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Chemical Limitations of Yoga Root Growth in an Acid Soil

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Abstract—Subsoil from an acid soil series was amended with $CaSO_4$, MgO, or $Ca(OH)_2$ to identify chemical factors that may be limiting of root growth of *Elaeocarpus joga* (yoga) in these soils. New root length of yoga seedlings in the three amendment treatments was increased about 70% above that in the untreated substrate. New root length did not differ among the three amendment treatments. These amendments increased dry weight of new roots about 85% above dry weight of new roots in the untreated substrate. The results indicate that both Ca deficiency and Al toxicity limit yoga root growth in the acid soils of Guam. These chemical limitations may be the reasons this species occurs exclusively in alkaline soils in Guam and Rota.

Introduction

The yoga tree, *Elaeocarpus joga* Merrill (Elaeocarpaceae) is a striking tree species endemic to the Mariana Islands and Palau. The population in Guam is highly disjunct, and trees are restricted to limestone soils (Stone, 1970).

The Akina soil series (very fine, kaolinitic, isohyperthermic Oxic Haplustalfs) in Guam is a highly weathered volcanic soil that formed in residuum derived dominantly from tuff and tuff breccia, and is strongly or very strongly acid (Young, 1988). The leaching of kaolinite clays under Guam's tropical climate produces aluminum and iron oxides. Acid soils such as the Akina soil series may influence yoga growth through direct influence of hydrogen ions, or through the indirect influence of pH on availability of mineral elements (Foy, 1992). Our objectives were to determine the relative influence of $CaSO_4$, MgO, or $Ca(OH)_2$ amendments on yoga root growth in the substrate of the Akina soil series.

Materials and Methods

Subsoil from the Akina soil series was collected from a site near the University of Guam's Ija Agricultural Experiment Station. Four soil treatments were developed, based on the methods of Adams and Moore (1983): (1) untreated subsoil substrate (pH 4.6), (2) substrate amended with $CaSO_4$ to supply Ca at 100 mg kg^{-1} (pH 4.7); (3) substrate amended with $Ca(OH)_2$ until pH was above 6; and (4) substrate amended with MgO until pH was above 6. Following this protocol of Adams and Moore (1983) allowed the following assumptions. Amending the substrate with $CaSO_4$ corrected Ca deficiency without affecting Al availability. Increasing the substrate pH to above 6 with MgO corrected Al toxicity without affecting Ca concentration. Increasing the substrate pH to above 6 with $Ca(OH)_2$ corrected Ca deficiency and Al toxicity.

The initial addition of the three amendments began in March 1999. After thoroughly mixing, water was added to the four substrate treatments until damp. The containers were enclosed in plastic bags to allow the substrate amended with $Ca(OH)_2$ or MgO to equilibrate. Following at least one week, the treated substrates were allowed to air dry. This procedure was repeated numerous times to reach a pH of 6 for these two treatments. We wetted and dried the untreated and $CaSO_4$ treated substrate along with the other two amendment treatments to ensure homogeneity among the treatments.

Fruits from a single yoga tree (lat. 13º 34.031" N, long. 144º 53.362" E) in Yigo were collected in September 1999. The site was characterized with Guam cobbly clay loam soil (clayey, gibbsitic, nonacid, isohyperthermic Lithic Ustorthents). The half-sibling yoga seeds were extracted from the fruits and planted in nursery tubes containing Sunshine Mix #4 (Sun Gro Horticulture, Bellevue, Wash.) on 4 October 1999. The cell volume was 115 mL. The seedlings were grown in a full sun nursery with daily watering and weekly drenching with a complete soluble fertilizer (15N –2.2P –12.5K –5Ca –2Mg + micronutrients) at a concentration that approximated 7.5 mM N.

The seedlings were transplanted into 656 mL containers filled with one of the four substrate treatments on 25 March 2000. There were five replications per treatment, and they were arranged in a completely randomized design. The seedlings received daily watering until 10 April 2000, when the substrate was carefully washed away from each nursery plug. This revealed roots that had egressed into the substrate, and these roots were carefully cut from the plugs using a razor blade. Excised roots were sealed in plastic bags and stored at 2ºC until measurements were made on 11 April 2000.

Total root length was determined using the modified line intersect method (Tennant, 1975). Roots were spread with minimum overlap over a grid and the number of intersects was used to estimate root length. Roots were dried at 70ºC for 48 h, then total root dry weight was measured. The data were subjected to analysis of variance, and mean separation when needed was determined by LSD. The three response variables were dry weight, root length, and the root length per unit dry weight.

Table 1. Total length and dry weight of yoga roots that egressed from a nursery plug after 16 d into untreated subsoil from Guam's Akina soil series, or into this subsoil amended with $CaSO_4$, MgO, or $Ca(OH)_2$. (n = 5).

Treatment	Mean root length (mm)	Mean root dry wt (mg)
Untreated	129b[z]	27b
$CaSO_4$	211a	47a
MgO	215a	49a
$Ca(OH)_2$	235a	55a

[z]Means within columns followed by a different letter are significantly different according to LSD test, $P \leq 0.05$.

Results

The yoga seedlings developed 129 mm of new root length into untreated acid substrate in the 16 d of growth (Table 1). Amending with $CaSO_4$, MgO, or $Ca(OH)_2$ resulted in an average of 70% increase in new root length when compared with untreated substrate ($P \leq 0.05$). There were no significant differences in new root length among the three amendments, although there was an arithmetic increase of 9–11% for $Ca(OH)_2$ over the other amendments.

Dry weight of new roots following 16 d of growth into the untreated substrate was 27 mg, and the three amendments increased ($P \leq 0.05$) root dry weight above that in the untreated substrate similarly (Table 1). This increase averaged around 85%.

Root length per unit dry weight was not influenced by substrate treatments for yoga seedlings (data not shown). Thus, the treatments did not influence specific root length.

Discussion

One limitation to determining the basis of poor root growth in acid soils is the need to separate the influence of Al toxicity from Ca deficiency (Foy, 1992). Based on the protocol of Adams and Moore (1983), our use of the $CaSO_4$, $Ca(OH)_2$, and MgO materials allowed separation of the effect of substrate pH, Ca deficiency, and Al toxicity. The addition of all three amendments to the substrate improved yoga root growth. The results supported the conclusion that Ca deficiency and Al toxicity are likely involved in limiting yoga root growth in subsoils of the Akina soil series.

This study does not identify the full range of physical and chemical factors that limit yoga root growth in acidic soils. The results do confirm, however, that improved root growth occurs without additions of Ca following an increase in pH above the critical value for Al toxicity. The results also confirm that improved root growth occurs without pH adjustment if sufficient Ca is available. Foy (1992)

Figure 1. Phenotype of new root growth following 16 days of growth into untreated Akina subsoil (left) or into this soil amended with $Ca(OH)_2$.

reported that Al toxicity is usually the most limiting growth factor for plants in soils below pH of 5.0. Our results indicate that Ca deficiency in an Akina subsoil is no less limiting of yoga root growth than is Al toxicity.

Characteristic visual symptoms of Ca deficiency are thin roots with necrotic tips; and of Al toxicity are swollen, stubby, and distorted roots (Foy, 1974, 1992; Kabata-Pendias and Pendias, 1984). We did not observe these Ca deficiency symptoms in untreated or MgO amended substrate, or Al toxicity symptoms in untreated or $CaSO_4$ amended substrate.

The yoga population in Guam is disjunct, and strictly located within alkaline soil series. These chemical limitations to yoga root growth in the acidic Akina soil may be the reasons the species occurs exclusively in alkaline soils in Guam and Rota. This understanding may be used in the future to make conservation management decisions.

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