid leaching in a tropical, temperate, subalpine and northern forest soil. *Arctic Alpine Res.* 9:329-343.
- Kucey, R.M. 1983. Phosphate-solubilizing bacteria and fungi in various cultivated and virgin Alberta soils. *Can. J. Soil Sci.* 63:671-683.
- Lajtha, K. and S.H. Bloomer. 1988. Factors affecting phosphate sorption and phosphate retention in a desert ecosystem. *Soil Sci.* 146:160-167.
- Lee, D., X.G. Han and C.F. Jordan. 1990. Soil phosphorus fractions, aluminum, and water retention as affected by microbial activity in an Ultisol. *Plant and Soil* 121:125-136.
- Le Mare, P.H. 1982. Sorption of isotopically exchangeable and non-exchangeable phosphate by some soils of Colombia and Brazil, and comparisons with soils of southern Nigeria. *J. Soil Sci.* 33:691-707.
- Lopez-Hernandez, D., G. Siegert and J.V. Rodriguez. 1986. Competitive adsorption of phosphate with malate and oxalate by tropical soils. *Soil Sci. Soc. Am. J.* 50:1460-1462.
- Nagarajah, S., A.M. Posner and J.P. Quirk. 1968. Desorption of phosphate from kaoline by citrate and bicarbonate. *Soil Sci. Soc. Am. Proc.* 32: 507-510.
- Nagarajah, S., A.M. Posner and J.P. Quirk. 1970. Competitive adsorption of phosphate with polygalacturonate and other organic anions on kaolonite and oxide surface. *Nature* 228:83-85.
- National Research Council. 1989. *Alternative Agriculture*. National Academy Press, Washington, D.C. 448p.
- Olson, R.A. and O.P. Engelstad. 1972. Phosphorus and sulfur. *In* *Soils of humid tropics*. National Research Council Committee on Tropical Soils. pp. 82-101. National Academy Science, Washington, D.C.
- Sanchez, P.A. 1976. *Properties and management of soils in the tropics*. Wiley, New York.
- Sibanda, H.M. and S.D. Young. 1989. The effect of humus acids and soil heating on the availability of phosphate in oxide-rich tropical soils. *In* J. Protor(ed.). *Mineral Nutrients in Tropical Forest and Savanna Ecosystems*. pp. 71-83. Blackwell. Oxford.

- Stevenson, F.J. 1986. Cycles of soil: Carbon, Nitrogen, Phosphorous, Sulfur, Micronutrients. Wiley, N.Y. 380p.
- Syers, J.K., R.F. Harris and D.E. Armstrong. 1973. Phosphate chemistry in lake sediments. *J. Environ. Qual.* 2:1-15.
- Tate, K.R. 1984. The biological transformation of P in soil. *Plant and Soil* 76:245-256.
- Tate, R.L. 1987. *Soil Organic Matter: Biological and Ecological Effects*. Wiley, N.Y. 219 p.
- Thomas, G.V., M.V. Shantaram and N. Saraswathy. 1985. Occurrence and activity of phosphate-solubilizing fungi from coconut plantation soils. *Plant and Soil* 87:357-364.
- Tiessen, H., J.W.B. Stewart and H.W. Hunt. 1984a. Concepts of soil organic matter transformations in relation to organo-mineral particle size fractions. *Plant and Soil* 76:287-295.
- Tiessen, H., J.W.B. Stewart and C.V. Cole. 1984b. Pathways of phosphorous transformations in soils of differing pedogenesis. *Soil Sci. Soc. Am. J.* 48:853-858.
- Traina, S.J., G. Sposito, D. Hesterberg and U. Kafkafi. 1986. Effects of pH and organic acids on orthophosphate solubility in an acidic, montmorillonitic soil. *Soil Sci. Soc. Am. J.* 50:45-52.
- Van Miegroet, H., and D.W. Cole. 1985. Acidification sources in red alder and douglas fir soils - importance of nitrification. *Soil Sci. Soc. Am. J.* 49:1274-1279.
- Wiese, A.F. 1983. No-tillage crop production in temperate agriculture. *In* No-tillage Crop Production in the Tropics. pp. 7-24. International Plant Protection Center, Oregon State Univ., Corvallis, OR.
- USDA. 1968. Soil survey, Clark and Oconee Counties, Georgia. United States Dept. Agriculture, Washington, D.C.
- Young, S.D. and B.W. Bache. 1985. Aluminum-organic complexation: formation constants and speciation model for the soil solution. *J. Soil Sci.* 36: 261-269.

(Received 24 September, 1994)