Journal of Horticultural Science & Biotechnology (2007) **82** (3) 460–466

Effects of clonal rootstocks on 'Hass' avocado yield components, alternate bearing, and nutrition

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SUMMARY
Growth, yield, and leaf nutrient concentrations were measured in 'Hass' avocado (*Persea americana* Mill.) trees grown on one of ten clonally-propagated rootstocks ('Borchard', 'D9', 'Duke 7', G1033, G755A, G755B, G755C, 'Thomas', 'Topa Topa', or 'Toro Canyon') over a 10-year period in southern California. After 10 years, trees on 'Borchard' were larger than trees on all other rootstocks. Trees on all rootstocks displayed an alternate-bearing pattern, typical of avocado. Alternate-bearing was most pronounced in trees grafted onto 'Topa Topa' and 'Toro Canyon'. Rootstocks in the G755 series had the lowest alternate-bearing index, but also had the lowest yields. Trees on 'Duke 7' and 'Borchard' had the highest cumulative yields, and trees on G755A, G755B, and G755C had the lowest yields. Differences in yield were due to differences in the number of fruit per tree, not individual fruit weight. When yield was evaluated in terms of canopy efficiency (kg fruit m^{-3}), no rootstock outperformed 'Duke 7', the industry standard rootstock. Leaf concentrations of all nutrients examined (N, P, K, Ca, Mg, S, Zn, Cl, Mn, B, Fe, and Cu) were within, or close to the recommended ranges. P, Ca, and S were higher, and Fe was lower in high-yielding years in all rootstocks.

Avocado (*Persea americana* Mill.) production in California tends to be low compared to other avocado-producing regions worldwide (www.avocadosource.com). Furthermore, the costs of production are increasing in California (Takele *et al*., 2002). Therefore, any factor that can increase yield is of interest to California growers.

Until the mid-1970's, avocado was propagated on seedling rootstocks. It was not until the mid-1970's that clonally produced rootstocks for avocado were made available for commercial use (Ben Ya'acov and Michelson, 1995). Clonal avocado rootstocks have been selected primarily on the basis of their resistance to avocado root rot (*Phytophthora cinnamomi* Rands.; Menge *et al*., 1992). Increasingly, avocado rootstocks are also being selected on the basis of their salt tolerance (Mickelbart and Arpaia, 2002), especially in regions such as Israel, Australia, and California. Ultimately, these rootstocks must also allow the full yield potential of the scion to be realised, although this is usually a secondary screen after material has been selected based on its relative tolerance to stress. There has been little evaluation of avocado rootstocks in terms of their effects on yield and yield components.

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Apart from yield *per se*, consistent annual yield is an important consideration in avocado production. Annual production is subject to fluctuations caused by alternate-bearing patterns. Seasons in which high yields occur are usually followed by a yield decline of approx. 50% (Anon., 2005). Differences in crop volumes from year-to-year may result in the loss of revenue during low-yield years, and in oversupply during high-yield years. Therefore, it is important to screen avocado rootstocks, not simply for their effect on average annual yield, but also for their effect on alternate-bearing. The goal of this long-term study was to evaluate ten clonal avocado rootstocks for horticultural factors of interest to growers.

MATERIALS AND METHODS

Plant material and field environment

'Hass' avocado was clonally propagated on one of ten rootstocks (G755A, G755B, G755C, G1033, 'Duke 7', 'Borchard', 'D9', 'Thomas', 'Toro Canyon', or 'Topa Topa'). Most trees were planted in April 1986 at the University of California South Coast Research and Extension Center (SCREC) in Irvine, California (33°44' N; 117°49' W). Trees on G1033 and 'Thomas' rootstocks were planted in April 1987, in pre-selected sites that were included in the original experimental design. Twenty trees per rootstock were used for all measurements. The trees were planted at a spacing of 6.1 m × 6.1 m on slightly raised, 1.5 m-wide by 0.5 m-high berms to facilitate water drainage. The soil type was a Hanford sandy loam (average depth 18 m), and the site was determined to be free of avocado root rot (*P. cinnamomi* Rands.). At the time of planting, one drip-emitter was placed at the base of each tree. Two years after planting, the drip-emitter was replaced with a single low-volume microsprinkler (45.4 l ha^{-1}). The trees were irrigated as needed, using evapotranspiration data from the California Irrigation Management Information System as a guide (www.cimis.water.ca.gov). Standard fertilisation practices for California (Goodall *et al*., 1981) were followed.

The experimental block had no polliniser cultivars; however, immediately adjacent to the North side of the block was a row of seedling avocados of mixed origin. Analysis of yield in the block in relation to proximity to the seedling row did not reveal any significant influence on overall tree yield. Additionally, pollination was not supplemented by the addition of honey bees (*Apis mellifera* L.) to the site.

Measurements

Canopy volume was measured in the Autumn of each year (after cessation of growth). Tree height and canopy width were recorded for individual trees. Two perpendicular canopy width measurements were taken (*ca*. 1.75 m from the ground): the down-row width and the across-row width. The average of these two values was used to estimate canopy volume. The canopy volume was estimated by assuming the tree approximated to the shape of one-half of a prolate spheroid; hence $V = 4/3\pi ab^2$, where V is canopy volume, a is the radius of the major semi-axis (canopy height) and b is the radius of the minor semi-axis (tree width; Turrell, 1946). Trunk circumference (cm) was measured with a cloth measuring tape 10 cm above and 10 cm below the graft union. The trunk circumference ratio was calculated as the circumference above to that below the graft union of an individual tree.

During the flowering period (early Spring) each year, each tree in the study was visually assessed for the presence of flowers every 2 – 3 weeks. From these visual assessments, estimates of the timing and duration of flowering were made. Flowering was estimated to begin when any sign of flowers at anthesis was noted, and the end of flowering was estimated to occur when no additional flowers at anthesis were noted.

'Hass' avocado trees flower in the Spring in southern California, and the resulting fruit is mature [based on commercially standardised measurements of dry matter percentage (% DM)] within approx. 6 – 7 months. The fruit may remain on the tree, however, for an additional 10 months after reaching maturity (depending on the environment). Commercial harvesting of 'Hass' avocado in the coastal regions of southern California may extend from mid-November to the following August, depending on weather and overall market conditions. Trees in this study were harvested in Spring (April) of each year (approx. 12 – 14 months after fruit set). There is no "standard practice" in the southern California avocado industry, but this is an acceptable harvesting scheme under southern California conditions. Years given in the text indicate the year in which the fruit was harvested. Yield (total fruit weight and fruit number) of individual trees was measured, and mean fruit weight was calculated from these values. Canopy efficiency (kg fruit m^{-3}) was calculated by dividing the yield of an individual tree by its canopy volume.

Fruit maturity was assessed in year-6 of the trial on a subset of rootstocks ('Thomas', 'Topa Topa', 'Duke 7', 'D9', and 'Toro Canyon'). Fruit were harvested *ca*. every 15 d for 2 months leading up to fruit maturity. Fruit maturity was assessed using the industry standard dry weight method (Morris and O'Brien, 1980).

Leaves were harvested each Autumn (September) for nutrient analyses, based on the recommendations of Goodall *et al*. (1981). Five leaves were collected from the Spring-growth flush of fruitless branches in each of four tree quadrants, giving a total of 20 leaves per tree. Leaves were washed in distilled water, dried in a forced-air chamber (60°C), and ground (40 mesh screen). Total N was determined by Kjeldahl analysis. P and B were analysed by colorimetric assays, Ca, Mg, Fe, and Mn were analysed by atomic absorption spectroscopy, and K was analysed by atomic emission spectroscopy. S was determined by automated combustion, and Cl was determined by titration with silver nitrate.

Statistical design and analysis

Trees were planted in a randomised complete block design with rows (North-South orientation) acting as blocks, and with each rootstock represented once in each of twenty blocks. Analysis of variance was conducted using the GLM procedure of SAS (SAS Institute, Cary, NC, USA). Mean separation was performed with Duncan's New Multiple Range test. Where appropriate, analyses were conducted with transformed data. Trees on 'Thomas' or G1033 were analysed separately, due to their later planting date.

Alternate-bearing index was calculated according to the method of Hoblyn *et al*. (1936). Because of alternate-bearing, yield data in an individual year violated the assumptions of the analysis of variance, due to non-normally distributed errors. There is no suitable transformation to force data to conform to the assumptions of the analysis of variance. Instead, data were analysed as 2-year "bearing cycles". A bearing cycle was defined as a 2-year period consisting of an "on-year" and an "off-year". All measurements of fruit weight per tree, fruit number per tree, and mean fruit weight are the mean values of a given bearing cycle [i.e., mean yield of year-5 and year-6; (Y56) = (Y5+Y6)/2].

RESULTS AND DISCUSSION

Growth

Rootstock-related differences in tree canopy volume in year-8 (Table I) were representative of differences in all years (data not shown). Tree size was similar among trees on all rootstocks, with the exception of those on 'Borchard', which were larger than trees on all other rootstocks. Trees on 'Thomas' and G1033 were of a similar size to trees of the same age on the other rootstocks, although trees on 'Thomas' were larger than trees on G1033. Tree height after ten years was *ca*. 5.5 m, with no significant differences among rootstocks (data not shown). Therefore, differences in tree canopy volume (Table I) were due to differences in tree width on the various rootstocks, the mean of which varied from 4.3 – 5.2 m (data not shown). Canopy volume differences may be related to rootstock-induced differences not only in vigour, but also in shoot architecture (Thorp and Sedgley, 1993).

TABLE I
Canopy volume, trunk circumference above and below the graft union, and trunk circumference ratio of 'Hass' avocado trees growing on ten clonal rootstocks[†]

Rootstock	Canopy volume (m^3)	Trunk circumference (cm)		
		Above	Below	Ratio
'Borchard'	111.0a*	72.0a	67.8abc	1.07b
'D9'	81.9b	67.4ab	70.5ab	0.96d
'Duke 7'	92.0b	69.9ab	69.6ab	1.00c
G755A	85.9b	72.8a	65.8bc	1.11ab
G755B	89.6b	69.7ab	62.2c	1.13a
G755C	79.4b	70.8ab	70.8ab	1.00c
'Topa Topa'	91.2b	69.3ab	72.0a	0.96d
'Toro Canyon'	87.1b	64.9b	63.1c	1.03c
G1033	63.4b	68.8a	65.6	1.05
'Thomas'	77.4a	59.4b	59.7	1.00

*Mean separation within columns by Duncan's New Multiple Range test ($P = 0.05$).
[†]Trees were grown at the University of California South Coast Research and Education Center. All measurements shown were made in year-8 (year-7 for rootstocks 'Thomas' and G1003 because of different planting dates). (n = 20).

'D9' is said to be a "slightly dwarfing" rootstock (Zentmeyer, 1991), but our results do not support this supposition (Table I). For the first 3 years after planting, trees on 'D9' were significantly shorter than on all other rootstocks (data not shown), which may explain early reports of dwarfing by this rootstock. After 4 years, however, trees on 'D9' were the same size as trees on all other rootstocks (Arpaia *et al*., 1990), and this remained the case up to 9 years after planting (Table I). The same trend (early dwarfing followed by normal growth) has been observed in 'Gwen' trees on 'D9' (Arpaia *et al*., 1992).

Rootstock incompatibility has not been widely noted in avocado, although overgrowth of the scion or the rootstock, due to differences in vigour, has been noted and has resulted in the death of small trees in some cases (Ben-Ya'acov and Michelson, 1995). Therefore, the ratio of trunk circumference above the graft union to that below the graft union is useful in assessing potential rootstock-scion incompatibility. Scion overgrowth of the rootstock occurred in trees on G755A and G755B, but not in trees on G755C (Table I). The smooth bud union of G755C has also been noted in Australia (Firth and Allen, 1992). Rootstock overgrowth of the scion occurred in trees on 'Topa Topa' and 'D9'. Trees on all other rootstocks had smooth rootstock-scion junctions. Trunk circumference was not correlated with tree height or canopy volume in this study (data not shown), although others have noted correlations among these parameters (Ben-Ya'acov and Michelson, 1995).

TABLE II
Alternate-bearing index of 'Hass' avocado trees growing on ten clonal rootstocks at the University of California South Coast Research and Education Center

Rootstock	Alternate-bearing index (I)[†]
'Borchard'	0.54ab*
'D9'	0.49b
'Duke 7'	0.52ab
G755A	0.52ab
G755B	0.47b
G755C	0.33c
'Topa Topa'	0.55ab
'Toro Canyon'	0.56a
G1033	0.60
'Thomas'	0.59

*Mean separation by Duncan's New Multiple Range test ($P = 0.05$). Rootstocks G1033 and 'Thomas' were analysed separately because of different planting dates.
[†]Yield from year-5 to year-10 were used to calculate I, based on the calculation of Hoblyn *et al*. (1936):

$$I = (1/n) \times [\Sigma^{n}_{i=2} |y_i - y_{i-1}| / (y_i + y_{i-1})],$$

where y_i is the i[th] observed yield in an ordered series of size n, and $|y_i - y_{i-1}|$ is the absolute difference between successive yields.

Yield

The yield of trees on all rootstocks followed a similar alternate-bearing pattern (Figure 1A). "On-years" (years with high yields) were followed by "off-years" with yields that averaged 28% of "on-year" yields. The alternate-bearing index gives an indication of the long-term alternate-bearing patterns of each rootstock. Alternate-bearing was greatest in trees on 'Topa Topa' and 'Toro Canyon' and lowest in trees on the G755 series of rootstocks (Table II). Because of the alternate-bearing

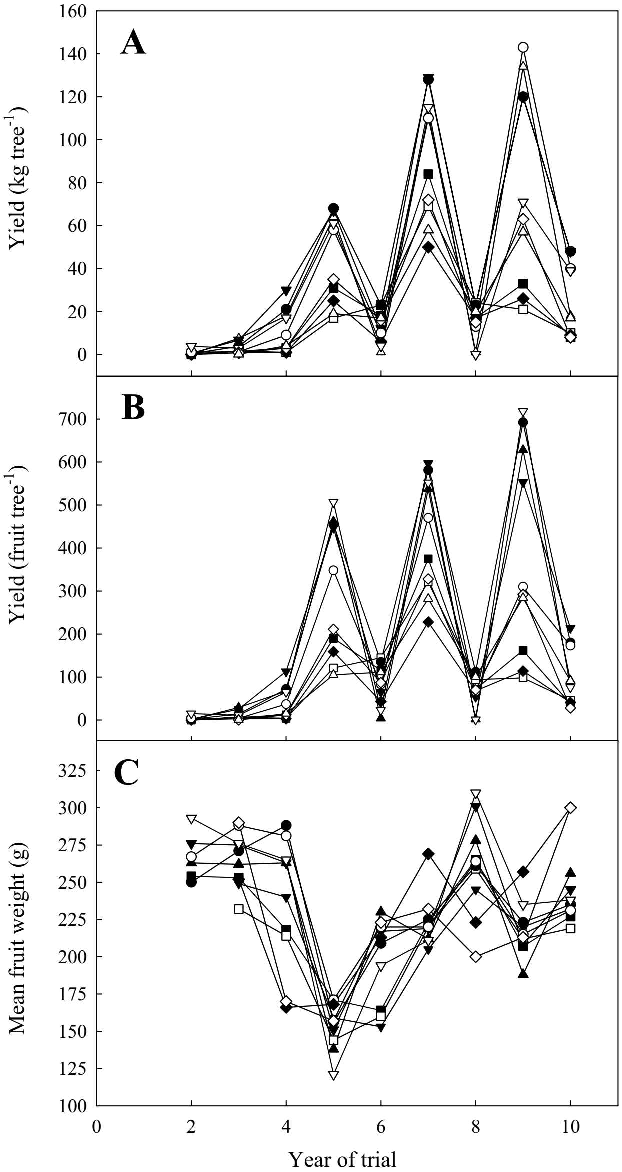

FIG. 1
Yield in fruit weight per tree (Panel A), yield in fruit number per tree (Panel B), and mean fruit weight (Panel C) of 'Hass' avocado trees growing on ten clonal rootstocks ['Borchard' (●), 'D9' (○), 'Duke 7' (▼), G1033 (△), G755A (■), G755B (□), 'G755C' (◆), 'Thomas' (◇), 'Topa Topa' (▲), or 'Toro Canyon' (▽)] 2 – 10 years after planting at the University of California South Coast Research and Education Center.

TABLE III

Yield (kg/tree) of 'Hass' avocado trees growing on ten clonal rootstocks at the University of California South Coast Research and Education Center

	Yield (kg/tree)			
Rootstock	Year 5/6	Year 7/8	Year 9/10	Total†
'Borchard'	46a*	75a	92a	452a
'D9'	34bc	61b	55c	313b
'Duke 7'	39b	71a	84ab	425a
G755A	24d	50b	21d	195c
G755B	20de	47b	15d	168c
G755C	15e	34c	17d	134c
'Topa Topa'	32c	56b	74b	350b
'Toro Canyon'	33bc	58b	76b	358b
G1033	17b	37	41	193
'Thomas'	26a	44	35	213

*Mean separation within columns by Duncan's New Multiple Range test ($P = 0.05$).
Rootstocks G1033 and 'Thomas' were analysed separately because of different planting dates.
†Total yield indicates yield (kg) per tree over the 6-year period, as opposed to the yields shown for 2-year cycles, which indicate yield per year.
Data are presented as 2-year bearing cycles from year-5 to year-10 after planting. (n = 20).

TABLE IV

Yield (no. of fruit/tree) of 'Hass' avocado trees growing on ten clonal rootstocks at the University of California South Coast Research and Education Center

	Yield (fruit/tree)			
Rootstock	Year 5/6	Year 7/8	Year 9/10	Total†
'Borchard'	296a*	346a	430a	2232a
'D9'	200c	290bcd	242c	1507c
'Duke 7'	257ab	326ab	381ab	2066ab
G755A	154d	231cd	101d	992d
G755B	137de	211d	72d	850de
G755C	98e	155e	77d	668e
'Topa Topa'	233bc	268bcd	367b	1830b
'Toro Canyon'	265ab	277bc	404ab	1981ab
G1033	99b	181	208	993
'Thomas'	155a	204	160	1048

*Mean separation within columns by Duncan's New Multiple Range test ($P = 0.05$).
Rootstocks G1033 and 'Thomas' were analysed separately because of different planting dates.
†Total yield indicates total number of fruit per tree over the 6-year period, as opposed to yields shown for the 2-year cycles, which indicate yield per year.
Data are presented as 2-year bearing cycles from year-5 to year-10 after planting. (n = 20).

pattern on all rootstocks, yield data were analysed as 2-year "bearing cycles". This allowed legitimate statistical analyses of the data and simpler presentation of long-term means for each rootstock. Yield analyses were done after 5 years of growth (4 years for 'Thomas' and G1033), the time when avocado trees are considered to be at full production capacity.

The G755 series of rootstocks had low yields relative to the other rootstocks examined (Table III). These rootstocks were also less precocious than the other rootstocks examined (data not shown). Trees on most rootstocks (apart from G755A and G755C) produced some fruit in year-4 after planting, although yields were low (Figure 1A,B). Overall yields were highest for trees on 'Borchard' and 'Duke 7' rootstocks (Table III; Table IV). While trees on 'Thomas' and G1033 were not compared statistically with trees on the other rootstocks due to differences in planting date, overall yields were lower on the former two rootstocks than on most rootstocks, with the exception of the G755 series.

Fruit number per tree followed similar patterns to the total weight of fruit per tree (Figure 1A,B), with trees on 'Borchard' and 'Duke 7' producing a large number of fruit, and trees on the G755 series producing a small number of fruit (Table IV). As expected, the number of fruit per tree was the primary determinant of alternate-bearing, with a very low number of fruit being produced in "off-years" (Figure 1B).

Individual fruit weight ranged from 120 – 310 g in all 10 years of the trial, across all rootstocks. Fruit from trees on 'Toro Canyon' tended to be smaller than those from trees on all other rootstocks (Table V). Fruit size was smaller, overall, in high-yielding years (Figure 2C); however, the trend was not consistent from year-to-year (Figure 1C). On some rootstocks and in some years, fruit size was correlated with crop load (Figure 1C). This pattern was not observed in all years (e.g., year-7), even though total yields exhibited the regular alternate-bearing pattern throughout the trial (Figure 1A).

This trial was designed to examine the long-term effects of clonal avocado rootstocks on the growth and yield of 'Hass' avocado under southern California conditions. Gregoriou and Economides (1991) found no rootstock ('Lula' or "West Indian") effects on the yield of 'Hass', 'Fuerte', or 'Ettinger' avocado. However, in a larger trial, Gregoriou (1992) found that rootstock affected yield and tree size. In neither study did rootstock affect mean fruit weight. Our data, however,

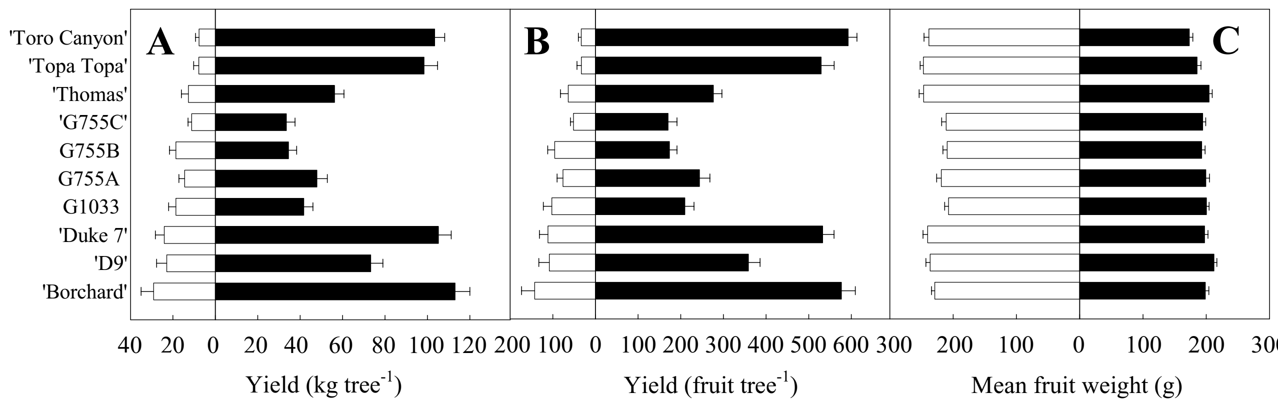

FIG. 2
Mean yield (from 5 – 10 years after planting) in fruit weight (Panel A), fruit number (Panel B), and mean fruit weight (Panel C) of 'Hass' avocado trees growing on ten clonal rootstocks in low-yielding "off-years" (open bars) or in high-yielding "on-years" (solid bars).

TABLE V

Mean fruit weight of 'Hass' avocado trees growing on ten clonal rootstocks at the University of California South Coast Research and Education Center

Rootstock	Mean fruit weight (g) Year 5/6	Year 7/8	Year 9/10	Mean
'Borchard'	175ab*	219	222abc	209ab
'D9'	192a	216	237a	218a
'Duke 7'	173bc	218	229ab	211ab
G755A	169bc	223	213c	207ab
G755B	157bcd	224	212c	201b
G755C	159bcd	214	221c	200b
'Topa Topa'	154cd	213	223abc	198b
'Toro Canyon'	149d	211	222abc	196b
G1033	174	217	209b	202b
'Thomas'	166	233	240a	219a

*Mean separation within columns by Duncan's New Multiple Range test ($P = 0.05$).
Rootstocks G1033 and 'Thomas' were analysed separately because of different planting dates.
Data are presented as 2-year bearing cycles from year-5 to year-10 after planting. (n = 20).

TABLE VI

Canopy efficiency of 'Hass' avocado trees growing on ten clonal rootstocks at the University of California South Coast Research and Education Center

Rootstock	Canopy efficiency (kg m^{-3}) Year 5/6	Year 7/8	Year 9/10	Mean
'Borchard'	0.96ab*	1.17a	0.94a	1.13ab
'D9'	0.95ab	1.15a	0.70b	0.96b
'Duke 7'	0.97ab	1.23a	0.96a	1.15a
G755A	0.60c	0.87b	0.24c	0.62c
G755B	0.48cd	0.83b	0.18c	0.54cd
G755C	0.42d	0.69b	0.24c	0.51d
'Topa Topa'	0.81b	1.06a	0.94a	1.08ab
'Toro Canyon'	0.90ab	1.13a	0.95a	1.16a
G1033	0.49	0.94	0.69	0.74
'Thomas'	0.78	1.00	0.50	0.75

*Mean separation within columns by Duncan's New Multiple Range test ($P = 0.05$).
Rootstocks G1033 and 'Thomas' were analysed separately because of different planting dates.
Data are presented as 2-year bearing cycles from year-5 to year-10 after planting. (n = 20).

suggest that rootstock does play a role in determining fruit size in avocado (Table V).

Canopy efficiency followed an alternate pattern that reflected total yield, being higher overall in "on-years" than in "off-years" (data not shown). Trees on rootstocks of the G755 series had the lowest canopy efficiencies (Table VI). Trees on other rootstocks had canopy efficiencies close to 1 kg m^{-3}. Trees on 'Thomas' and G1033 had low canopy efficiencies relative to the other rootstocks examined. Rootstock has been shown to affect canopy efficiency in avocado (Kremer-Köhne and Köhne, 1995), as well as in other sub-tropical tree crops such as mango (Kurian *et al*., 1996) and mandarin (Georgiou, 2000; Tsakelidout *et al*., 2002).

Young (1992) noted rootstock-related differences in fruit maturity. In this study, however, there were no differences in fruit maturity among rootstocks when ten clonally-propagated rootstocks were examined (data not shown). In Young (1992), rootstocks of various races were used, whereas in this study, the rootstocks used to assess fruit maturity were of Mexican-race origin. There were no significant differences in flowering (in timing or intensity) among trees in this study (data not shown). Therefore, it appears that the ten clonal rootstocks examined in this trial had no effect on the timing of fruit set, or on the timing of fruit maturity.

Nutrient analysis

The values for all leaf nutrients fell within the commercially recommended range (Goodall *et al*., 1981). Rootstock had a significant effect on the leaf concentrations of most nutrients in most years (Table VII). In general, trees on the G755 series (especially G755C) had the lowest leaf concentrations of nutrients (e.g., N, Mn, and Fe), although this was not the case for all nutrients (e.g., Ca, Mg, B, and S). Trees on 'Thomas' rootstock had higher N, Cl, S, Mn, Cu, and Cl; but lower K, Ca, and Mg than trees on G1033 rootstock. In general, Guatemalan rootstocks (i.e., the G755 series, and G1033) had higher Ca and Mg, but lower N, than the Mexican rootstocks. Willingham *et al*. (2001) also found that a Guatemalan rootstock had lower leaf N than a Mexican rootstock. Haas (1950a,b) found that seedling Guatemalan-race rootstocks had higher Ca than seedling Mexican-race rootstocks. None of these studies showed any differences in leaf Mg or K between the two races.

The levels of some nutrients cycled with the alternate-bearing pattern. In general, levels of P, Ca, and S were highest in high yielding "on-years", while Fe was highest in low yielding "off-years" (data not shown). There were no significant correlations between nutrient concentrations and fruit size or canopy volume.

TABLE VII

Influence of rootstock on foliar concentrations (% DW or μg g^{-1} DW) of nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sulphur (S), chloride (Cl), boron (B), zinc (Zn), iron (Fe), manganese (Mn), and copper (Cu)

Rootstock	N	P	K	Ca (% DW)	Mg	S	Cl	B	Zn	Fe (μg g^{-1} DW)	Mn	Cu
'Borchard'	2.38b[Y]	0.15b	1.29c	1.74ef	0.60e	0.34e	0.24de	33bc	21de	62ab	171a	6.9ab
'D9'	2.37b	0.16a	1.41b	1.65fg	0.56f	0.36de	0.26bc	35a	23bc	58c	131bc	6.7b
'Duke 7'	2.31c	0.15b	1.30c	1.77de	0.64d	0.42c	0.26bcd	34abc	23b	61abc	166a	7.0ab
G1033	2.30c	0.15b	1.51a	1.84d	0.61de	0.34e	0.21f	31d	26a	59bc	134b	5.9c
G775A	2.17d	0.15b	1.26c	2.06b	0.80ab	0.49a	0.26bcd	31d	23b	54d	111cd	6.6b
G775B	2.16d	0.15b	1.27c	2.15a	0.82ab	0.50a	0.28ab	31d	23bcd	53d	103d	6.5b
G775C	2.12d	0.13c	1.25c	2.12ab	0.82a	0.35de	0.30a	35ab	20e	63a	116bcd	5.1d
'Thomas'	2.43a	0.16a	1.39b	1.57g	0.52g	0.47b	0.26cd	35a	24b	58c	178a	7.3a
'Topa Topa'	2.32bc	0.15b	1.18d	1.80de	0.70c	0.40c	0.27abc	34abc	21de	60abc	163a	6.8b
'Toro Canyon'	2.27c	0.13c	1.18d	1.94bc	0.79b	0.37d	0.22ef	32cd	22cde	58c	118bcd	5.7c
F value[Z]												
RS	26***	28***	21***	33***	99***	70***	10***	8***	8***	6***	15***	12***
YR	108***	611***	150***	187***	256***	238***	483***	480***	101***	83***	291***	52***
RS*YR	4***	6***	3***	5***	5***	7***	5***	2*	3***	2*	4***	2***

[Y]Mean separation within columns by Duncan's New Multiple Range test ($P = 0.05$). Values are the mean of annual concentrations from 5 – 10 years after planting (n = 20).
[Z]Data were analysed using repeated measures model, with year (YR) as the repeated measures factor. RS, rootstock.
*, ***, $P \leq 0.05$ and $P < 0.001$, respectively.

CONCLUSIONS

One of the limitations of a single-site rootstock trial is that it is difficult to extrapolate from the results. However, this trial provided a classification of the horticultural aspects of the most important clonal rootstocks under a "best-case" scenario. The highest yields recorded in this trial were higher than the 20-year State average of 6,015 kg ha^{-1} (Anon., 2005). There could be several reasons for the high yields observed. All trees were free from *Phytophthora* root rot, were located near seedling avocado trees that may be a source of pollen, and were planted on berms to facilitate drainage.

Other studies on a subset of these rootstocks, under non-stress conditions, generally resulted in similar rankings in terms of growth (Slowik *et al*., 1979; Smith, 1993), yield (Köhne, 1991; Roe *et al*., 1995), and nutrient concentrations (Slowik *et al*., 1979).

It should be noted that this trial was conducted under *Phytophthora*-free soil conditions, and that absolute values or relative rankings may differ substantially in *Phytophthora*-infested soils. In this trial, trees on 'Borchard' rootstock had the highest yields (along with 'Duke 7'; Table III), and exhibited most growth (Table I). However, 'Borchard' is highly susceptible to *Phytophthora* root rot, and trees grafted to this rootstock have low yields and slow growth in *Phytophthora*-infested soils (Menge *et al*., 1992). Furthermore, although there were consistent differences in nutrient concentrations between trees on 'Duke 7' and 'Toro Canyon' (Table VII), Menge *et al*. (1992) found no differences in leaf nutrient concentrations between trees on these rootstocks in *Phytophthora*-infested soils. The relative rankings of these rootstocks are also different when exposed to salinity (Oster *et al*., 1985), which is a common environmental stress in avocado-growing regions such as California, Australia, and Israel.

The results of this study also emphasise the need for rigorous evaluations of growth and yield prior to the release of rootstocks selected for tolerance to a particular stress. The original G755 tree was from a Guatemalan market collection of hybrids of avocado and coyou (*P. schiedeana* Nees; Ellstrand *et al*., 1986). Progeny from this tree were selected for their tolerance to *Phytophthora* root rot. G755A, G755B, and G755C are three seedlings from the original tree, and all have resistance to *P. cinnamomi*. However, in this trial, trees on these rootstocks had very low yields. Similar low yields of 'Hass' on G755C have been reported in South Africa (Köhne, 1991). Since our trial was undertaken, the G755 series of rootstocks are no longer recommended for planting, even under *Phytophthora*-infested conditions.

'Duke 7' is one of the most popular avocado rootstocks in California (L. Rose, Brokaw Nursery, personal communication), primarily due to its moderate resistance to *Phytophthora* (Menge *et al*., 1992; Zentmyer, 1991). In terms of overall performance (yield, canopy efficiency, fruit size, and alternate-bearing), none of the rootstocks in this trial were better than 'Duke 7'. 'Duke 7' has remained the dominant clonal rootstock worldwide, although more *Phytophthora*-resistant rootstocks such as 'Dusa' and 'Evestro', from South Africa, have recently been introduced and are gaining in popularity.

This project was funded, in part, by a grant-in-aid from the California Avocado Commission. The authors wish to thank Michelle Gottleib (deceased), Stacey Ontai, Steve Reints, Paul Robinson, and David Stottlemyer for assistance in data collection, and Stacey Mickelbart for editing the manuscript.

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