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# Texture Modifies Water Transport of Nutrient Ions in Coastal Plain Soils

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**SUMMARY**

In a laboratory test, movement of surface-applied phosphorus, potassium, and calcium into and through undisturbed cores of loamy sand, sandy loam, and loam topsoil, increased as texture became coarser and as greater amounts of water percolated through the soil. Downward displacement of ions was enough to insure that nutrients were accessible to feeder roots in established pine plantations.

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## INTRODUCTION

Selection of a procedure for applying commercial fertilizers requires knowing the crop to be fertilized, its stage of development, the soil on which the crop is growing, and mobility in the soil of the nutrients to be applied. Mobility is especially important in supplying nutrients to established pine plantations. Mobile ions may be broadcast or banded on the surface. But immobile ions need to be incorporated into the soil if they do not diffuse or are not carried by rain to a depth where feeder roots can absorb them. Once the trees fully occupy the site, however, mechanical incorporation of fertilizers into the soil cannot be done without damaging pine roots.

In the research reported here, we studied how soil texture affects water transport of phosphorus, potassium, and calcium into and through columns of undisturbed soil from the Coastal Plain of Louisiana. We were especially interested in the behavior of phosphorus because this element moves very little in many soils. Potassium mimics ammonium nitrogen in its reaction with negatively charged soil particles (Bolt et al. 1976). So, we were able to study the behavior of two important nutrient ions by observing the movement of potassium. Calcium is a constituent of ordinary and concentrated superphosphates and competes with other cations for exchange sites when these fertilizers are applied.

## MATERIALS AND METHODS

Three fertilizer-leaching treatments were applied to undisturbed cores of soil from the upper 27 cm of a Lucy loamy sand (loamy, siliceous, thermic, Arenic Paleudult), a Ruston sandy loam (fine-loamy, siliceous, thermic, Typic Paleudult), and a Beauregard loam (fine-silty, siliceous, thermic, Plinthaquic Paleudult). The combinations were:

1. Leaching of unfertilized cores with 10 pore volumes of distilled water.
2. Leaching with 5 pore volumes of distilled water after a surface application of reagent grade monocalcium phosphate and potassium nitrate. The salts supplied 25.0 mg of Ca, 38.6 mg of P, and 85.1 mg of K per core, or 1.25 meq each of Ca and $H_2PO_4$ and 2.18 meq of K.
3. Fertilization as in (2) followed by leaching with 10 pore volumes of distilled water.

All cores of a given texture were collected from a single location where the soil was uniform and conformed to the modal concept for untilled soil of the series. Lucy and Ruston soil cores were uniform in texture throughout their entire length (table 1). Beauregard cores were uniform to a depth of about 18 cm. Below 18 cm, clay content increased about one percentage point per cm and averaged 18 percent in the 24- to 27-cm layer. Organic matter in the surface 1.5 cm ranged from 4.3 percent for Ruston to 6.0 percent for Beauregard soil. Organic matter decreased with depth in all soils, but the decline was most abrupt in the Lucy loamy sand. We obtained these data by sectioning three randomly selected cores of each soil. Particle size distribution was determined by the hydrometer method (Day 1965) and organic matter by wet digeston without external heat (Jackson 1958).

Since pores are the avenues through which water and solutes move in soil, we reasoned that equal pore volumes would produce more uniform leaching of the three soils than would equal amounts of water. Total soil porosity averaged 32 percent for Lucy loamy sand, 35 percent for Ruston sandy loam, and 36 percent for Beauregard loam. So each pore volume of water that percolated through the columns was equivalent to 8.5 cm rainfall for loamy sand, 9.5 cm for sandy loam, and 9.8 cm for loam. In all, an average of 42 to 49 cm of

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Table 1.—*Physical properties of soils by series and depth*

| Section | Depth (cm) | Lucy loamy sand Organic matter | Sand | Silt | Clay | Ruston sandy loam Organic matter | Sand | Silt | Clay | Beauregard loam Organic matter | Sand | Silt | Clay |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Percent | | | | | | | | | | | |
| 1 | 0–1.5 | 4.4 | 81 | 13 | 6 | 4.3 | 65 | 30 | 5 | 6.0 | 41 | 50 | 9 |
| 2 | 1.5–3 | 1.9 | 80 | 13 | 7 | 3.3 | 67 | 28 | 5 | 4.7 | 45 | 46 | 9 |
| 3 | 3–6 | .7 | 80 | 13 | 7 | 1.5 | 69 | 27 | 4 | 3.5 | 45 | 46 | 9 |
| 4 | 6–9 | .8 | 88 | 5 | 7 | 1.3 | 65 | 30 | 5 | 2.3 | 47 | 44 | 9 |
| 5 | 9–12 | .8 | 83 | 10 | 7 | 1.1 | 64 | 31 | 5 | 1.8 | 46 | 46 | 8 |
| 6 | 12–15 | .3 | 84 | 10 | 6 | 1.3 | 66 | 30 | 5 | .9 | 47 | 45 | 8 |
| 7 | 15–18 | .6 | 83 | 11 | 6 | .5 | 62 | 32 | 6 | .7 | 44 | 47 | 9 |
| 8 | 18–21 | .4 | 84 | 10 | 6 | .6 | 64 | 31 | 5 | .3 | 44 | 44 | 12 |
| 9 | 21–24 | .4 | 83 | 11 | 6 | .4 | 64 | 30 | 6 | .4 | 41 | 44 | 15 |
| 10 | 24–27 | .2 | 82 | 12 | 6 | .3 | 61 | 33 | 6 | .6 | 41 | 41 | 18 |
| Average | | .8 | 83 | 11 | 6 | 1.2 | 65 | 30 | 5 | 1.8 | 44 | 45 | 11 |

water percolated through columns leached with 5 pore volumes of water and 85 to 98 cm through those leached with 10. Time required for each pore volume averaged about 45 minutes for Lucy, 120 minutes for Ruston, and 3200 minutes for Beauregard soil.

Pore volumes (PV) were computed as:

$$PV = \text{Volume of soil in core} - \left(\frac{\text{dry weight of soil in core}}{\text{particle density}}\right)$$

Ovendry weights of soil in the columns were estimated from moisture percentages of composite bulk samples collected at each location and dried to constant weight at 105°C. Particle densities were determined by water displacement.

Containers for the cores were 30-cm segments of polyvinyl chloride well-casing having an inside diameter of 5 cm and a cross-sectional area of 19.6 cm$^2$. To allow its insertion into the soil without disturbance of the sample core, we beveled one end of each tube on the outside to a cutting edge. The tubes were carefully driven into the soil to a depth of 28.5 cm below the mineral soil surface and then the columns (soil and casing) were removed with a shovel. To prevent loss of moisture we sealed the columns in plastic bags and stored them at 1°C until they were used. In the laboratory, we removed the bottom 1.5 cm of soil from the cores and inserted into the lower ends of the columns tight-fitting rubber stoppers equipped with a drain and with a filter that would trap loose soil particles. In the process, we reduced overall core length to 27 cm and soil volume to 530 cm$^3$. Nutrient salts were applied uniformly to the soil surface. Columns were capped with rubber stoppers having an inlet for water and an outlet for air.

We purged air from the columns by saturating them with distilled water from below. Then the air outlet was closed and the flow of water reversed. Flow was continuous under a constant head of 30 cm until the specified pore volumes of leachate had percolated through the columns (fig. 1). Each pore volume of water was analyzed for phosphorus, calcium, and potassium.

The leached cores were sectioned horizontally into 3.0-cm thick segments. The uppermost segments were further divided into two 1.5-cm thick wafers. Soils in each segment were analyzed for available phosphorus and exchangeable calcium and potassium.

We extracted phosphorus from ovendry soil samples with 0.03$\underline{N}$ $NH_4F$ and 0.025$\underline{N}$ HCl (Jackson 1958) using a shaking time of 15 minutes. Exchangeable bases were replaced with 1.0$\underline{N}$ $NH_4OAc$ as described by Chapman (1965).

Samples of soil extracts and leachates were analyzed for phosphorus by the chlorostannous-reduced-molybdophosphoric-blue-color method (Jackson 1958). Calcium and potassium were determined by atomic adsorption spectrophotometry. As needed, leachates were diluted with distilled water and soil extracts with 1.0$\underline{N}$ $NH_4OAc$ for the cation determinations.

Treatments were replicated four times in a randomized block, double-split-plot design. Fertilizer-leaching treatments were the first split, and pore volume of leachate or column segment of soil were the second. Data were evaluated by analyses of variance with significance preset at the 0.05 level.

## RESULTS

### Nutrients in Leachate

Both texture and fertilizer treatment significantly affected amounts of phosphorus, potassium, and calcium that were leached from the soil by 10 pore

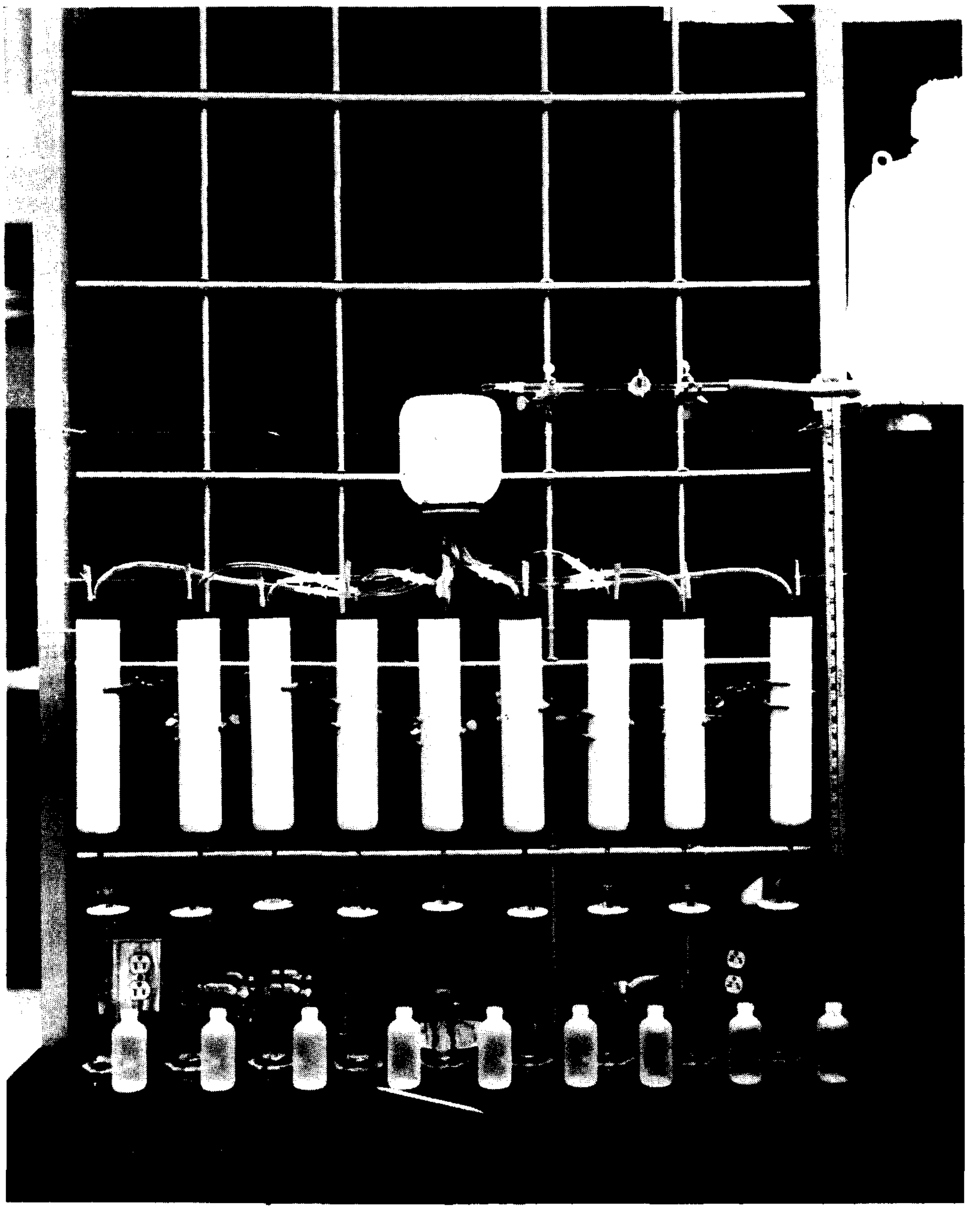

Figure 1.—*Laboratory set-up for leaching soil columns.*

volumes of water (fig. 2). Individual pore volumes of leachate differed from each other in the amounts of nutrients they contained. Nutrient content of the first 5 pore volumes of leachate from fertilized columns was unaffected by the total amount of water that percolated through them. So we report only results of the two 10 pore-volume treatments in this section.

No phosphorus was leached from unfertilized soil or from the fertilized loam. Leachates from the fertilized loamy sand and sandy loam contained 7.8 and 6.6 mg of phosphorus or 20 and 17 percent of the amount applied to the surface. Phosphorus was first detected in the 3rd pore volume of leachate from the two soils. Amounts per pore volume increased until 51 cm of water had percolated through the fertilized loamy sand and 57 cm had percolated through the fertilized sandy loam. After that, amounts per pore volume declined. The 10th pore volume of loamy sand leachate contained 1.0 mg of phosphorus. The 10th pore volume of sandy loam leachate contained 0.7 mg.

Ten pore volumes of water removed only 0.2, 0.6, and 0.1 mg of potassium from unfertilized loamy sand, sandy loam, and loam soils. Cumulative losses from fertilized columns were 6.3 mg for the loamy sand, 9.5 mg for the sandy loam, and 0.6 mg from the loam, or 7, 11, and 1 percent of the amount of potassium applied. The 2d pore volume contained 19 to 37 percent of the total potassium leached from fertilized columns. Later pore volumes did not differ markedly in the amount of potassium they contained.

Cumulative losses of calcium from unfertilized soil amounted to 3.0-5.5 mg. Losses were greatest from the

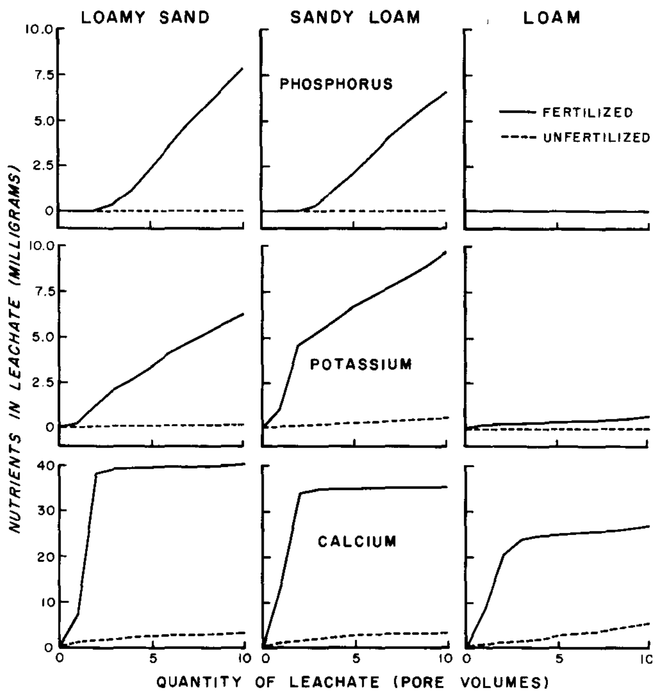


Figure 2.—*Cumulative losses of phosphorus, potassium, and calcium from fertilized and unfertilized soil leached with 10 pore-volumes of water. Each value is an average of four measurements.*

loam soil, where they increased as more water percolated through the columns. As leaching of other unfertilized soils continued, calcium content of successive pore volumes of water declined.

Fertilizion caused 7 to 60 percent more calcium to be leached from the columns than was added in the fertilizer. The 10 pore volumes of leachate from fertilized columns of loamy sand contained 40.0 mg of calcium, of sandy loam 35.1 mg, and of loam 26.7 mg. The 1st and 2d pore volumes of leachate contained 76 to 95 percent of the calcium leached from fertilized columns. This pattern of loss suggests that calcium functioned as the primary cation for maintaining electrical neutrality of the solution when nitrate nitrogen was being leached from the columns.

## Distribution of Nutrients in Leached Columns

The fertilizer and leaching treatments developed significant and large differences in the concentration and distribution of available phosphorus and exchangeable calcium and potassium in the soil columns. How these treatments affected concentrations of nutrients at different distances from the surface varied by soils. This variation was evident in the significant three-factor interactions among soils, treatments, and soil sections in analyses of variance for individual nutrients.

*Phosphorus*—After being leached with 10 pore volumes of distilled water, the unfertilized loamy sand contained fewer than 10 p/m of available phosphorus (fig. 3). Concentrations decreased with depth from 9.3 p/m in the surface 1.5 cm to 1.8 p/m in the 24- to 27-cm layer. Fertilized columns leached with 5 pore volumes of water contained 27 p/m of phosphorus, or about three times as much in the surface subsample as unfertilized soil. Concentration increased with distance from the surface through the 9- to 12-cm layer, which contained 40 p/m of available phosphorus, and then declined steadily to a low of 11 p/m in the bottom section. Leaching with an additional 5 pore volumes of water had little impact on the amount of phosphorus retained in the surface 3 cm but did reduce the concentration in the 3- to 15-cm layer and increased it in the 15- to 27-cm layer. This soil appeared to have a limited capacity to retain available phosphorus against continuous leaching—at no level did concentrations exceed 30 p/m after fertilized columns had been leached with 10 pore volumes of water.

After being leached with 10 pore volumes of distilled water, the unfertilized sandy loam also contained fewer than 10 p/m of available phosphorus. Concentrations decreased with depth from 9.6 p/m in the surface 1.5 cm to 2.4 p/m in the 24- to 27-cm layer. Fertilized columns leached with 5 pore volumes of water contained 31-32 p/m in the top 6 cm—about four times as much phosphorus as in the same portion of the unfertilized soil. Soil between the 6- and 18-cm depth contained 26-28 p/m. Available phosphorus levels then decreased with depth to 13 p/m in the bottom section. The leaching with 10 pore volumes moved the available phosphorus downward, thus lowering the concentrations in the surface 18 cm and increasing the

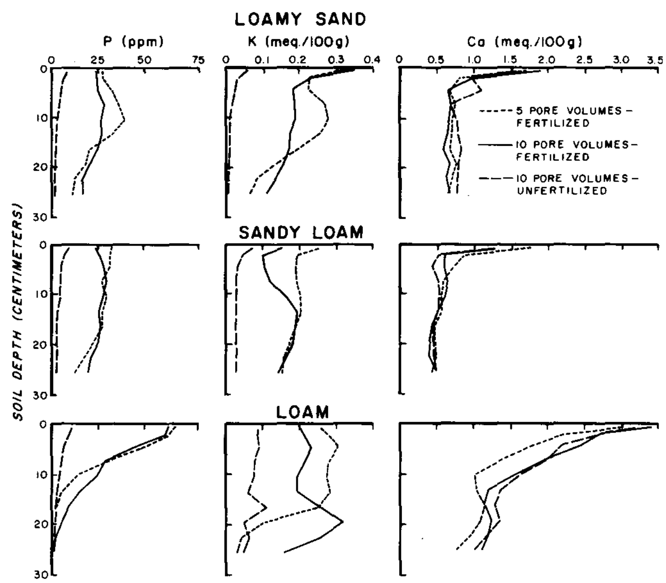


Figure 3.—*Post-leaching distribution of available phosphorus and exchangeable potassium and calcium in fertilized and unfertilized soil. Each value is an average of four measurements.*

amounts found in the 18- to 27-cm layers. This downward movement accounted for a decrease to 23 p/m in the surface section and an increase to 20 p/m in the bottom section. This soil appears to be like loamy sand in its limited capacity to retain available phosphorus against continuous leaching.

After being leached with 10 pore volumes, the unfertilized loam contained 11 p/m available phosphorus at the surface. Phosphorus content decreased evenly with depth to 2 p/m in the bottom section. The fertilized treatment receiving 5 pore volumes contained 66 p/m at the surface—more than twice the highest amount retained in either the loamy sand or sandy loam. Concentrations were above 50 p/m in the upper 6 cm then dropped sharply to 29 p/m in the 9- to 12-cm section. In the 12- to 15-cm section the concentration was 13 p/m, and concentrations fell to a low of 1.3 p/m in the bottom section. With the addition of 5 more pore volumes, concentrations in the surface 9 cm dropped slightly while those in the 9- to 24-cm layers increased. Phosphorus content of the 24- to 27-cm layer was unaffected by fertilization and leaching, so no phosphorus leached through the loam soil regardless of treatment.

The loam soil retained more of the added phosphorus in "unavailable" forms than did the loamy sand and sandy loam. In the 10 pore-volume treatment, we recovered about 60 percent of the added phosphorus in soil extracts and leaching waters from the sandy soils. We extracted only 34 percent of the added phosphorus from the loam soil and recovered none from the leachate. So 26 percentage points more of the added phorphorus was immobilized by the loam than by the sandy soils. Similar trends were apparent in the 5 pore-volume treatment.

*Potassium*—After being leached with 10 pore volumes of distilled water, soil in unfertilized loamy sand columns contained 0.05 meq or less of exchangeable potassium/100 g. Concentrations in the surface 3 cm ranged from 0.04 to 0.05 meq/100 g and gradually decreased to 0.01 meq/100 g at the 12- to 15-cm depth. They remained at this level to the bottom of the column. Fertilized columns leached with 5 pore volumes of water contained 0.32 meq of potassium/100 g in the surface 1.5 cm section or about six times as much as the unfertilized soil. Potassium levels decreased to 0.22 meq/100 g, in the 3- to 6-cm section, and then rose to 0.28 meq/100 g at the 9- to 12-cm depth. Concentrations then dropped steadily until the 24- to 27-cm layer, which had only 0.06 meq/100 g. This value was still higher than any concentration in the unfertilized treatment. In the surface 3 cm of soil, potassium level was the same for the 5 pore-volume leaching and 10 pore-volume leaching. Below that depth, 10 pore-volume leaching distributed exchangeable potassium more evenly through the column.

The leached, unfertilized sandy loam averaged 0.08 meq exchangeable potassium/100 g in the surface 1.5 cm and 0.05 meq/100 g in the 1.5- to 3-cm section. Lower sections (6-27 cm) contained less than 0.05 meq/100 g.

Sandy loam columns that were fertilized and leached with 5 pore volumes of water contained 0.25 meq of potassium/100 g in the surface 1.5 cm and 0.19 or 0.20 meq/100 g in individual segments to a depth of 18 cm. Below 18 cm, potassium concentration declined with depth. Leaching with an additional 5 pore volumes lowered the potassium levels in the surface 9 cm as much as 0.10 meq/100 g. Levels of potassium in the 9- to 27-cm soil sections were unaffected by the additional leaching.

In leached, unfertilized loam soil, exchangeable potassium exceeded 0.10 meq/100 g only at the 15- to 18-cm depth. The 5 pore-volume treatment moved much added potassium to the 18-cm depth. An additional 5 pore volumes of water decreased the amount of potassium in the surface 15 cm of soil and increased it in the 21- to 27-cm segments.

*Calcium*—Fertilizer and leaching treatments had only minor impacts on calcium levels in leached soil because: (1) less than 0.2 meq of calcium/100 g of soil was applied, and (2) only 0.1 or 0.2 meq/100 g more calcium was leached from fertilized than from unfertilized soil. In the loamy sand, which sustained the greatest loss of calcium through leaching, fertilization increased calcium levels near the surface and decreased them in lower parts of the leached columns. Similar, less distinct trends developed in the other soils. Calcium levels were higher in the loam than in the sandier soils because the loam contained more organic matter and more clay, which gave it a higher cation exchange capacity.

## DISCUSSION AND CONCLUSIONS

The study clearly demonstrated that considerable downward displacement of all ions accompanied the saturated flow of water through the soil. Ion movement appeared to be sufficient to insure efficient use of phosphorus and potassium fertilizers applied to the surface of loam or sandier soils. Because potassium and ammonium ions react similarly in soil (Bolt et al. 1976), surface application of $NH_4$-N should also be practical on these soils.

Except for phosphorus, the results also suggest that surface-applied nutrients may be carried by water through surface layers where feeder roots are concentrated. To avoid excessive loss through leaching, apply fertilizers when feeder roots are active and can intercept these ions before they move below the rooting zone.

Though these results were obtained under highly artificial laboratory conditions, they have practical meaning. Related research in a 13-year-old slash pine

(*Pinus elliottii* Engelm. var *elliottii*) plantation (Shoulders and Tiarks 1980) supports this conclusion. In that study, triple superphosphate, ammonium nitrate, and muriate of potash were applied to the surface of a Caddo loam (fine-silty, siliceous, thermic Typic Glossaqualf) in January. Ten months after application, distribution of phosphorus through the surface 13 cm of soil paralleled the distribution we observed after leaching in the fertilized loam in this study. Essentially all added potassium had disappeared from the soil. Apparently, it had been used by the pines. Fertilizers increased nitrogen, phosphorus, and potassium contents of the foliage produced in the 1st year after treatment. Phosphorus and potassium content of foliage produced in the 8th year after treatment was also increased by fertilization. Measurable differences in diameter growth developed by mid-May of the 1st year, and the fertilizer increased annual volume growth during the next 6 years by 8.3 $m^3$/ha (120 $ft^3$/acre).

Mechanical incorporation of fertilizers into the soil will continue to be the preferred forest fertilization procedure where incorporation is feasible. But surface application is a practical alternative in pine plantations where tree roots would be injured by mechanical incorporation and immediate availability of nutrients to plants is not required.

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Downward displacement of ions by water through loamy sand, sandy loams, and loam topsoils increased as texture became sandier but was adequate in all soils to insure that nutrients will be accessible to feeder roots in established pine plantations.

**Additional keywords:** Soil leaching, phosphorus, potassium, calcium.

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