Determination of Aluminum Toxicity in Indiana Soils by Petri Dish Bioassay

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Introduction

A rapid determination of aluminum toxicity for a given cultivar on a particular soil would aid the investigator in making timely research or management decisions. Such a technique could be applied to survey acidic Indiana soils for phytotoxic levels of Al. Al injured roots are characteristically short, stubby, and lacking in fine branching. Root tips become thickened and turn brown (Foy 1978). Such roots are inefficient in absorbing nutrients and water. The degree to which Al toxicity symptoms are expressed is dependent on complex interactions among the amount and species of Al present in the soil (Pavin 1982), the presence of other toxic, essential and non-essential ions, the soil humus content, mineralogy and horizon, (Cedews 1981, 1983) and the plant genotype (Foy 1983). Because of this, chemical analysis of Al is a poor predictor of Al toxicity. In addition, the specifically toxic form of aluminum, and hence, the correct type of Al analysis, needs to be determined (Adams 1983). Recently, Pavin (1982) found that growth reduction of seedlings correlated best the Al^{3+} activity value, but the determination of Al activity requires a detailed knowledge of the chemical composition of the soil solution and the use of the GEOCHEM computer program to make the complex computations (Sposito 1980).

The purposes of this study were to develop techniques of using soil filled petri dishes for rapid root bioassays, to look at Indiana soils for the presence and distribution of Al toxicity, and to compare the results to various chemical parameters of the soil.

Materials and Methods

The small soil samples remaining from the Purdue Soil Characterization Laboratory analyses run for soil classification and mapping purposes were used to study horizons in pedons. Thirty-two horizons from eleven acid Indiana soils were wetted to field capacity and equilibrated for 12 hours. Al sensitive Abe wheat was germinated and selected for 0.5 cm root lengths. Square petri dishes measuring 9.0 X 9.0 X 1.5 cm were filled with soil and each planted with 5 germinated seeds, all placed 1 cm from the same edge of the dish. The dishes were taped shut, gently tapped to ensure good root-soil contact, placed vertically in a rack, covered with a plastic bag to retard moisture loss, and incubated for 48 hours in the dark. The seedlings were then removed and total root lengths per plant were measured.

Six replications were run for a total of 30 seedlings per horizon. Root growth in dishes was also compared to growth in pots using the limed and unlimed A and B horizons of an acid Cecil loam.

Root growth vs. pH relationships in H_2O, 0.01M $CaCl_2$ and 1N KC1 were examined. In addition, exchangeable acidity and Al were determined by lN KCl ex-

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traction following the method of Thomas (1982). The values for pH and other exchangeable ions were taken from the Soil Characterization Laboratory analyses of these samples. Root growth was also compared to exchangeable Al and percent Al saturation.

For a reference system 20 ml of solution with varying concentrations of $Al(NO_3)_3$ was added to 200 g sand, placed in petri dishes and planted with 6 Abe wheat seedlings. The root lengths were measured after 48 hours of incubation. This experiment was conducted in randomized blocks with six replications.

Results and Discussion

No significant differences in root growth were apparent between petri dishes and pots in the Cecil loam study. This verifies that the small amount of soil and the close proximity of the petri dish surfaces to the roots does not affect the validity of the test.

Analysis of root length in Indiana soils showed root reductions in 20 of the 32 horizons, some as high as 60%. Ten out of the eleven soils studies showed significant root reductions, most of which occurred in the B horizons. These roots were thickened, with spatulate ends and few root hairs. Roots from sand systems containing Al showed similar root toxicities at higher Al levels. Incremental additions of Al to sand systems (Figure 1) showed a modest decline in root length to 5 mg Al/kg sand and a steep decline between 5.0 and 7.5 mg Al/kg. This suggests that there may be a critical level of Al for toxicity to Abe wheat in the region of the steep decline.

The occurrence of Al toxicity in the soils showed great variation and little adherence to any pattern. Figure 2 shows two soils with pH declining with depth. In the Peoga soil, the root growth declines with pH, but this clearly is not the case for the Clermont. Figure 3 shows differences in root growth versus horizon. A decline in root growth occurs on going to deeper horizons in the Avonburg, but this relationship does not hold for the Rockcastle.

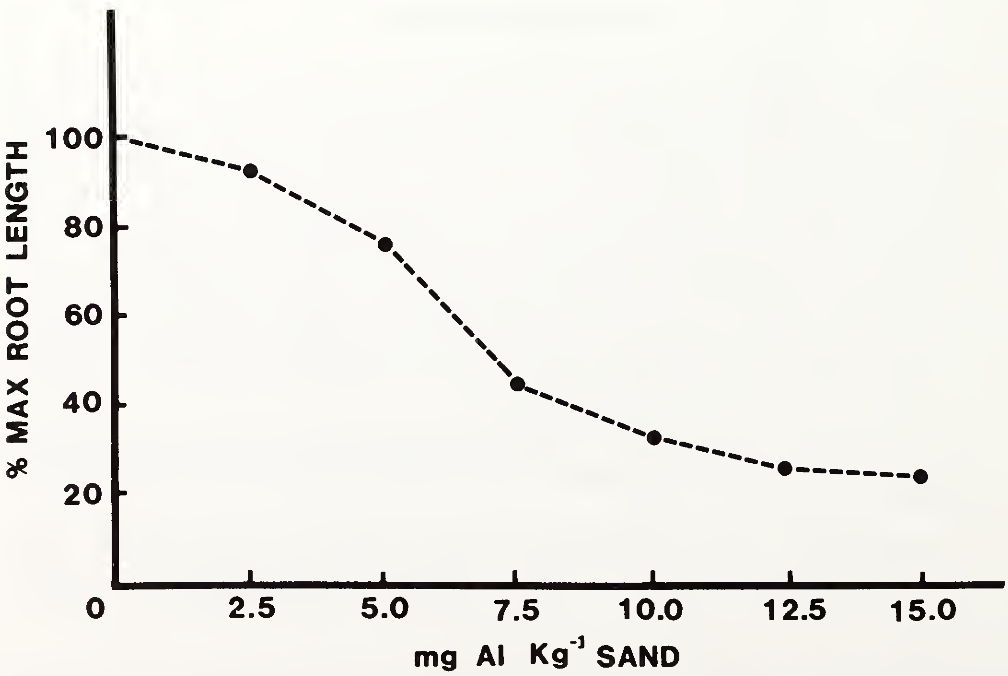

FIGURE 1. *The effect of incremental additions of Al to sand systems on root growth.*

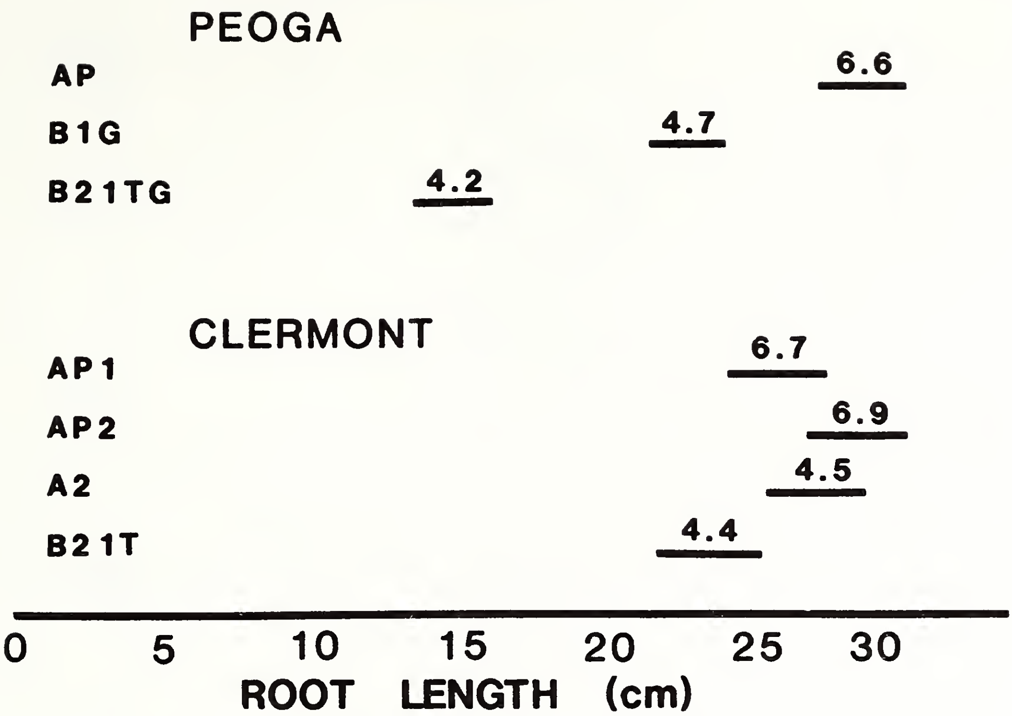

FIGURE 2. *Root length vs. horizon for the Peoga and Clermont soils, with pH shown. Line widths represent a 95% confidence interval for the population mean.*

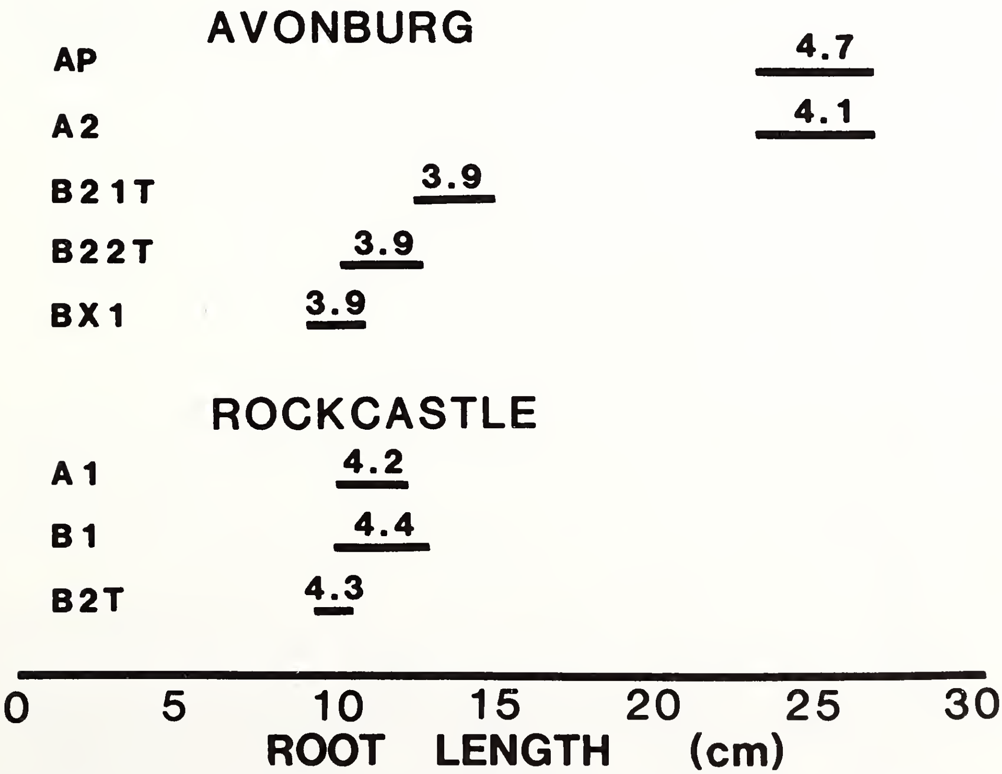

FIGURE 3. *Two soils showing root lengths at various horizons. pH in H_2O is shown above confidence intervals.*

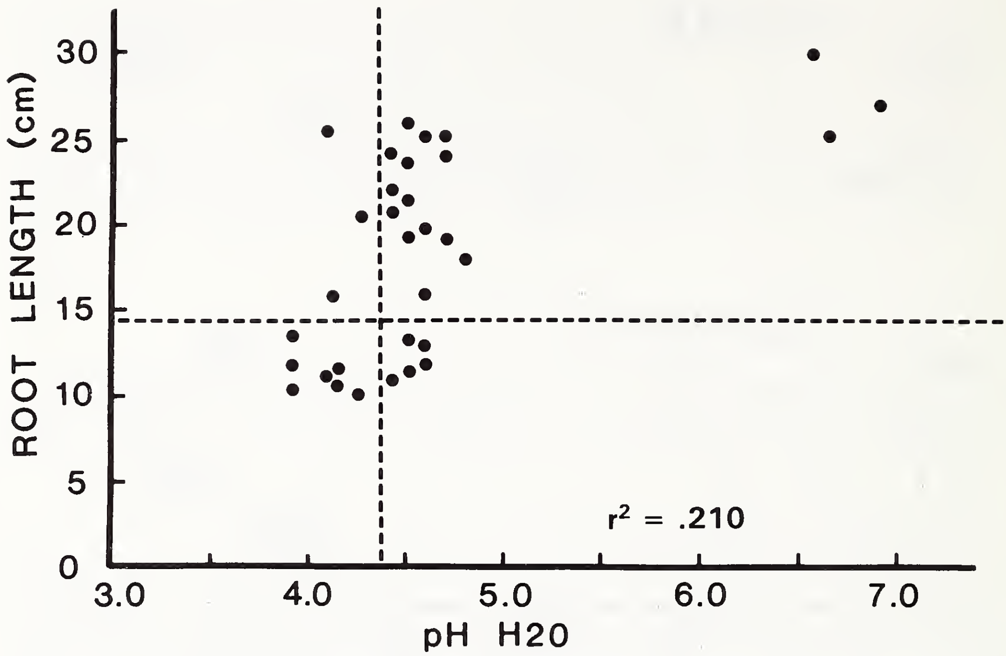

FIGURE 4. *pH in $H_2$0 versus root length. Quadrants are drwan for Cate-Nelson critical level graphical analysis.*

In the acid range, where soil pH might be expected to cause toxicities, the root lengths showed almost no relationshp to pH in $H_2$0 (Figure 4). This was also true for root growth vs. pH read in 0.01M $CaCl_2$. The relationship for pH read in KCl vs. root growth (Figure 5) is somewhat better. The Cate-Nelson critical level graphical analysis technique (1973) suggests that Al toxic symptoms for Abe wheat occur often at a pH (KCl) below 3.3.

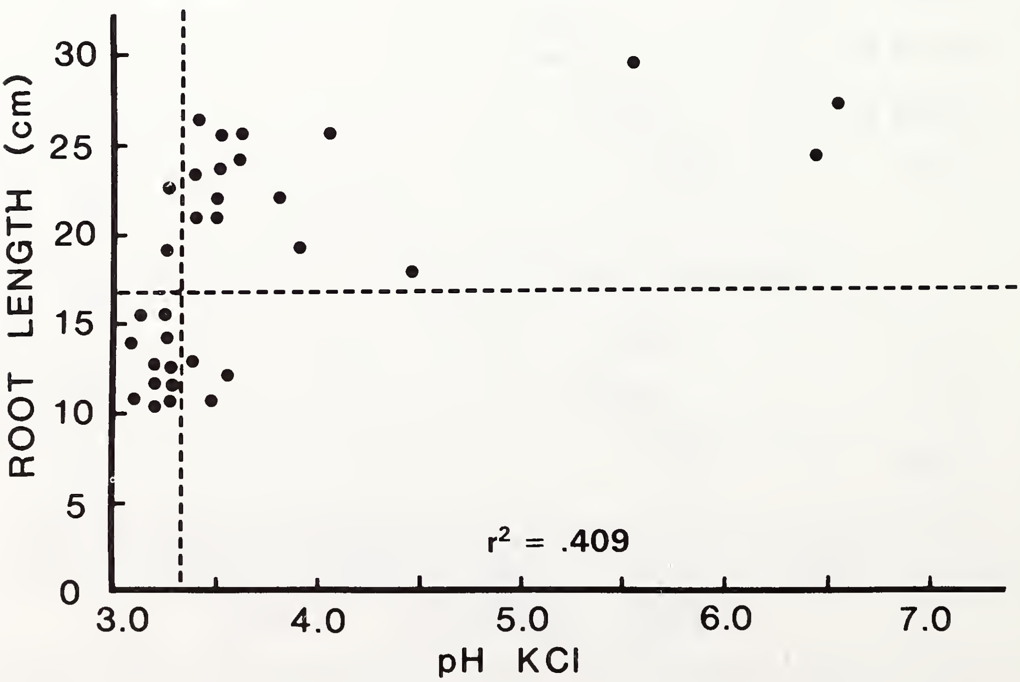

FIGURE 5. *pH in 1N KCl versus root length.*

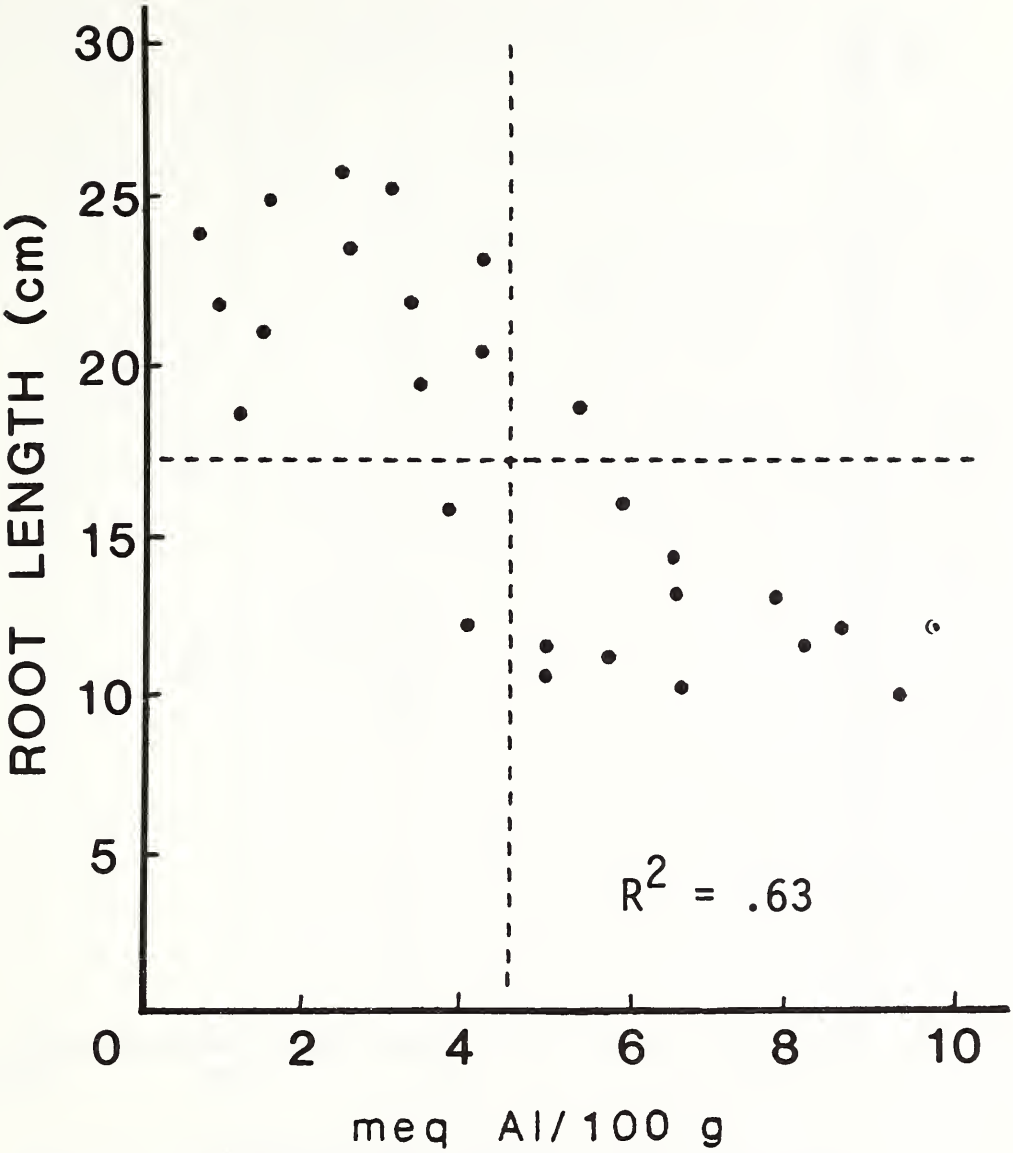

FIGURE 6. *The relationship between exchangeable Al and root length.*

The plot of root growth vs. exchangeable Al gives a fairly definite critical level at 4.5 meq for Abe wheat using the Cate-Nelson technique (Figure 6). Figure 7 shows the relationship of % Al saturation to root growth, and the critical level for toxicity is quite marked at 55%. However, at less than 55% Al saturation there is still much variation in root growth for the various horizons.

Results of our studies support comments by Adams (1983) as there is almost no relationship between pH in water or 0.01M $CaCl_2$ and Al toxicity. In addition there is only a modest relationship between the chemical parameters of pH (KCl), exchangeable Al, percent Al saturation and Al toxicity. The petri dish bioassay is a rapid procedure that bypasses these problems because it is sensitive in detecting Al toxicity directly for a plant genotype on a specific soil. In addition, one can control almost all other factors known to affect root growth, such as soil moisture tension, aeration, bulk density and temperature. The soil's nutrient status, particularly P and K, should not affect seedling root growth, which occurs in the dark, because the energy for growth

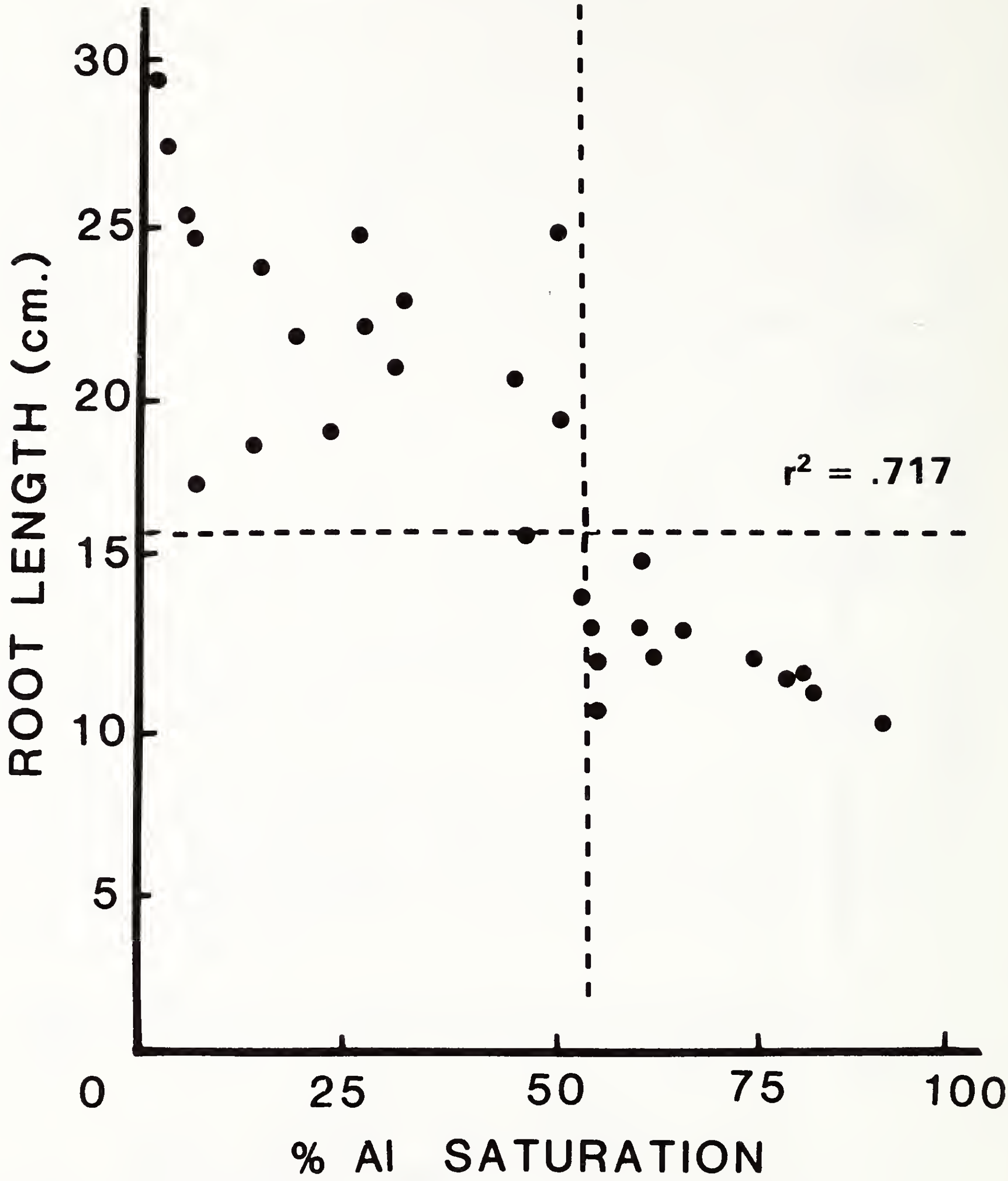

FIGURE 7. *The relationship between % Al saturation and root length.*

is derived from seed reserves and not from the product of nutrient uptake and photosynthesis. Thus, the information gained by this method would help the investigator make sound management or research decisions on acidity problems.

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