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The Performance of Rootstocks Tolerant to Root Rot Caused by *Phytophthora cinnamomi* under Field Conditions in Southern California

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Abstract. **A survey was made of 16 avocado groves planted with rootstocks which are tolerant to root rot caused by *Phytophthora cinnamomi.* All groves sampled were infested with *P. cinnamomi.* Eleven rootstocks were evaluated for performance. All *Phytophthora-tolerant* rootstocks performed better than Borchard, a *Phytophthora*-susceptible rootstock. Thomas gave the best overall performance, followed closely by D9 and Barr Duke. Duke 7 exhibited moderate tolerance to *Phytophthora* but provided a standard with which to rate other tolerant rootstocks. G755 did not perform well and many trees exhibited leaf chlorosis, thin canopies and poor fruit set. Duke 7 performance could be correlated with soil Mn, and G755 performance could be correlated with soil Fe. All rootstocks exhibited low amounts of P, Cu and Zn in their foliage, indicating that certain nutrient sprays may assist in the establishment of *Phytophthora*-tolerant rootstocks.**

Phytophthora root rot of avocado *(Persea americana* Mill.) caused by *Phytophthora cinnamomi* Rands is the limiting factor for avocado production in many areas of the world (Zentmyer, 1980; Pegg *et al.,* 1982; Kotzé and Darvas, 1983; Coffey, 1987a, 1991). In California it affects 60 to 75% of the groves and loss in 1987 was estimated to be approximately $30 million (Coffey, 1987a).

The best long-term solution for controlling avocado root rot is the use of *Phytophthora*-tolerant rootstocks. Zentmyer began the search for *Phytophthora*-resistant rootstocks in the 1940's and 1950's and this led to the selection of Duke 6 and Duke 7 varieties (Zentmyer, 1963). In 1975, Duke 7 became the first *Phytophthora*-tolerant rootstock to become commercially successful. Since then extensive screening, selection and breeding by Zentmyer, Coffey, and Gabor has led to a number of new and promising varieties (Zentmyer, 1978; Coffey, 1987b, Gabor, 1990). Many of these varieties have now been in the field for 10 to 20 years. The purpose of this study was to survey existing groves of *Phytophthora*-tolerant rootstocks growing in *Phytophthora*-infested soil and to note their long-term performance. Furthermore, an attempt was made to correlate *Phytophthora*-tolerant rootstock performance with various soil factors.

Materials and Methods

Sixteen avocado groves planted to *Phytophthora*-tolerant*,* clonal rootstocks were surveyed January to June, 1990. All groves sampled had cv. Hass scions. All groves sampled had more than one tolerant rootstock, which facilitated comparisons. The groves were chosen to represent a cross section of the avocado industry in southern California. There were six groves from Santa Barbara county, four from Ventura county, two from Riverside county and four from San Diego county. Rootstocks in the survey included the *Persea americana* rootstocks Parida, Thomas, D9, Barr Duke, Toro Canyon, Duke 7, G6, Duke 6, and UCR 1033 as well as the *P. americana* x *Persea schiedeana* Nees hybrid, G755 (Martin Grande). Borchard was included in the survey as a *Phytophthora*-susceptible comparison. Table 1 indicates the horticultural race and the geographic origin of each rootstock. Ten trees per grove per rootstock were considered a minimal number to include for analysis. Further information on these rootstocks is summarized by Coffey (1987b) and Coffey and Guillemet (1987). The total number of trees examined per rootstock varied from 4 to 253, although rootstocks with fewer than 20 total trees were not included in the analysis.

Table 1. Avocado rootstocks surveyed for field performance

Rootstock	Horticultural race	Geographic origin
G755 Martin Grande	Hybrid *P. americana* x *P. schiedeana*	Coban, Guatemala Market collection
Thomas	Mexican	Escondido, California Field collection root rot area
D9	Mexican	Riverside, California Irradiated Duke budwood
Barr Duke	Mexican	Fallbrook, California Duke 6 seedling
Duke 7	Mexican	Riverside, California Duke seedling, root rot test
G1033	Guatemalan	Hawaii Hayes seedling
Toro Canyon	Mexican	Toro Canyon, California Field collection root rot area
G6	Mexican	Acatenango volcano Guatemala, Field collection
Parida	Guatemalan	Carpinteria, California Field collection
Duke 6	Mexican	Riverside, California Duke seedling, root rot test
Borchard	Mexican	Camarillo, California Field Collection

Individual trees were rated by: 1) visual rating of tree foliage on a scale of 0-5 (Gabor, 1990), where 0 = healthy and 5 = completely defoliated; 2) tree diameter growth/year two cm above the bud union was calculated by measuring the diameter and dividing by the tree age; 3) canopy volume growth/year was calculated by measuring the height and diameter of the canopy using the formula for the volume of an ellipse and dividing the result by tree age.

Soil samples were collected from the top 30 cm in the soil profile from ten trees in each grove. The soil was bulked and mixed for each grove. Soil samples for each grove were analyzed for total nitrogen using a semi micro-kjeldahl method (Black *et al.,* 1965). The soil was digested in 97% KSO_4 and 3% $CuSO_4{\cdot}5H_2O$. Extractable P was determined using the bicarbonate (Olsen) method and quantified calorimetrically using the phosphomolybdenate complex (Chapman and Pratt, 1961). Exchangeable soil CA, Mg, K and Na were determined using atomic absorption spectroscopy following extraction with lithium chloride and lithium acetate (Yaalon *et al.,* 1962). Soil Zn, Mn, Cu, and Fe were extracted using DTPA and quantified by atomic absorption spectrophotometry (Linsey and Norrell, 1969). Chlorine was detected in the saturation extract using a chlorodometer (Black *et al.,* 1965). Percent soil organic matter was determined by the ignition method (Ball, 1964). Electrical conductivity (salinity) and pH were determined for each soil from a water saturation paste (Chapman and Pratt, 1961). Saturation % was the amount of water added to 100 g of soil which was necessary for saturation. Sodium absorption ration (CAR) was calculated with the formula

$$SAR = \frac{Na}{\sqrt{(Ca + Mg) \div 2}}$$

Soil composition Ca + Mg (clay, silt and sand) was determined (Black *et al.,* 1965).

Three to four leaves from 10 trees per grove were gathered from groves containing G6, Duke 7, G755, and Toro Canyon rootstocks. Leaves were harvested October 1-10, 1990, selected from the most recently expanded and matured terminal leaves, from non-flushing and non-fruiting terminals. Leaves for each rootstock from each grove were combined, dried, ground and mixed thoroughly. Leaves were analyzed for P, K, Ca, Mg, Na, Zn, Mn, Cu, and Fe. Methods for sample preparation extractions and nutrient analysis were previously described (Labanauskas *et al.,* 1967).

Performance data was com- pared using ANOVA and LSD analysis for data with unequal replications (Borland, Inc., 1985). Soil and foliage nutrient characteristics were correlated with performance values using regression (Impact Program).

Results

Although mortality was high in some groves, in general the *Phytophthora*-tolerant rootstocks appeared capable of surviving, growing and producing adequate fruit under optimal growing conditions and optimal care. All of the resistant rootstocks performed significantly better then Borchard, which is a *Phytophthora*-susceptible rootstock (Table 2). The rootstock which performed the best under field conditions was Thomas. It was the leader in all categories: foliage rating, trunk diameter/year and canopy volume/year (Table 2). D9 and Barr Duke also performed well in the field and were not significantly different from Thomas in most categories. However, D9 appears to establish slowly and young trees are often much smaller than other rootstocks. This is shown by the fact that D9 had a significantly smaller trunk diameter/year than Thomas.

Toro Canyon and Duke 7 performed adequately (Table 2). Duke 7 possesses only moderate resistance to *P. cinnamomi* but is vigorous and yields well. It is an excellent all-round rootstock and may be viewed as a standard against which other tolerant rootstocks may be tested. Toro Canyon exhibited considerable variability in the survey. In some groves it appeared to do very well, while in other groves it did not perform well. Neither correlation with soil analysis nor leaf analysis could explain this variability, although It did appear to absorb significantly more sodium than did Duke 7 or G755. Toro Canyon appeared to be very vigorous and in growth of canopy volume/year was not significantly different from that of Thomas.

G755 based on a visual rating did not perform as well as Thomas, D9, Barr Duke, or Duke 7 (Table 2). G755 often appeared to exhibit slightly chlorotic leaves and a thin canopy. Poor fruit production was evident in many groves. However, growth was vigorous and increases in trunk diameter/year and canopy volume/year were not significantly different from Thomas. In general, G6 did not perform well in the field, although values for trunk diameter/year and canopy volume/year were similar *to* those of Duke 7 (Table 2).

Performance listings were included for Parida, Duke 6 and UCR 1033 although the number of trees examined for these rootstocks was not sufficient to be included in the analysis (Table 2).

In an attempt to correlate root- stock performance with soil conditions, we could find no correlations between soil pH, salinity, total N, P, K, Ca, Na, Mg, Cu, Zn, Mn, CI, saturation %, organic matter %, clay %, silt % or sand % and performance of Thomas, Toro Canyon, Duke 7, G6 or G755. However both trunk diameter/year and canopy volume/year for Duke 7 were positively correlated ($P \leq 0.10$) with soil Mn. All rootstocks, together, were positively correlated with soil Mn ($P \leq 0.05$). Canopy volume of G755 was positively correlated ($P \leq 0.10$) with soil Fe.

Performance of Thomas, Toro Canyon, G6 and G755 rootstocks could not be correlated with concentrations of any of the following nutrients in leaves: N, P, K, Ca, Mg, Na, Zn, Mn, Cu, or Fe.

When leaf analysis was compared for Thomas, Toro Canyon, G6 and G755, the only differences occurred with Na (Table 3). Duke 7 and G755 had less Na in their leaves than G6 and Toro Canyon. All of the root- stocks exhibited relatively low leaf analysis values for p, Zn and Cu (Table 3).

Table 2. Performance of *Phytophthora-tolerant* clonal rootstocks under root rot conditions in southern California. Z

Rootstock	# Trees	# Groves	Rootstock rating (0 = no disease; 5 =dead)	Diameter trunk (mm/yr)	Canopy volume (cu m/yr)
Parida	4	1	0.0	17	1.6
Thomas	66	3	0.2 A	23 A	13.2 A
D9	29	2	0.3 AB	19 BC	11.1 AB
Barr Duke	42	2	0.3 AB	21 AB	10.8 AB
Duke 7	253	10	0.7 B	16 E	9.4 B
Toro Canyon	53	4	1.0 BC	18 CD	12.0 AB
G755	235	11	1.1 C	21 AB	10.6 AB
G6	80	5	1.3 C	20 BC	9.9 B
Duke 6	7	1	1.5	10	9.9
Borchard	20	2	1.8 D	13 F	5.9 C
UCR 1033	15	1	4.1	14	2.0

[Z] Values in each column not followed by an identical letter are significantly different LSD, P ≤ 0.05). Values not followed by a letter were not included in the analysis because of insufficient data.

Table 3. The effect of *Phytophthora-tolerant* clonal rootstocks on leaf analysis under root rot conditions in southern California. Z

Leaf nutrient	G6	Duke 7	G755	Toro Canyon
Phosphorus (%)	0.056 A	0.050 A	0.052 A	0.056 A
Calcium (%)	0.97 A	0.91 A	0.97 A	1.10 A
Magnesium (%)	0.54 A	0.51 A	0.52 A	0.59 A
Potassium (%)	1.92 A	1.97 A	2.18 A	1.81 A
Sodium (%)	0.024 A	0.005 B	0.008 B	0.015 A
Zinc (ppm)	18.67 A	16.67 A	25.50 A	13.40 A
Manganese (ppm)	128.83 A	112.33 A	81.08 A	61.00 A
Copper (ppm)	2.50 A	2.78 A	2.58 A	2.80 A
Iron (ppm)	67.67 A	67.33 A	68.50 A	61.40 A

[Z] Values in each row not followed by an identical letter are significantly different P ≤ 0.05).

Discussion

In general results from this field survey support and verify results from field and greenhouse work (Coffey, 1987a; Coffey and Guillemet, 1987; Gabor, 1990). All *Phytophthora*-tolerant varieties performed better than the susceptible rootstock, Borchard. Duke 7 exhibited moderate tolerance to *Phytophthora* root rot and may provide a standard with which to compare other *Phytophthora*-tolerant rootstocks. Thomas gave the best field performance, closely followed by D9 and Barr Duke.

The performance of D9 was somewhat surprising. In previous field trials, the performance of D9 was somewhat variable (Coffey, 1987a, Gabor, 1990), although Gabor found it to exhibit the highest level of resistance to *P. cinnamomi.* It appears that D9 grows relatively slowly when young, and it may not establish as well as more vigorous rootstocks. However, the survey revealed that after 10 to 12 years, trees of D9 rootstocks were among the largest trees in the survey.

G755 rootstock, although exhibiting a very high level of tolerance to *P. cinnamomi,* did not perform well in the field. The foliage often exhibited a slight chlorosis and the canopy was often thin. More disturbing was the fact that fruit production was poor in many groves. The poor performance of G755 is not thought to be due to lack of *Phytophthora* tolerance, since poor performance evaluations were also made in fields lacking *Phytophthora.* It is thought that G755 requires additional iron fertilization, and this fact was verified by the correlation in canopy volume/year and soil iron. However, in addition to this problem, it is now believed that G755 suffers excessively from cold temperatures (unpublished data). Since G755 parentage includes *P. schiedeana,* which is cold sensitive, it may be slightly damaged each winter. This would affect visual ratings and perhaps fruit set during the spring. Observations later in the summer and fall confirm that at this time G755 appears greener and extremely vigorous.

Attempts at correlating soil and foliage nutrient characteristics with performance of *Phytophthora*-tolerant avocados was not highly successful. Much greater replications will be necessary to identify soil factors which affect rootstock performance. Nevertheless, correlations between soil Mn and Fe and rootstock performance indicate that rootstocks should be evaluated carefully for effects on nutrient absorption as well as *Phytophthora* resistance.

Foliar P, Zn, and Cu values for all *Phytophthora*-tolerant varieties tested were quite low (Goodall *et al.,* 1965). In addition soil Mn and Fe were found to affect performance in some rootstocks. These elements do not diffuse readily in soil and *Phytophthora* root rot may inhibit uptake of these elements. Supplemental fertilization with these elements may enhance the performance of *Phytophthora*-tolerant rootstocks.

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