EFFECTIVENESS OF NORTH CAROLINA PHOSPHATE ROCK AND FERTILIZER TABLETS IN RECLAIMING DISTURBED LAND IN COPPER BASIN, TENNESSEE, USA

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Abstract. Open smelting of copper ore about 100 years ago resulted in approximately 9,300 ha of disturbed land with severely eroded acidic soils at Copper Basin, Tennessee, USA. A field study was initiated in 1992 to compare revegetation from surface application of North Carolina phosphate rock (PR) and triple superphosphate (TSP) at 20, 59, and 295 kg P ha^{-1}, and determine benefits of fertilizer tablets. Measurements included survival and growth of transplanted pine seedlings, ground cover from an aerially seeded grass/legume mixture, and soil acidity. Tree survival was greater than 87% with no difference among treatments. When fertilizer tablets were not used, tree height and diameter increased with increasing soil P rates with growth maximized at 59 kg P ha^{-1}. After 96 and 240 d, there was no difference between PR and TSP with respect to growth of loblolly pine. After 960 days, PR caused greater tree growth compared to TSP. Weeping love grass provided the most ground cover, and its growth was stimulated with fertilizer tablets and P application. Fescue, lespedeza, and black locust trees responded more to PR than to TSP. Soil pH increased, and 0.01-M $SrCl_2$ extractable Al decreased, with increasing rate of PR. The molar ratios of Ca:Al in 0.01-M $SrCl_2$ soil extracts were also greater with PR compared to TSP. Decreased soil acidity, increased growth of loblolly pines, and increased diversity of ground cover vegetation from PR application makes PR a suitable material for reclaiming extremely acidic soils. Fertilizer tablets had an effect of improving loblolly pine growth when no P was surface applied. However, with surface P application of 59 kg ha^{-1} as PR, fertilizer tablets did not add any additional benefit to loblolly pine growth. Some improvement in tree growth was observed using fertilizer tablets with P applied as TSP at 59 kg ha^{-1}. Fertilizer tablets did greatly improve ground coverage of weeping love grass. Use of fertilizer tablets in reclamation efforts in conjunction with adequate surface P application may benefit growth and ground coverage of weeping love grass but, depending on the P source used, would provide little to no benefit to loblolly pine trees in early stages of growth.

1. INTRODUCTION

Phosphate rock is a good source of P for crops growing in acid soils, in particular for for perennial crops because of its slow dissolution over time. Land in the Copper Basin, Tennessee, USA is disturbed, resulting from past copper mining activities and further degraded, mainly by erosion. The soils are severely eroded and acidic [1]. Revegetation of disturbed lands is currently an area of environmental concern and active research. Phosphate rock is a superior source for supplying P to plants when the P fixing capacity is very high [2], as observed in Copper Basin soil with salt-extractable Al as high as 300 mg/kg. Phosphate rock would appear to be well suited for supplying P to trees and grasses planted in this area during reclamation efforts. In addition to supplying P, the higher Ca to P weight ratio in phosphate rock (approximately 2) compared to water soluble fertilizers (TSP = 0.67) would result in greater Ca addition to soil per unit of P applied. Calcium added to the soil may increase the Ca:Al molar ratio in soil solution, thus contributing to control the effects of Al toxicity on plant growth [3].

Fertilizer tablets have been developed to provide a slow release of nutrients to trees when added to soil when transplanting tree seedlings [4]. Fertilizer tablets and sludge placed in slits in soil close to transplanted tree seedlings were found to greatly improve early growth of sweetgum, sawtooth oak, black locust, black alder, and loblolly pine planted at the Copper Basin when compared to controls without tablets or sludge [5, 6]. Current reclamation practices in the Copper Basin involve the use of fertilizer tablets in addition to aerial application of fertilizers to the soil surface at the time of planting [1]. Although studies by Berry [5, 6] proved the effectiveness of using fertilizer tablets without any surface application of fertilizer, the utility of fertilizer tablets when also broadcasting fertilizer remains in question.

A study was conducted at the Copper Basin to determine the effectiveness of broadcasting North Carolina phosphate rock on the soil surface compared to triple superphosphate (TSP) during revegetation efforts. In addition to comparing P sources, the benefit of applying fertilizer tree tablets was evaluated with concurrent surface application of fertilizer.

2. MATERIALS AND METHODS

The experimental site was in the Copper Basin area in Tennessee behind the Copperhill High School. Baseline soil chemical characteristics were determined in soil collected at 0 to 15 cm depth in each of the experimental plots prior to implementing treatments. Soil pH was determined with 1:1 soil:water paste and a glass electrode. Cation exchange capacity was determined with the pH 7 NH_4OAc extraction methods. Exchangeable Al was determined with 50 ml of 1 N KCl added to 5 g soil, shaken for 30 minutes, filtered through Whatman 42 paper, and analyzed in the filtrate via atomic absorption spectroscopy. The 0 to 15 cm soil depth at the site had a soil pH of 4.5 ± 0.1 s.u. and exchangeable Al content of 191 ± 70 mg/L. The cation exchange capacity and base saturation were 1.7 cmol/kg and 2.4%, respectively.

The study consisted of plots having dimension of 7.3 x 9.1 m^2. The treatments consisted of 4 P application rates of 0, 20, 59, or 295 kg/ha P using North Carolina PR or TSP. In addition to the P source and rate, an additional treatment was including which consisted of using or not using a fertilizer tablet with each tree during transplantation. The experimental design was a randomized complete block with split plots. The split plot treatment was using or not using fertilizer tree tablets. The control treatment with 0 kg/ha P was only used once in each split plot with the application of 20, 59, and 295 kg/ha P with PR or TSP to result in 7 experimental units in each split plot. With two split plot treatments (with or without fertilizer tablet) and 4 replications, the total number of experimental plots was 56.

The experimental plots were prepared and established in March 1992. Before any fertilizer addition or planting, the site was sub soiled with 2-foot rippers on a crawler-type tractor. The TSP and PR treatments were hand applied to each plot. In addition, 112 kg/ha N and 112 kg/ha K were broadcast by hand over each plot as NH_4NO_3 and KCl fertilizer. Loblolly pine seedlings (*Pinus taeda*) were obtained from a local nursery at the 1-0 seedling stage and were not inoculated with mycorrhizal fungi. Twenty tree seedlings were planted 2 m apart from one another in each plot, which resulted in 4 rows along the longer dimension of each plot. The tree seedlings were planted with a hand-held device that created a slit in the soil where the root mass of the seedling was placed. Another slit was created parallel to the previous slit to tampon soil up against the root mass. For the treatments with fertilizer tablets, a 21 g fertilizer tablet was placed in the second slit. The fertilizer tablets had a grade of 20-10-5. Nitrogen consisted of urea formaldehyde. The tablets also contained 2.6, 1, and 0.35% Ca, S, and Fe. The calcium carbonate equivalence of the tablets was 5%. Each plot was planted with 20 pine seedlings spaced 6 feet apart. A commercial seed mixture containing 46% sericea lespedeza (*Lespedeza cuneata*), 16% Kobe lespedeza (*Lespedeza striata*), 27% Kentucky 31 tall fescue (*Festuca arundinacea*), 4% weeping love grass (*Eragrostis curvula*), and 6% tree-black locust (*Robinia pseudoacacia*) was aerially applied at 84 kg/ha.

The experimental site was visited during November or December of 1992, 1993, and 1994, which was 96, 240, and 960 days, respectively, after preparing the site. During each of these visits, measurements were made and samples were collected for laboratory analyses. During each of the visits, tree height and trunk diameters were measured. Tree height was determined with a 1-m rule and trunk diameter was determined 2.5 cm from the soil surface using a digimatic caliper. The predominance of vegetative ground coverage was determined using the line intersect method with a kit developed by the National Resource Conservation Service. The method involves stretching a line on the ground with beads every 18 cm on the line and counting the number of beads intersected by a particular plant species as viewed directly from the top. The number of beads showing an intersection divided by the total number of beads times 100 provides a good approximation on the percent coverage of plant species. Three lines were laid out in each plot exactly in between the four rows of pine trees.

Vegetative intersections with 150 beads were possible in each plot. Loblolly pine survival rates were measured by counting the number of live trees in each plot. The number of black locust trees in each plot was counting during the 1994 visit.

During the visits in 1992 and 1993, soil was collected from 0 to 2.5-cm depths in each plot. Several samples were taken in each plot and composited to obtain a representative sample. The soil was collected in plastic bags and transported to the lab. The soil was air- dried and ground to pass a 2 mm screen. The soil was extracted for Bray P using 2 g soil and 20 ml of Bray solution, shaken for 60 minutes, and filtered through Whatman 42 filter paper. The filtrate was analyzed for P via ascorbic acid colorimetric procedure [7]. Soil pH was determined using 1:1 soil:water paste and a glass electrode. Soil solution Al and Ca was extracted with 0.01 M-$SrCl_2$ where 10 g soil was added to 20 ml of extractant, shaken for 60 minutes, and filtered through Whatman 42 paper. The filtrate was analyzed for Al and Ca via atomic absorption spectroscopy.

During the visit in 1993, loblolly pine needles were collected from the last fully elongated flush in each of the plots. Several samples were collected in each plot to obtain a representative sample. The pine needles were brought back to the lab, dried in paper bags at 60°C, and ground in a Wiley mill to pass a 60-mesh screen. Total nitrogen was determined via Kjehldahl digestion [8] and NH_4^+ analyses via segmented flow colorimetry. For P, K, Al, and Ca analyses, 0.5 g of tissue was dry-ashed at 450°C and dissolved in 6 M HCl. The digestate was analyzed for P using the ascorbic acid colorimetric procedure [7]. The digestate was analyzed for K, Al, and Ca using atomic absorption spectroscopy.

3. RESULTS AND DISCUSSION

3.1. Plant growth

After 96, 240, and 960 days, tree growth responded to increasing levels of P application without application of fertilizer tablets, with maximum growth reached at 59 kg/ha P (Fig. 1).

Phosphate rock and TSP caused similar response in loblolly pine after 96 and 240 days. Phosphorus sources, P rates, and fertilizer tablets had no effect on tree survival. Survival rates were above 87% for all treatments (data not shown). There was little response to PR or TSP with fertilizer tablets. No benefits were observed using both fertilizer tree tablets and surface application of PR at 59 kg/ha P. After 960 days, PR caused greater tree growth than TSP at a P application rate of 59 kg/ha, when fertilizer tree tablets were not used.

The vegetative coverage of the grasses, tall fescue and weeping love grass, decreased with time (Figs. 2 and 3). After 96 days, the highest fescue coverage approached 20% but was reduced to levels below 3% after 960 days. Weeping love grass coverage was much higher at approximately 80% after 96 days and was reduced to 60% in the best growing plots after 960 days. Although fertilizer tablets did not appear to benefit tree growth with surface P application at 59 kg/ha P, there were noticeable effects on ground cover of weeping love grass. The percent ground coverage of weeping lovegrass was greater with fertilizer tablets than without them, indicating the weeping love grass may have utilized nutrients within the fertilizer tablets. The result was puzzling since ground cover was measured in between the tree rows (3' from the sides of each tree row) where the utilization of the nutrients in the fertilizer tablets would appear to be limited. Either weeping lovegrass had an extensive rooting system, or the fertilizer tablets solubilized with rain events and N and K got washed throughout the plot. Greater surface applications of N and K may have minimized the effect of fertilizer tablets on weeping love grass growth. Phosphate rock caused greater fescue coverage compared to TSP at the highest rate of P application. There was no difference between P sources in ground coverage of weeping love grass.

Vegetative ground coverage of the leguminous plants, lespedeza and black locust, are shown in Figs. 4 and 5. Unlike fescue and weeping lovegrass, coverage of the legumes increased with time. No lespedeza was observed at 96 days, but increased to 22% in the best growth plots after 960 days.

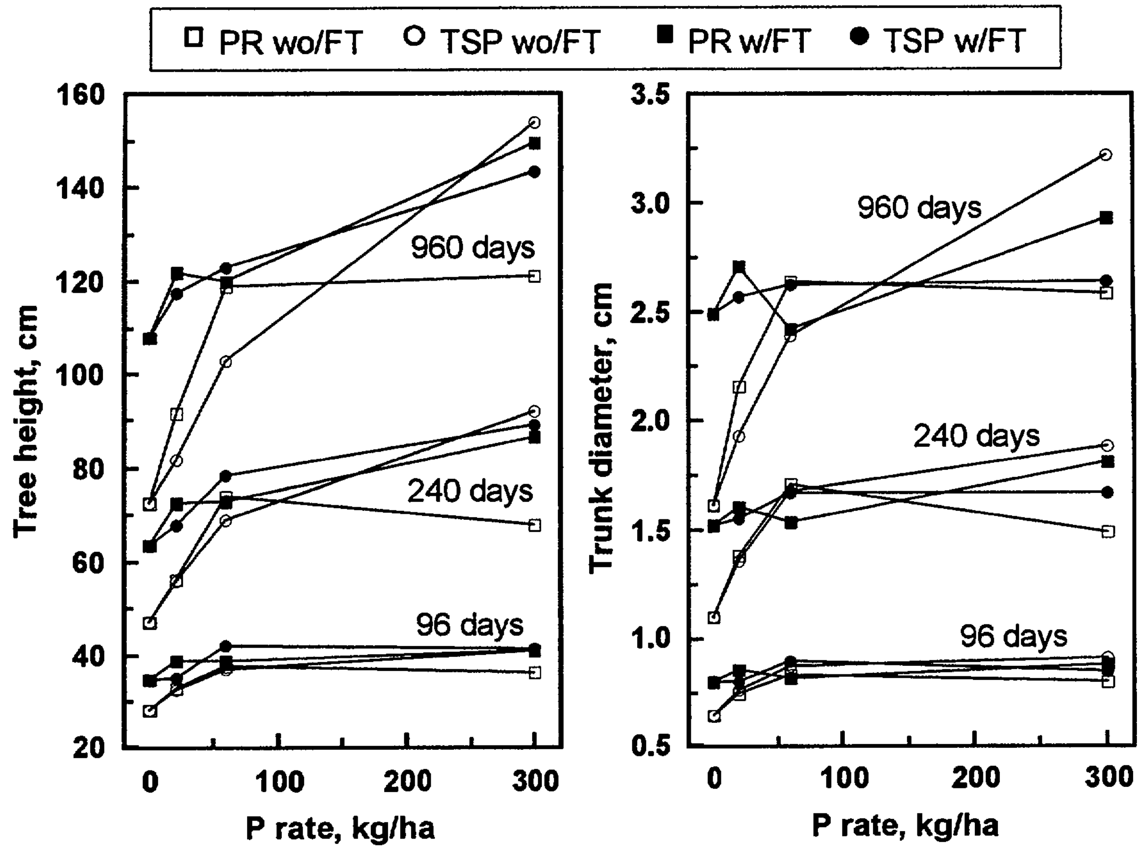

Fig. 1. Loblolly pine height and trunk diameter as affected by various soil application rates of PR and TSP, with or without application of fertilizer tree tablets (FT), at 96, 240, and 960 days after site preparation.

Very few black locust trees were observed after 240 days, but several were observed and counted after 960 days. Phosphate rock was a better P source for growth of lespedeza and black locust. Legumes produce an acidic rhizosphere, which makes them well suited to utilize P in PR [9]. The greater growth of legumes in the PR treatments was probably due to the acidic rhizosphere having a greater ability to solubilize apatite in PR compared to aluminum phosphates formed in soil with application of TSP. Use of PR improved vegetative diversity of ground cover species by increasing legume growth. Since legumes can fix atmospheric nitrogen, the improved legume growth from PR addition has important long-term consequences for the developing ecosystem.

3.2. Soil chemistry

Phosphate rock caused a greater increase in soil pH compared to TSP (Fig. 6). Phosphate rock contains P as PO_4^{3-}. When PR dissolves in soil, PO_4^{3-} can hydrolyze water to form HPO_4^- and $H_2PO_4^-$, which causes an increase in the pH due to release of OH^-:

$$PO_4^{3-} + H_2O \longleftrightarrow HPO_4^{2-} + OH^-$$
$$PO_4^{3-} + H_2O \longleftrightarrow H_2PO_4^- + 2\,OH^-$$

Although slight, PR had a liming effect due to the above reactions. As phosphorus in TSP is present as $H_2PO_4^-$, TSP dissolution in soil had no effect on soil pH.

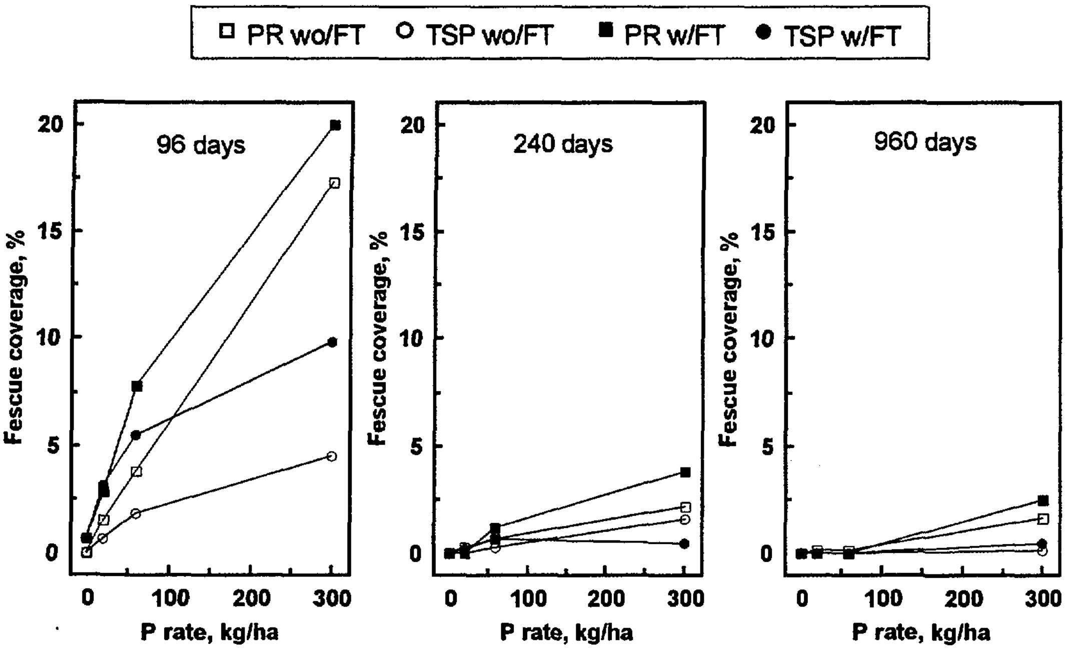

Fig. 2. Fescue coverage in experimental plots as affected by by various soil application rates of PR and TSP, with or without application of fertilizer tree tablets, at 96, 240, and 960 days after site preparation.

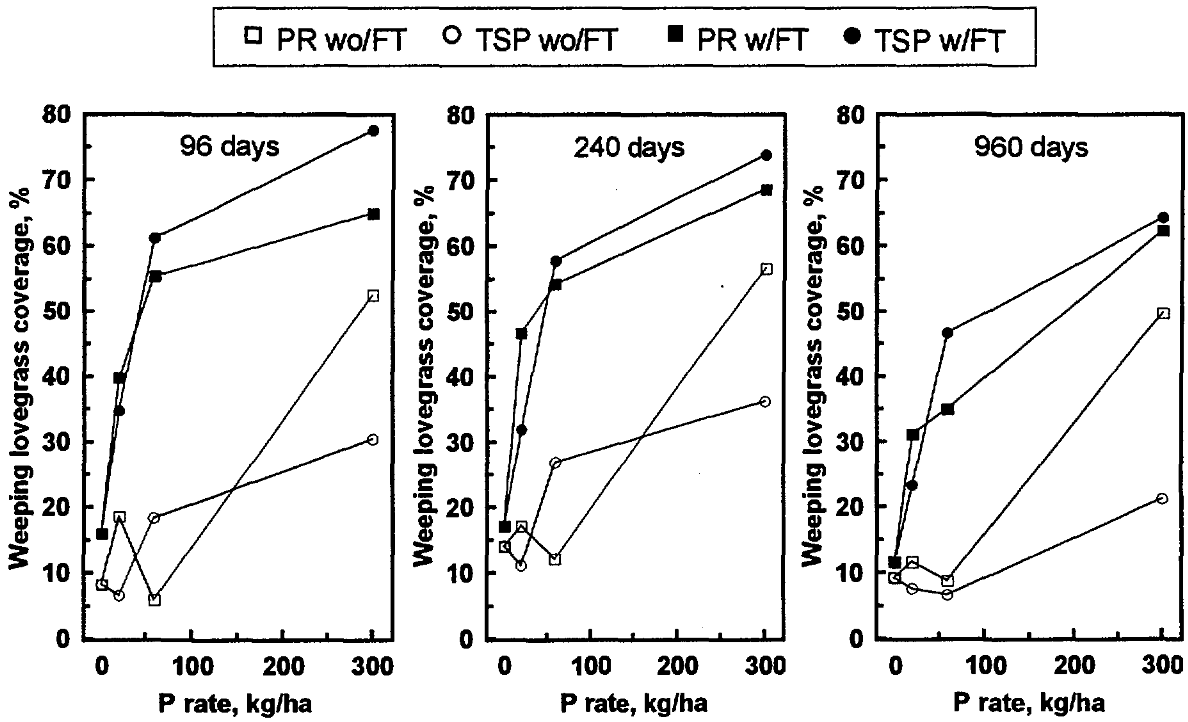

Fig. 3. Weeping lovegrass coverage in experimental plots as affected by various soil application rates of PR and TSP, with or without application of fertilizer tree tablets, at 96, 240, and 960 days after site preparation.

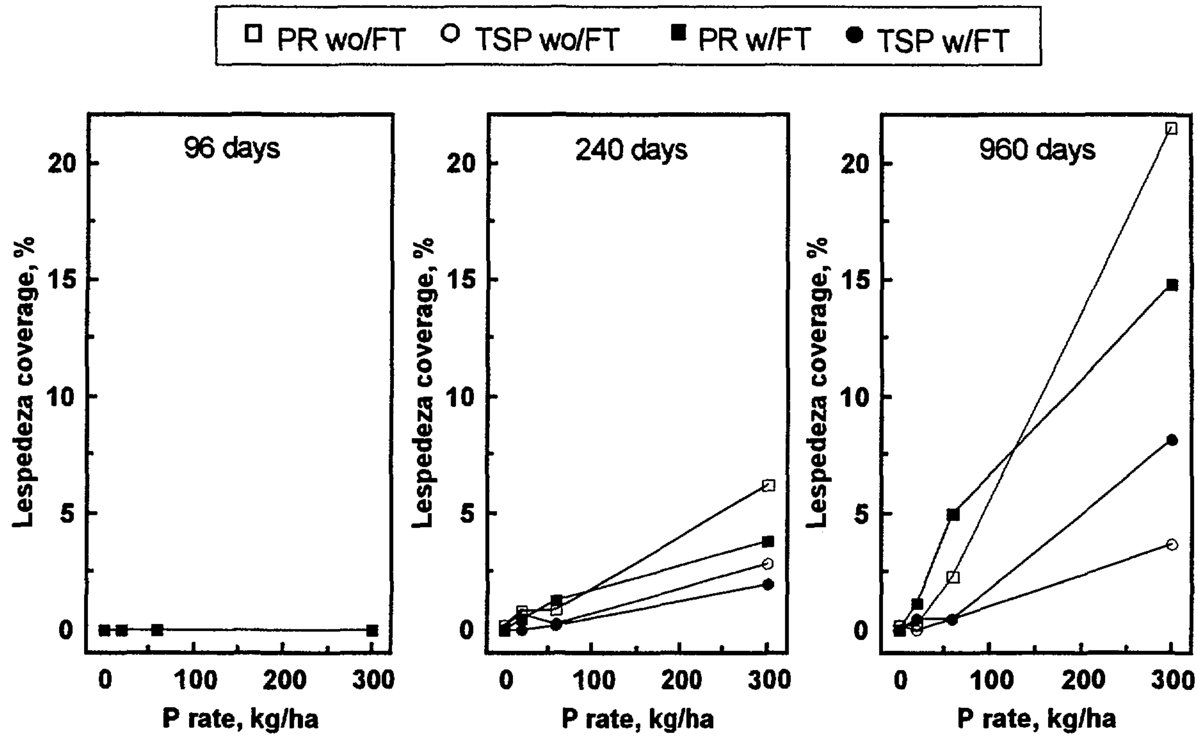

Fig. 4. Lespedeza coverage in experimental plots as affected by various soil application rates of PR and TSP, with or without application of fertilizer tree tablets, at 96, 240, and 960 days after site preparation..

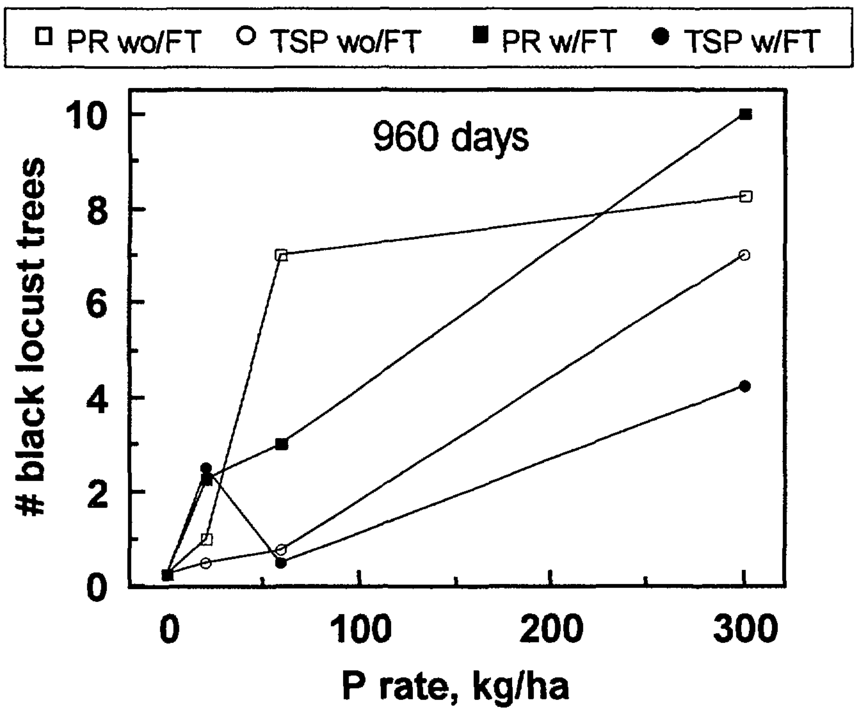

Fig. 5. Number of black locust trees in each experimental plot as affected by various soil application rates of PR and TSP, with or without application of fertilizer tree tablets, at 960 days after site preparation.

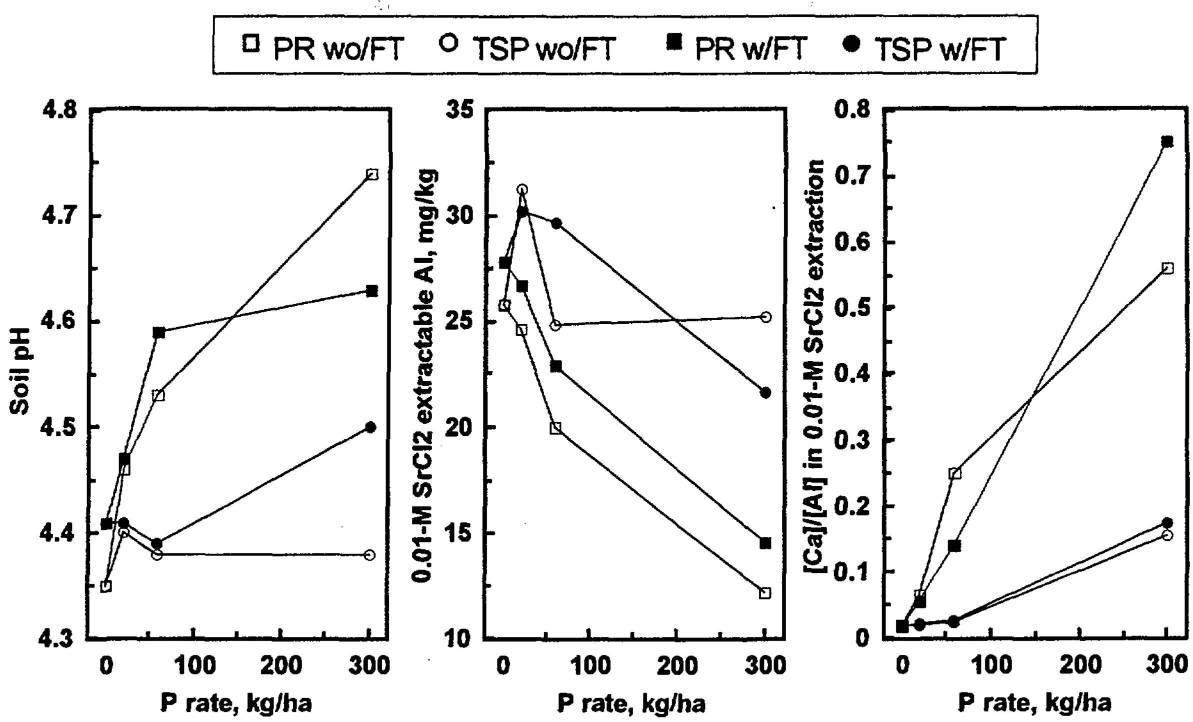

Fig. 6. Soil pH, 0.01-M $SrCl_2$ extractable soil Al, and Ca:Al molar ratios in 0.01-M $SrCl_2$ of surface 2.5 cm soil 240 days after site preparation as affected by various soil application rates of PR and TSP, with or without application of fertilizer tree tablets.

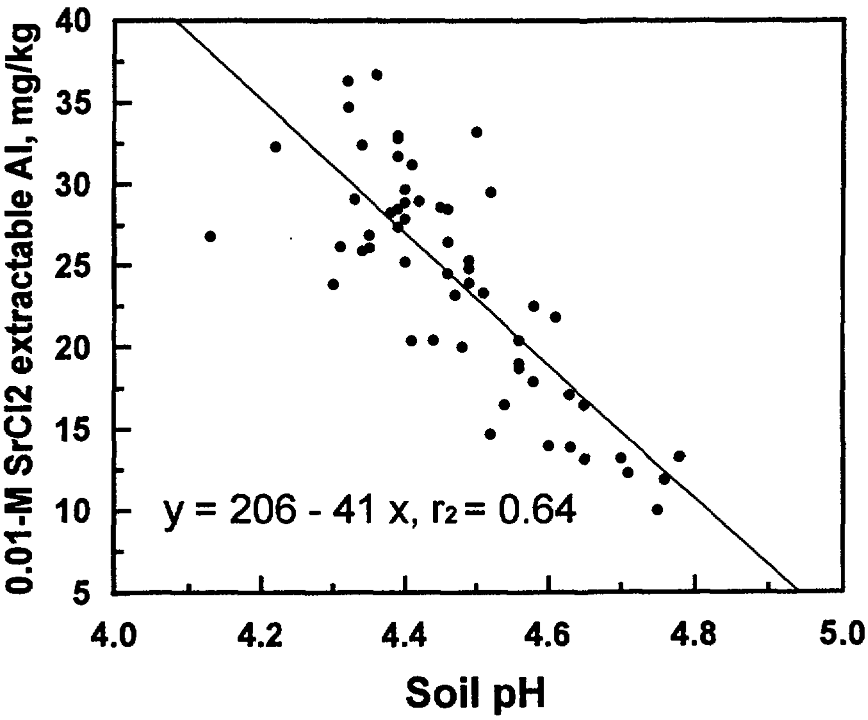

Fig. 7. Correlation between 0.01-M $SrCl_2$ extractable soil Al and soil pH in the surface 2.5 cm soil 240 days after site preparation.

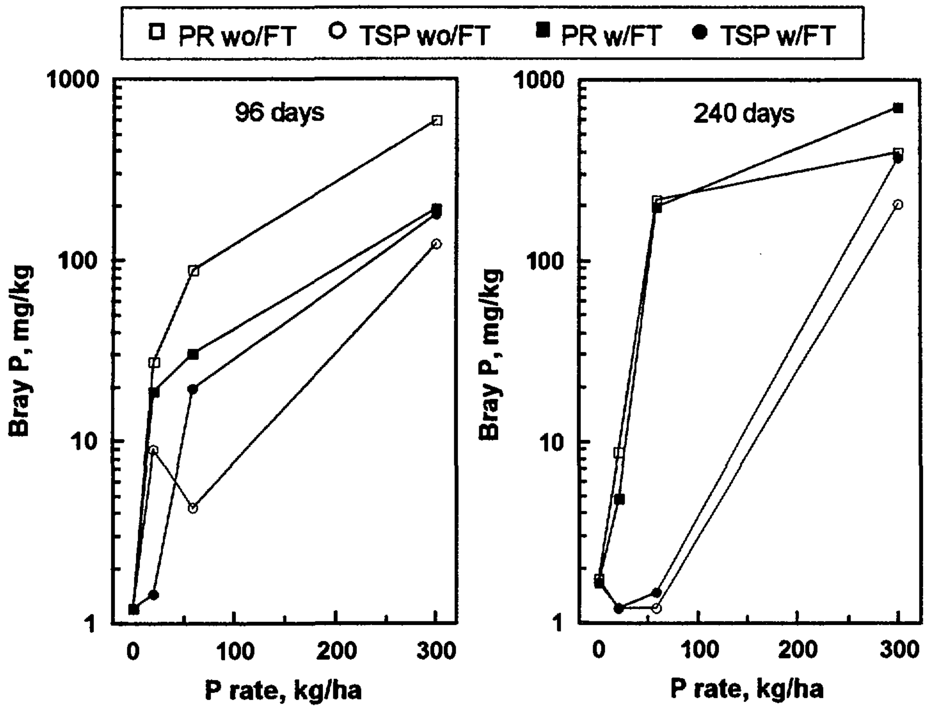

Fig. 8. Soil Bray P in surface 2.5 cm soil 240 days after site preparation as affected by various soil application rates of PR and TSP, with or without application of fertilizer tree tablets.

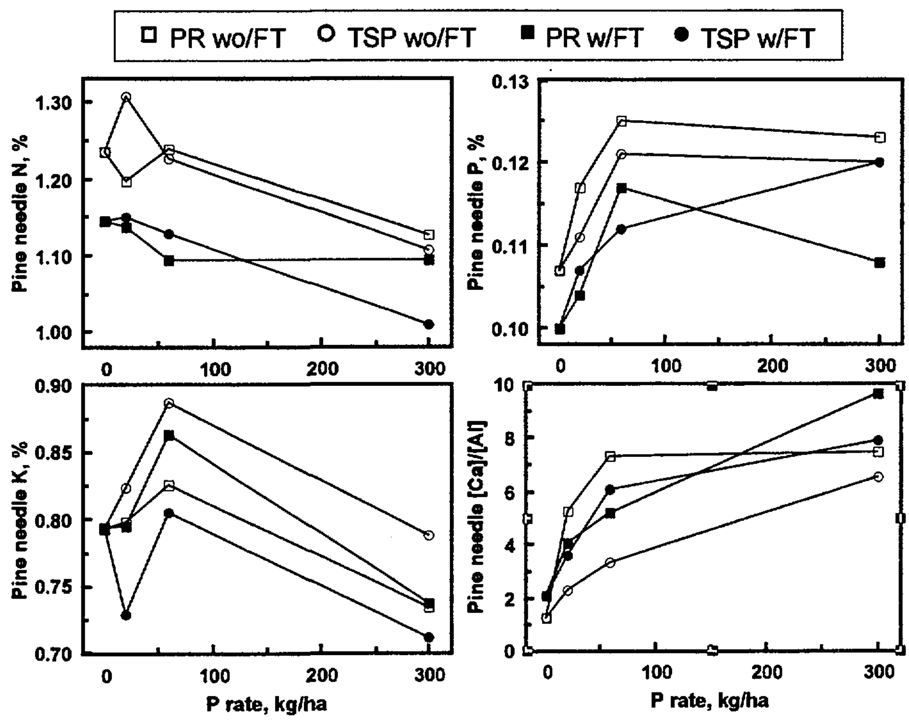

Fig. 9. Chemical composition of loblolly pine needles as affected by various soil application rate of PR and TSP, with or without application of fertilizer tree tablets, at 240 days after site preparation.

A noticeable decrease in 0.01-M $SrCl_2$ extractable Al was observed with increased PR soil application (Fig. 6). The decrease in Al can be explained by a soil pH increase caused by PR decreasing the solubility of Al in soil. The correlation between 0.01-M $SrCl_2$ Al and soil pH is shown in Fig. 7. Although PR may not increase pH greatly, the slight amount it does increase pH may be enough to reduce Al toxicity at very low soil pH levels. Another good indicator for Al toxicity and nutrient stress in forest soils is the molar ratio of Ca:Al in soil solution [3] where a value of 0.2 indicates a 100% likelihood of toxicity stress and a value of 0.5 indicates a 75% likelihood of toxicity stress. The molar ratio of Ca:Al in the 0.01-M $SrCl_2$ extract is shown in Fig. 6. The ratio was much greater in PR compared to TSP. The greater Ca:P weight ratio of 2 in PR compared to 0.67 in TSP and the influence of PO_4^{3-} in PR to increase pH and decrease soluble Al caused the Ca:Al molar ratio to be much higher in PR -amended soils compared to TSP. Phosphate rock greatly decreases the probability of toxicity stress occurring in vegetation grown on extremely acid forest soils.

As expected, Bray P increased with increased soil P application (Fig. 8). The very low Bray P in soils with TSP application after 240 days was probably due to a high fixation capacity of the water-soluble P from TSP in the Copper Basin soil containing high levels of Al. Bray P was much greater in PR amended soils. The acidic Bray extractant was much more effective at solubilizing Ca-phosphates in PR remaining in the soil compared to Al-phosphate formed when water-soluble TSP was applied to soil.

3.3. Loblolly pine needle analyses

Needles from recent growth of loblolly pine were harvested after 240 days for tissue analysis. Phosphorus concentrations increased with increase soil P application rate (Fig. 9). The lower P concentrations in the needles with fertilizer tablets compared to those grown on soil without fertilizer tablets could be a dilution effect from greater tree growth with fertilizer tablets (Fig. 1). Nitrogen concentrations in needles were greatest with trees grown without fertilizer tablets. As with P, the N differences were most probably due to a dilution effect with greater tree growth in soil with fertilizer tablets and at higher soil P application rates. There were little discernible differences in needle K concentrations. Needle Al concentrations decreased with increased soil P application rate (data not shown). The decreased Al was also most likely due to dilution of Al in the trees with improved growth at higher soil P application rate. The Ca:Al molar ratio in needles increased with increasing P rate but little difference was observed between PR and TSP treatments when fertilizer tablets were used. There may have been enough Ca in the fertilizer tablets to increase the Ca:Al ratio in pine needles regardless of the source of P that was surface applied. The TSP treatment did result in lower Ca:Al ratios compared to PR when fertilizer tablets were not used which was probably due to greater Ca application in PR compared to TSP. Cronan and Grigal [3] suggest a Ca:Al molar ratio less than 12.5 indicates a 50% likelihood of toxicity stresses being present. Phosphorus application rates improved the Ca:Al molar ratios but the ratios were still in the low range where the likelihood of toxicity stress was high.

4. CONCLUSIONS

Use of PR in reclaiming extremely acidic soils provides several benefits that water-soluble P fertilizers cannot supply. Phosphate rock improves the growth of legumes due to the acidic rhizosphere of legumes solubilizing apatite in PR and releasing P. Better legume growth in turn enhances the overall sustainability of vegetative growth due to the N input into the ecosystem via atmospheric N fixation. Phosphate rock also decreases soil acidity as observed with increases in soil pH and decreases in soluble Al. This is also confirmed by the increase in the molar ratio of Ca:Al in 0.01-M $SrCl_2$ extracts with increased PR addition. Decrease in soil acidity and improvement of legume growth associated with PR may have been the explanation for improved loblolly pine growth with PR compared to TSP when P was applied at 59 kg/ha without fertilizer tree tablets.

Fertilizer tree tablets provided great benefit in increasing loblolly pine growth when no surface application of P occurred. However, with surface P application of 59 kg/ha as PR, no additional benefit in tree growth was observed with the fertilizer tablets. Some improved tree growth still occurred with the use of fertilizer tablets when P was applied at 59 kg P/ha as TSP. The effect of fertilizer tablets on tree growth with some surface application of P may have been slight, but it was striking on growth of weeping love grass, with much greater ground cover observed with PR compared to TSP. With surface application of P in reclaiming extremely acid soils, fertilizer tree tablets may add more benefit to growth of ground cover grass species than to survival and growth of loblolly pine trees.

The experimental site was only monitored for 960 days. All of the observed effects were in a short time window considering the life expectancy of the developing ecosystem. Observations at longer time periods would be worthwhile to determine long-term effects of PR and fertilizer tablets on soil chemistry and growth of plant species.

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