J. Amer. Soc. Hort. Sci. 104(2): 172-175. 1979.

Influence of Rootstocks, Soil Oxygen, and Soil Moisture on the Uptake and Translocation of Nutrients in Young Avocado [1]

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ADDITIONAL INDEX WORDS. *Persea americana*

ABSTRACT. The effects of 2 rootstocks of avocado (Persea americana Mill.), 2 soil oxygen levels, and 2 soil moisture levels on nutrient uptake and translocation showed that seedling Duke and Topa Topa rootstocks produced little change in the growth of 'Hass' scion, nutrient concentrations in the leaves, stems, and roots or the total amount of nutrients absorbed per plant. Total amounts of 11 nutrients studied were significantly lower, irrespective of concentrations found in the various plant tissues, in plants grown in with 2% soil oxygen than in plants supplied with 21% soil oxygen. Low soil moisture reduced dry weights of leaves and stems, and total dry weight of plants. Total amounts of N, P, K, Ca, Mg, Zn, and Mn per plant, irrespective of nutrient concentrations in the leaves, stems, and roots, were significantly lower in plants grown under low soil moisture.

Effects of the most common rootstocks of apple (*Malus domestica*), citrus (*Citrus* spp.) or pear (*Pyrus communis*) on nutrient uptake and translocation have been extensively investigated (1, 3, 14, 16). Data clearly indicate the influence of root-stocks on nutrient uptake and translocation to the plant tops. A considerable body of literature has been published (6, 8, 11) pertaining to the influence of soil oxygen supply to the roots of various plants on the nutrient concentrations in plant material. Low levels of soil oxygen in the root zone resulted in significant reduction in total nutrient uptake by the plant. Low levels of soil oxygen supplied to citrus roots also resulted in an accumulation of Na and Cl in the stems (6). Low oxygen supply to the roots of avocado plants significantly decreased concentrations of N, P, K, Ca, Mg, and B, increased Na and Fe in the tops (8), and significantly decreased those of K, Mg, Na, and Cl in the roots. Total amounts per plant of N, P, K, Ca, Mg, Na, and Cl decreased with low soil oxygen supply.

Field experiments with bearing avocado trees showed that too much soil moisture because of frequent irrigations decreased the concentrations of Fe and Zn in the leaves (5). A greenhouse experiment with avocado seedlings showed that avocado leaves and stems (combined) contained significantly lower concentrations of N, P, K, and B, and

[1]Received for publication June 17, 1978.

The cost of publishing this paper was defrayed in part by the payment of page charges. Under postal regulations, this paper must therefore, be hereby marked advertisement solely to indicate this fact.

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higher concentrations of Na, Mn, and Fe than control plants when the water table was maintained at half the soil column for the entire experimental period of 35 days (8).

Na concentration in the roots under the same conditons was significantly lower than in the roots of control plants. Labanauskas et al. (4) studied moisture effects on the nutrient uptake in citrus. They found total amounts of N, Cl, Na, Zn, Cu, and Fe per plant were significantly influenced by differential irrigation treatments. Lower concentrations of Ca, Mg, and Fe were found in the leaves of citrus seedlings grown in "wet soil" than in analogous leaves from trees grown in "dry soils."

Soil exploitation is governed by the density of roots in the soil as affected by cultivar differences, soil oxygen supply, and soil moisture level, hence the study of these factors and their interactions on nutrient uptake and translocation in avocado plants was combined in 1 experiment. This paper reports the influence of 2 rootstocks, 2 soil oxygen levels, and 2 soil moisture levels on the concentration of nutrients in avocado leaves, stems, and roots, and total uptake of 11 macro- and micronutrients.

Materials and Methods

'Hass' scions on 2 rootstocks, Duke and Topa Topa, were chosen to evaluate effects of soil oxygen and soil moisture on the nutrient concentrations in avocado leaves, stems, and roots, and total nutrient content per plant. Duke has been considered sensitive and Topa Topa tolerant to high soil moisture and low soil oxygen as they affect growth and nutrient uptake (15).

Seedlings were grown in a soil medium consisting of 5 top soil: 3 silt: 2 peat for 10 months, then grafted with 'Hass' scions. Plants were transplanted 9 months after grafting into acrylic cylinders 20 cm in diameter and 50 cm high filled with Fallbrook sandy loam. The soil was packed to a bulk density of 1.42 in each container. The containers were tightly sealed with plastic lids so that the atmosphere above the soil surface could be altered. The lids were provided with intake and exhaust ports through which air or a gas mixture could be circulated over the surface to control oxygen supply to the root system as previously described by Stolzy et al. (12, 13). Openings for tensiometers were provided in the lids.

Two oxygen levels were maintained above the soil surface in the containers: air (21% O_2) and a mixture of 2.5% 0_2 plus 97.5% N (referred to hereafter as high and low, respectively). Two levels of soil moisture were maintained in the containers by using tensiometers, which were inserted in the soil at 15 cm and 40 cm depths. One-half of the containers were watered with 0.1 strength Hoagland's solution when the tensiometer reading at the 15 cm depth indicated a soil water potential of 15 centibars. The other half were watered with 0.1 strength Hoagland's solution when the potential reached 55 centibars. These 2 soil moisture levels will be referred to hereafter as high and low soil moisture treatments, respectively. Each treatment was replicated 4 times in a factorial design. Experimental treatments in 2 consecutive years were identical and ran for 90 days. The trees for both experiments were raised identically starting from the seeds. The first experiment was initiated in October, 1974, and terminated in December, 1974. The second experiment was initiated in June, 1975, and terminated in September, 1975.

Greenhouse night temperatures were maintained at about 22°C and day temperatures at 35° during the hotter part of the day during the experimental periods. Soil root temperature was maintained at 25° ± 2° in constant temperature tanks. Plants were harvested at the end of the 90-day experimental period. Each plant was divided into leaves, stems, and roots, hand-washed in tap water containing 0.1% detergent (Joy), rinsed in demineralized water, and dried in a forced-draft oven at 60° for 48 hr. Methods of sample preparation for nutrient analyses were as previously described by Labanauskas and Bitters (3).

Results and Discussion

ROOTSTOCK EFFECTS. Rootstocks did not have a significant effect on dry weight of the leaves, stems, or roots. Dry weight of the plants was not affected significantly by the 2 rootstocks but concentrations of N, P, and Cu were higher and Mn lower in the leaves of 'Hass' on Duke (Table 1).

Concentrations of other macro- and micro-nutrients found in the leaves were not affected significantly by the 2 rootstocks. Dry weight of stems was not affected measurably by the root-stock differences; however, concentrations of Mn, Cu, and Fe in scion stems on Duke rootstock were significantly higher. Concentrations of other macro- and micro-nutrients found in the stems were not influenced significantly by the 2 root-stocks. Mn and Fe concentrations were significantly higher and Mg lower in Duke roots. Concentrations of other nutrients in the roots did not differ. Total amounts of N and Fe taken up by the scion grown on Duke rootstock were significantly higher. Thus, the 2 rootstocks produced little change in plant growth, nutrient uptake, and nutrient translocation under the same environmental conditions.

AERATION EFFECTS. The low level oxygen supply reduced dry weight of the whole plant as compared to plants supplied with high level oxygen. Dry weights of the leaves and stems were not affected significantly (Table 1). There was a significant reduction in dry weight of roots of plants supplied with low level of oxygen.

Low level soil oxygen treatment significantly reduced leaf concentrations of N, P, K, Ca, Mg, Zn, Mn, and Cu, while Fe was increased (Table 1). Concentrations of Na and Cl in leaves were not affected by the soil oxygen treatments. Low soil oxygen significantly reduced the concentrations of K, Mn, and Cu in the stems as compared with plants supplied with high soil oxygen (Table 1). Dry weight of plant stems was not affected by the oxygen treatments, but concentrations of Na and Cl in the stems were substantially higher where the soil oxygen supply was low.

The decreased amount of soil oxygen available to the roots significantly reduced the concentrations of N, K, and Mg, and increased those of Na, Cl, and Zn in the roots as compared to roots supplied with high levels of oxygen. Total amounts of all nutrients studied were significantly lower in plants grown in soils supplied with low oxygen, regardless of the nutrient concentrations found in the various plant tissues.

The low oxygen treatment had little effect on the dry weight of leaves and stems, but it reduced the dry weight of the roots enough to make even differences in total plant weight significant. Dry weights of leaves and stems were not reduced by the soil oxygen treatments, as reported earlier by Valoras et al. (15). This also agrees with earlier

findings that vegetative growth of some plants was relatively insensitive to low soil oxygen (10). The findings presented in this paper also agree closely with those reported from citrus (6) in which low level oxygen supply to the roots of citrus seedlings significantly reduced the dry weight of the roots, but showed no measurable effect on the dry weights of the leaves and stems.

Our data on effects of oxygen supply to the roots on nutrient concentrations in plant tops are in fairly close agreement with previous reports (8, 10). Those experiments showed that low levels of soil oxygen increased Cl and Na concentrations in the stems, but not in the leaves, as had been previously assumed. Increases in Cl and Na concentrations in stems of avocado plants grown under low soil oxygen supply were not related to dry weight produced. This would imply that Cl and Na are more effectively translocated from roots to stems under a low soil oxygen regime. Concentrations of most of the nutrients determined were lower in plant roots under low soil oxygen supply, with the exception of Na and Cl, which supports similar findings pertaining to Cl and Na in avocado (7, 8). Cl and Na concentrations in stems were shown to have increased in the present and previous experiments, whereas total amounts per plant were reduced under a low soil oxygen supply. This indicates that poor soil aeration may lead to Cl and Na toxicity problems, particularly in plants such as avocado which is extremely sensitive to Cl, and which may occur although the soils are not particularly high in Cl.

The uptake of such ions as P and K by roots differs from Na accumulation with respect to anaerobiosis. Both P and K accumulations are immediately suppressed by anaerobic conditions and return to normal only under aerobic conditions. Leggett and Stolzy (9) found that Na is in part an exception to this generalization — that uptake of Na by roots occurs under both aerobic and anaerobic conditions. Previously observed accumulation of Na in plants under anaerobic conditions over a long period of time was often considered a possible passive entry due to damage of the plant's root system (2, 10). The increase or decrease in the other macro- and micro-nutrient concentrations in plants grown under differential soil oxygen supply may be related to dry weight of the plant produced. The total amounts absorbed of 11 nutrient elements decreased in this experiment with decreasing dry weight when the oxygen supply to roots was low.

MOISTURE EFFECTS. Low soil moisture supply significantly reduced dry weight of leaves, stems and the total dry weight of the plants. Concentrations of Na, Mg and Cu in the leaves of plants grown under low level soil moisture were significantly higher. The differential levels of soil moisture affected Ca concentration in the stems, which increased with a low level of water in the root zone. Other macro- and micro-nutrients in the stems were not influenced by moisture level in the soil. The concentration of Mn in the roots of plants grown under low level moisture was significantly lower. The total amounts of N, P, K, Ca, Mg, Zn, and Mn per plant were significantly lower in plants grown under low soil moisture, irrespective of nutrient concentrations in the leaves, stems, or roots. No meaningful interactions were found among rootstocks, oxygen, and moisture treatments.

The effects of differential irrigation treatments on dry weight of plant tissues produced, on nutrient concentrations in plant tissues, and total amounts of nutrients taken up by avocado plants are in close agreement with earlier reports (4, 5, 8). High concentrations of N, Mg, and Cu were found in the leaves of plants grown in drier than in wetter soil.

Concentrations of nutrients found in the leaves, stems, or roots did not correspond to the total amounts of nutrients taken up by the avocado plants which were significantly lower in the plants grown under the low soil moisture regime. This was due to lower amounts of dry weight produced by plants, grown on dry soils than on wet. Similar results from previous work with avocado have been reported earlier. (4, 5, 8).

Table 1. Effects of rootstocks, oxygen, and moisture levels on the dry weight of avocado plants, nutrient concentrations, and total amounts of nutrients per plant.[z]

Variable		Rootstock		Level of Signif.	Oxygen		Level of Signif.	Moisture		Level of Signif.	Experiments		Level of Signif.	CV[y] (%)
		Topa-Topa	Duke		High	Low		High	Low		1974	1975		
Dry wt	Leaves (g)	21.9	22.7	NS	23.7	21.0	NS	25.3	19.3	***	23.4	21.3	NS	30
	Stems (g)	24.9	25.5	NS	26.4	23.9	NS	28.5	21.9	***	26.9	23.4	NS	41
	Roots (g)	28.7	31.4	NS	38.0	22.2	***	29.7	30.4	NS	36.1	24.0	***	28
	Total/Plant (g)	75.5	79.6	NS	88.1	67.0	***	83.5	71.6	**	86.4	68.7	**	28
N	Leaves (%)	1.9	2.0	***	2.0	1.9	**	1.8	2.0	***	2.5	1.3	***	7
	Stems (%)	0.9	0.9	NS	0.9	0.9	NS	0.9	0.9	NS	1.2	0.6	***	15
	Roots (%)	1.1	1.1	NS	1.2	1.0	**	1.1	1.0	NS	1.3	0.8	***	19
	Total/Plant (mg)	941.4	1044.0	*	1143.6	841.8	***	1046.3	939.1	**	1386.9	598.5	***	23
P	Leaves (%)	0.11	0.12	**	0.12	0.10	***	0.11	0.11	NS	0.13	0.09	***	15
	Stems (%)	0.10	0.10	NS	0.11	0.10	NS	0.10	0.11	NS	0.12	0.09	***	24
	Roots (%)	0.15	0.14	NS	0.14	0.15	NS	0.15	0.14	NS	0.15	0.14	NS	17
	Total/Plant (mg)	91.03	96.24	NS	110.71	76.56	***	99.82	87.45	*	116.77	70.50	***	27
K	Leaves (%)	0.69	0.65	NS	0.74	0.60	***	0.65	0.69	NS	0.76	0.58	***	21
	Stems (%)	0.65	0.62	NS	0.67	0.60	*	0.64	0.63	NS	0.66	0.61	*	14
	Roots (%)	0.67	0.65	NS	0.70	0.62	**	0.68	0.64	NS	0.74	0.58	***	17
	Total/Plant (mg)	516.33	520.52	NS	618.32	418.52	***	555.94	480.91	**	628.29	408.56	***	30
Ca	Leaves (%)	1.5	1.4	NS	1.6	1.4	***	1.4	1.5	NS	1.8	1.1	***	9
	Stems (%)	0.6	0.6	NS	0.6	0.6	NS	0.5	0.6	**	0.7	0.4	***	21
	Roots (%)	0.2	0.2	NS	0.2	0.2	NS	0.2	0.2	NS	0.3	0.1	***	23
	Total/Plant (mg)	531.3	544.2	NS	597.2	478.3	***	567.6	507.9	**	717.9	357.6	***	24
Mg	Leaves (%)	0.57	0.55	NS	0.61	0.51	***	0.54	0.58	*	0.59	0.53	***	10
	Stems (%)	0.17	0.18	NS	0.18	0.17	NS	0.17	0.18	NS	0.20	0.25	***	14
	Roots (%)	0.20	0.18	*	0.20	0.17	**	0.19	0.19	NS	0.18	0.20	*	20
	Total/Plant (mg)	226.40	224.60	NS	266.50	184.50	***	239.40	211.70	**	255.60	195.40	***	28
Na	Leaves (%)	0.02	0.02	NS	0.02	0.02	NS	0.02	0.02	NS	0.01	0.02	***	10
	Stems (%)	0.04	0.04	NS	0.02	0.06	***	0.04	0.04	NS	0.04	0.04	NS	88
	Roots (%)	0.18	0.18	NS	0.16	0.20	***	0.17	0.19	NS	0.14	0.21	***	16
	Total/Plant (mg)	61.00	60.60	NS	69.30	52.30	***	59.60	62.00	NS	63.30	58.30	NS	26
Cl	Leaves (%)	0.06	0.07	NS	0.07	0.06	NS	0.06	0.07	NS	0.05	0.08	***	30
	Stems (%)	0.01	0.01	NS	0.01	0.01	*	0.01	0.01	NS	0.01	0.01	*	72
	Roots (%)	0.18	0.17	NS	0.16	0.19	*	0.18	0.17	NS	0.11	0.24	***	23
	Total/Plant (mg)	63.70	63.40	NS	79.70	47.40	***	65.70	61.40	NS	54.00	73.10	**	40
Zn	Leaves (ppm)	24	24	NS	27	21	***	23	24	NS	26	22	***	12
	Stems (ppm)	22	23	NS	23	23	NS	22	23	NS	26	20	***	24
	Roots (ppm)	26	24	NS	23	27	*	25	25	NS	25	25	NS	33
	Total/Plant (mg)	1.8	1.8	NS	2.1	1.6	***	1.9	1.7	**	2.2	1.5	***	30
Mn	Leaves (ppm)	87	74	*	95	66	***	80	82	NS	87	74	*	24
	Stems (ppm)	11	14	*	14	11	*	13	12	NS	14	11	NS	41
	Roots (ppm)	18	32	***	24	26	NS	28	21	**	18	31	***	40
	Total/Plant (mg)	2.7	3.1	NS	3.5	2.3	***	3.3	2.5	***	3.0	2.7	NS	38
Cu	Leaves (ppm)	5.7	6.2	*	7.0	4.9	***	5.7	6.2	*	7.2	4.7	***	16
	Stems (ppm)	6.4	7.3	**	7.6	6.1	***	7.1	6.6	NS	6.9	6.8	NS	17
	Roots (ppm)	17.4	17.5	NS	16.8	18.1	NS	17.8	17.1	NS	14.1	20.8	***	36
	Total/Plant (mg)	0.8	0.9	NS	1.0	0.6	***	0.9	0.8	NS	0.9	0.8	NS	33
Fe	Leaves (ppm)	45	42	NS	39	47	**	43	44	NS	40	46	NS	32
	Stems (ppm)	26	30	*	26	30	NS	27	29	NS	31	25	***	20
	Roots (ppm)	353	395	*	366	382	NS	374	374	NS	367	381	NS	20
	Total/Plant (mg)	11.6	13.8	*	15.6	9.8	***	12.8	12.5	NS	14.8	10.5	***	35

[z]Each value is a mean of 32 individual determinations for 2 years.
*, **, ***, [NS]Significant at 5% (*), 1% (**), 0.1% (***) level. NS = not significant.
[y]CV = Coefficient of variability (%).

EXPERIMENTAL EFFECTS. Experimental materials and methods were identical in both of these experiments, but there were significant differences obtained in the dry weight of avocado plants, attributable mainly to season (Table 1). Concentrations and total nutrients per plant were significantly different each year. These differences were

attributed to differences in dry weight of plant material produced in the different seasons.

Assessment of plant nutrient status cannot be made solely on the basis of elemental concentrations because it is affected by soil oxygen, soil moisture, rootstocks, and translocation in the plant. Consideration of dry weight production, total nutrient uptake, and distribution within the plant are essential to a proper description of plant nutritional status.

Literature Cited

1. Embleton, T. W., C. K. Labanauskas, and W. P. Bitters. 1962. The influence of certain rootstocks on the concentration of boron, iron, manganese, and other elements in lemon leaves, and on boron toxicity symptoms. *Proc. Amer. Soc. Hort. Sci.* 80:285-290.
2. Hopkins, H. T., A. W. Specht, and S. B. Hendricks. 1950. Growth and nutrient accumulation as controlled by oxygen supply to plant roots. *Plant Physiol.* 25:193-209.
3. Labanauskas, C. K. and W. P. Bitters. 1974. The influence of rootstocks and interstocks on the nutrient concentrations in 'Valencia' orange leaves. *J. Amer. Soc. Hort. Sci.* 99:32-33.
4. _____, R. C .Baines, and L. H. Stolzy. 1965. Effects of citrus nematode (*Tylenchulus semipenetrans*) and two levels of water suction on nutrient concentrations in navel orange leaves and roots. *Soil Sci.* 89:367-374.
5. _____, T. W. Embleton, M. J. Garber, and S. J. Richards. 1958. Effects of irrigation treatments and rates of nitrogen fertilization on young 'Hass' avocado trees. V. Micronutrient content of leaves*. Proc. Amer. Soc. Hort. Sci.* 71:315-319.
6. _____, L. H. Stolzy, and M. F. Handy. 1972. Concentrations and total amounts of nutrients in citrus seedlings (*Citrus sinensis* 'Osbeck') and in soil as influenced by differential soil oxygen treatments. *Soil Sci. Soc. Amer. Proc.* 36:454-457.
7. _____, _____, L. J. Klotz, and T. A. DeWolfe. 1965. Effects of soil temperature and oxygen on the amounts of macronutrients and micronutrients in citrus seedlings (*Citrus sinensis* var. 'Bessie'). *Soil Sci. Soc. Amer. Proc.* 29:60-64.
8. _____, _____, G. A. Zentmyer, and T. E. Szuszkiewicz. 1968. Influence of soil oxygen and soil water on the accumulation of nutrients in avocado seedlings. (*Persea americana* Mill.). *Plant & Soil* 29:391-406.
9. Leggett, J. E. and L. H. Stolzy. 1961. Anaerobiosis and sodium accumulation. *Nature* 192:991-992.
10. Letey, J., O. R. Lunt, L. H. Stolzy, and T. E. Szuszkiewicz. 1961. Plant growth, water use and nutritional response to rhizosphere differential oxygen concentration. *Soil Sci Soc. Amer. Proc.* 25:183-186.

11. Stolzy, L. H., C. K. Labanauskas, L. J. Klotz, and T. A. DeWolfe. 1975. Nutritional responses and root rot of *Citrus limón* and *Citrus sinensis* under high and low soil oxygen supplies in the presence and absence of *Phytophthora spp. Soil Sci.* 119:136-142.

12. _____ and J. Letey. 1964. Characterizing soil oxygen conditions with a platinum microelectrode. *Advan. Agron.* 16:249-279.

13. _____Letey, L. J. Klotz, and T. A. DeWolfe. 1965. Soil aeration and rooting-rotting fungi as factors in decay of citrus feeder roots. *Soil Sci.* 99:403-406.

14. Tukey, R. B., R. Langston, and R. A. Cline. 1962. Influence of rootstock, bodystock, and interstock on the nutrient content of apple foliage. *Proc. Amer. Soc. Hort. Sci.* 80:73-78.

15. Valoras, N., J. Letey, L. H. Stolzy, and E. F. Frolich. 1964. The oxygen requirements for root growth of tree avocado varieties. *Proc. Amer. Soc. Hort. Sci.* 85:172-178.

16. Woodbridge, C.G. 1973. Effects of rootstock and interstocks on nutrient levels in ‘Bartlett’ pear leaves, on growth, and on fruit. *J. Amer. Soc. Hort. Sci.* 98:200-202.