

Chemical Factors Enhancing Papaya Root Growth in a Tropical Volcanic Acid Subsoil

Thomas E. Marler and Ruben dela Cruz

Agricultural Experiment Station, University of Guam, UOG Station, Mangilao, Guam 96923

Additional index words. aluminum, calcium, *Carica papaya*

Abstract. Subsoil from an acid soil series was amended with CaSO_4 , MgO , or Ca(OH)_2 to identify chemical factors that may enhance papaya (*Carica papaya* L.) root growth in these soils. Root length of 'Red Lady' and 'Waimanalo' seedlings at two stages of development was increased by the addition of each of the materials. The increase in root length was similar for CaSO_4 or MgO amendments, and was greatest for Ca(OH)_2 amendment. These amendments increased dry weight of new roots for 'Red Lady' and increased root length per unit dry weight in one experiment for 'Waimanalo'. The results indicate that both Ca deficiency and Al toxicity may be responsible for limiting papaya root growth in the subsoils of the acid soils of Guam. Correcting these chemical factors should improve rooting depth, thereby increasing the volume of soil from which resources are accessible and lessening the susceptibility to toppling during tropical cyclones.

Management recommendations for papaya production indicate desirable soil pH is 5.5 to 7.0 (Marler et al., 1994; Samson, 1980). Awada et al. (1975) used lime to increase the pH of acid soils (pH of 4.3 to 5.3), and reported that the two doses resulting in a pH of 5.5 or 6.7 increased yield above that obtained in the untreated soil. Ikeda and Si (1976) reported similar results when they increased pH of acid soils (pH of 4.5) and measured a resulting increase in growth through a pH of 6.5.

Acid soils may influence papaya growth through direct influence of hydrogen ions, or through the indirect influence of pH on availability of mineral elements (Foy, 1992). Marler (1998) supplied a complete nutrient solution to 'Waimanalo' papaya seedlings; and growth, morphology, and mineral content of tissue were relatively uninfluenced by pH within the range of ≈ 4 –8.8. Growth variables in this study included root extension rates. Thus, the benefits of adding lime to acid soils above a pH of ≈ 4 (Awada et al., 1975; Ikeda and Si, 1976) do not result from the direct influence on pH. Acid soils usually contain insufficient amounts of Ca or excessive amounts of Al (Foy, 1992). These factors may be responsible for the increase in growth and yield of papaya when lime is added to acid soils.

The Akina soil (very fine, kaolinitic, isohyperthermic Oxic Haplustalfs) on Guam is a highly weathered volcanic soil that formed in residuum, and is strongly or very strongly acid (Young, 1988). The subsoil is a dark red clay. This is the predominant volcanic soil on Guam for agricultural use. We have excavated

papaya plants in this soil, and rooting depth is severely limited. An understanding of the chemical and physical factors responsible for the limited rooting depth may lead to management decisions that will improve papaya production in these and other acid soils. Our objectives were to determine the relative influence of CaSO_4 , MgO , or Ca(OH)_2 amendments on papaya root growth at two stages of seedling development in the subsoil of the Akina soil series.

Materials and Methods

Four soil treatments were developed, based on the methods of Adams and Moore (1983): 1) untreated subsoil obtained from the Akina soil series (pH 4.6); 2) subsoil amended with CaSO_4 to supply Ca at $100 \text{ mg}\cdot\text{kg}^{-1}$ (pH 4.7); 3) subsoil amended with Ca(OH)_2 until pH was >6 ; and 4) subsoil amended with MgO until pH was >6 . Following this protocol of Adams and Moore (1983) allowed the following assumptions. Amending the subsoil with CaSO_4 corrected Ca deficiency without affecting Al availability. Increasing the subsoil pH to above 6 with MgO corrected Al toxicity without affecting Ca concentration. Increasing the subsoil pH to above 6 with Ca(OH)_2 corrected Ca deficiency and Al toxicity.

The initial addition of the three amendments was 15 Mar. 1999. After thoroughly mixing, water was added to the four soil treatments until damp. The containers were enclosed in plastic bags to allow the subsoils amended with Ca(OH)_2 or MgO to equilibrate. Following at least one week, the soils were allowed to air dry and pH was tested. This procedure was repeated until 28 Apr. to reach a pH of 6 for these two treatments. We wetted and dried the untreated and CaSO_4 treated subsoils along with the other two treatments.

Experiment 1. 'Red Lady' and 'Waimanalo' papaya seeds were planted in nursery flats containing Sunshine Mix #4 (Sun Gro Horticulture, Bellevue, Wash.) on 23 Apr. 1999. The cell volume was 275 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 625 mL containers filled with one of the four soil treatments on 4 June 1999. There were four replications per treatment, and they were arranged in a completely randomized design. The soil received daily watering until 10 June, when the soil was carefully washed away from each nursery plug. This revealed roots that had egressed into the soil treatments, and these roots were carefully cut from the plugs using a razor blade. Excised roots were sealed in plastic bags and stored at 2°C until measurements were made on 11 June. Mean temperature extremes during 4–10 June were $28.2 \pm 0.4^\circ\text{C}$ and $22.6 \pm 0.3^\circ\text{C}$ (mean \pm SE).

Experiment 2. 'Red Lady' and 'Waimanalo' papaya seeds were placed within moistened paper towels on 8 June 1999. After 24 h, they were planted directly in one of the four soil treatments in 625 mL containers. Ten seeds were planted per container, and there were four replications per soil treatment arranged in a completely randomized design. Temperature extremes during the study were $28.9 \pm 0.2^\circ\text{C}$ and $23.0 \pm 0.2^\circ\text{C}$. Soil in each container was watered daily until 22 June, when the roots within each container were washed free of the media, sealed in plastic bags, and stored at 2°C until analysis on 24 June.

Response variables and analysis. 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 70°C 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. Data from each cultivar were analyzed separately. The three response variables were dry weight, root length, and the root length per unit dry weight.

Results

'Red Lady' transplants developed 145 mm of new root length into untreated acid subsoil in 6 d of growth (Table 1). Amending with CaSO_4 or MgO resulted in a 250% increase in new root length when compared with untreated soil ($P \leq 0.005$). Amending with Ca(OH)_2 increased new root length 310% above that in untreated soil. The pattern of response to the amendments as compared with the untreated soil was similar for 'Waimanalo' ($P \leq 0.030$), with a 190% increase in new root length for CaSO_4 or MgO and a 270% increase for Ca(OH)_2 (Table 1).

Dry weight of new roots in amended soils increased above that in the untreated soil simi-

larly for the three amendments (Table 1). This increase was $\approx 450\%$ for 'Red Lady' ($P \leq 0.009$), and $\approx 75\%$ for 'Waimanalo'. However, the increase was nonsignificant for 'Waimanalo'.

Root length per unit dry weight was not influenced by soil treatments for 'Red Lady' transplants (data not shown). In contrast, the soil amendments increased root length per unit dry weight for 'Waimanalo' transplants above that for untreated soil ($P \leq 0.036$). 'Waimanalo' roots developed $2.5 \text{ mm}\cdot\text{mg}^{-1}$ in the untreated soil, $\approx 4.0 \text{ mm}\cdot\text{mg}^{-1}$ in the CaSO_4 and MgO amended soil, and $5.3 \text{ mm}\cdot\text{mg}^{-1}$ in the Ca(OH)_2 amended soil.

The cumulative radicle length of 10 'Red Lady' seedlings after 13 d of growth in untreated soil was $\approx 5 \text{ cm}$ (Table 1). Amending with CaSO_4 or MgO increased length 114%, and amending with Ca(OH)_2 increased length 350% above root length of seedlings in untreated soil ($P \leq 0.014$). The response pattern for 'Waimanalo' radicles was similar, with a 72% increase with CaSO_4 , a 38% increase with MgO , and a 200% increase with Ca(OH)_2 ($P \leq 0.010$).

The influence of soil amendments on 'Red Lady' radicle dry weight followed the same pattern as that of radicle length (Table 1). The increase in radicle dry weight above that of untreated soil was 60% to 75% for CaSO_4 or MgO , and 190% for Ca(OH)_2 ($P \leq 0.029$). As in Expt. 1, the addition of amendments increased 'Waimanalo' radicle dry weight, but the increase was nonsignificant.

Radicle length per unit dry weight was not influenced by the soil treatments for either cultivar (data not shown).

Discussion

The addition of any of the three amendments to the subsoil improved papaya root growth. A limitation to diagnosing the basis of poor root growth in acid soils is the separation of Al toxicity from Ca deficiency and the interactions of the two phenomena (Foy, 1992). Based on the protocol and speculations of Adams and Moore (1983), our use of the CaSO_4 , Ca(OH)_2 , and MgO materials allowed separation of the effect of soil pH, Ca deficiency, and Al toxicity. We did not measure plant tissue concentrations of Ca and Al, however, both of our approaches to conducting the assay supported the conclusion that Ca deficiency and Al toxicity are likely involved in limiting papaya root growth in subsoils of the Akina soil series.

This study does not identify the full range of physical and chemical factors that limit papaya root growth in these subsoils. 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. Results also confirm that improved root growth occurs without pH adjustment following additions of Ca. Runoff in these soils formed from volcanic deposits is rapid, and the risk of erosion is severe (Young, 1988). Thus, lime deposits and deep tillage to address Ca deficiency and Al toxicity should be limited to the early parts of the dry season. CaCO_3 is a readily available natural resource that may be used for this purpose.

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 soil, or Al toxicity symptoms in untreated or CaSO_4 amended soil.

Foy (1992) reported that Al toxicity is usually the most limiting growth factor for plants in soils below pH of 5.0. Based on the assumptions of Adams and Moore (1983), our results indicate that Ca deficiency in Akina subsoils is no less limiting of papaya root growth than is Al toxicity. In fact, 'Waimanalo' root length was not significantly improved by amending with MgO in Expt. 2, when amending with CaSO_4 increased root length 72% (Table 1). However, amending with Ca(OH)_2 increased root length more so than did amending with CaSO_4 .

Corrective procedures leading to amending subsoils are difficult and costly. Thus, the use of plants that have a greater tolerance to

limiting factors of acid soils is a desirable alternative (Foy, 1992). Some species have wide genetic variation in tolerance to excesses and deficiencies of minerals. Although we did not test the responses of the two cultivars in this study, the amendments improved root growth in relation to the untreated subsoil more for 'Red Lady' papaya than for 'Waimanalo' papaya. Another way of interpreting this comparison is that untreated subsoil was less inhibitory of root growth for 'Waimanalo' than for 'Red Lady' when compared with amended soil. If 'Waimanalo' is representative of the Solo cultivars, and 'Red Lady' is representative of the Formosa cultivars in relation to acid soils, this may indicate the Solo breeding program has developed greater tolerance of acid soil conditions than has the Formosa breeding program.

We feel these results have application to other species. Rooting depth in Guam's volcanic soils is severely limited for most of the species we have studied in our germplasm collection. This not only limits the total volume of soil from which plants derive resources, it also leads to a high probability of toppling during tropical cyclones.

Literature Cited

Table 1. Total length and dry weight of 'Red Lady' and 'Waimanalo' papaya roots that egressed from a nursery plug after 6 d (Expt. 1) or papaya radicles that penetrated for 13 d into untreated subsoil from a volcanic soil series, or into this subsoil amended with CaSO_4 , MgO , or Ca(OH)_2 ($n = 4$).

Cultivar	Treatment	Root length (mm)	Root dry wt (mg)
<i>Expt. 1</i>			
'Red Lady'	Untreated	145 c ^z	53 b
	CaSO_4	514 b	286 a
	MgO	498 b	297 a
	Ca(OH)_2	595 a	298 a
'Waimanalo'	Untreated	284 c	115
	CaSO_4	821 b	209
	MgO	793 b	194
	Ca(OH)_2	1059 a	199
<i>Expt. 2</i>			
'Red Lady'	Untreated	53 c ^z	12 b
	CaSO_4	121 b	21 b
	MgO	106 b	19 b
	Ca(OH)_2	242 a	35 a
'Waimanalo'	Untreated	64 c	7
	CaSO_4	110 b	13
	MgO	88b c	11
	Ca(OH)_2	192 a	19

^zMean separation within columns and cultivars by LSD test, $P \leq 0.05$.

- Adams, F. and B.L. Moore. 1983. Chemical factors affecting root growth in subsoil horizons of coastal plain soils. *Soil Sci. Soc. Amer. J.* 47:99–102.
- Awada, M., R. Suehisa, and Y. Kanehiro. 1975. Effects of lime and phosphorus on yield, growth, and petiole composition of papaya. *J. Amer. Soc. Hort. Sci.* 100:294–298.
- Foy, C.D. 1974. Effects of aluminum on plant growth, p. 601–642. In: E.W. Carson (ed.). *The plant root and its environment*. Univ. Press of Virginia, Charlottesville.
- Foy, C.D. 1992. Soil chemical factors limiting plant root growth. *Adv. Soil Sci.* 19:97–149.
- Ikeda, M. and L.T. Si. 1976. Optimal soil pH values for the vegetative growth of papaya (*Carica papaya* L.). *Jpn. J. Trop. Agr.* 20:115.
- Kabata-Pendias, A. and H. Pendias. 1984. *Trace elements in soils and plants*. 2nd ed. CRC Press, Boca Raton, Fla.
- Marler, T.E. 1998. Solution pH influences on growth and mineral element concentrations of 'Waimanalo' papaya seedlings. *J. Plant Nutr.* 21:2601–2612.
- Marler, T.E., A.P. George, R.J. Nissen, and P.C. Andersen. 1994. *Miscellaneous tropical fruits*, p. 199–224. In: B. Schaffer and P.C. Andersen (eds.). *Handbook of environmental physiology of fruit crops*. Vol. II. Sub-tropical and tropical crops. CRC Press, Boca Raton, Fla.
- Samson, J.A. 1980. *Tropical fruits*. Longman, New York.
- Tennant, D. 1975. A test of a modified line intersect method of estimating root length. *J. Ecol.* 63:995–1001.
- Young, F.J. 1988. Soil survey of the territory of Guam. USDA Soil Conservation Serv., Natl. Coop. Soil Survey.