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ROOTSTOCK, SOIL OXYGEN, AND SOIL MOISTURE EFFECTS ON GROWTH AND CONCENTRATION OF NUTRIENTS IN AVOCADO PLANTS

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Effects of the most common rootstocks of apple *(Malus domestica),* citrus *(Citrus* spp.) and pear *(Pyrus communis)* trees on nutrient uptake and translocation have been extensively investigated (2, 4, 15, 17). Data presented here clearly indicate the influence of rootstocks on nutrient uptake and translocation to the plant tops. A considerable body of literature has been published (7, 9, 12) on the influence of soil oxygen supply to the roots of various plants on the nutrient concentrations in plant material. Low soil oxygen in the rootzone resulted in significant reduction in total nutrient uptake by the plant. Low soil oxygen resulted in an accumulation of Na and Cl in citrus stems (7). 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 (9), and significantly decreased K, Mg, Na, and Cl in the roots. Total N, P, K, Ca, Mg, Na, and Cl per plant decreased with low soil oxygen supply.

Field experiments with bearing avocado trees showed that excess soil moisture due to frequent irrigation decreased concentrations of Fe and Zn in the leaves (6). A greenhouse avocado seedling experiment showed that combined leaves and stems contained significantly lower concentrations of N, P, K, and B, and higher concentrations of Na, Mn and Fe when the water table was maintained at half the soil column for the experimental period of *35* days (9).

Na concentration in the roots under the same conditions was significantly lower than in the roots of control plants. Labanauskas et al. (5) studied moisture effects on the nutrient uptake in citrus. They found that total 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."

Density of roots governs soil exploitation and is affected by varietal differences, soil oxygen supply, and soil moisture level, hence the study of these factors 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 avocado scion on two rootstocks, Duke and Topa Topa, were chosen to evaluate the effects of soil oxygen and moisture on the nutrient concentrations in the 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 related to growth and nutrient uptake (16).

Seedlings were grown in a soil medium consisting of 5 parts top soil, 3 parts silt, and 2 parts peat for 10 months, then grafted with Hass scions. Nine months after grafting, plants were transplanted into 20 cm diameter and 50 cm high acrylic cylinders filled with Fallbrook sandy loam. The soil in each container was packed to a bulk density of 1.42, and were tightly sealed with plastic lids in order to alter the atmosphere above the soil surface. The lids were provided with intake and exhaust ports through which air or a gas mixture could be circulated over the surface to control the oxygen supply to the soil system as previously described by Stolzy et al. (13, 14). Openings for tensiometers were provided in the lids.

The oxygen levels were maintained above the soil surface in the containers: air—21% O_2 and a mixture of 2.5% O_2 plus 97.5% N. The soil O_2 treatments will be referred to, hereafter, as high and low, respectively.

Two levels of soil moisture were maintained in the containers by using tensiometers inserted in the soil at 15 cm and 40 cm depths. Half of the containers were watered with 0.l-strength Hoagland's solution when the tensiometer reading at the 15 cm depth indicated a soil water potential of 15 centibars, and the other half were watered with 0.l-strength Hoagland's solution when the potential reached 55 centibars. These 2 moisture levels will be referred to, hereafter, as high and low soil moisture treatments, respectively. Each treatment was factorially replicated 4 times. Experimental treatments in 2 consecutive years were identical except for calendar period 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°—and day temperatures at 35 ° C during the hotter part of the day over the course of the experimental periods. Soil root temperature was maintained at 25° ± 2°C in constant temperature tanks. Plants were harvested at the end of the 90-day 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° C for 48 hr. Methods of sample preparation for nutrient analysis were as described by Labanauskas and Bitters (4). The data obtained from chemical analysis of tissues were subjected to statistical analysis (1).

Results and Discussion

Rootstock Effects

Rootstocks had no 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 the concentrations of N, P, and Cu were higher and Mn lower in the leaves of Hass on Duke rootstock (Table 1).

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 weight	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
Nitrogen	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
Phosphorus	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
Potassium	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
Calcium	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
Magnesium	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	0.15	***	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
Sodium	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
Chloride	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
Zinc	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
Manganese	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
Copper	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
Iron	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)	393	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	14.3	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 (%).

Concentrations of the other macro- and micro-nutrients in the leaves were not affected significantly by the 2 rootstocks. Dry weight of stems was not affected measurably by the rootstock differences; however, the concentrations of Mn, Cu, and Fe in the scion stems on Duke rootstock were significantly higher.

Concentrations of the other macro- and micro-nutrients found in the stems were not significantly influenced by the 2 rootstocks. 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 soil oxygen reduced dry weight of the whole plant as compared to plants supplied with high soil 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 soil oxygen.

Low 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 stems was not affected by the soil oxygen treatments, but the concentrations of Na and Cl in the stems were substantially higher where the soil oxygen supply was low.

Decreased soil oxygen significantly reduced concentration of N, K, and Mg, and increased Na, Cl, and Zn in the roots as compared with high level oxygen. Total amounts of all nutrients studied were significantly lower in plants grown under low soil oxygen, irrespective of nutrient concentrations found in plant tissues.

The low oxygen treatment had little effect on the dry weight of leaves and stems, but it lowered root dry weight very significantly—to produce high significance in total plant weight. Dry weights of leaves and stems were not reduced by the soil oxygen treatments, as reported earlier by Valorasetal (16). This confirmed earlier findings that vegetative growth of some plants was relatively insensitive to low soil oxygen (11). The findings presented in this paper agree closely with those reported on citrus (7) in which low oxygen supply to the roots of citrus seedlings significantly reduced dry weight of the roots, but showed no measurable effect on the dry weights of the leaves and stems.

These data on effects of oxygen supply to the roots on nutrient concentrations in plant tops are in fairly close agreement with previous reports (9, 11). Those experiments showed that low soil oxygen increased Cl and Na concentrations in the stems, but not in the leaves as had been previously assumed. Increased Na and Cl concentrations in stems of avocado plants grown under low soil oxygen supply were in effect cumulative, not related to dry weight reduction, and associated with root injury. 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 supported similar findings pertaining to Na and Cl in avocado (8, 9). Na and Cl 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 Na and Cl toxicity problems, particularly in plants such as avocado which are 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. Legget and Stolzy (10) 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 (3, 11).

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 reduced. The total uptake 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 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 soil moisture were significantly higher. Low soil moisture increased Ca concentration in the stems. Other macro- and micro-nutrients in the stems were not influenced by moisture level in the soil. The concentration of Mn was significantly lower in the roots of plants grown under low soil moisture. Total 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. Interactions among rootstocks, oxygen, and moisture treatments were not significant.

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 were in close agreement with earlier reports (5, 6, 9). Higher 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 (5, 6, 9).

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 nutrition status.

Summary

The effects of 2 avocado *(Persea americana* Mill.) rootstocks, 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 in the various plant tissues, in plants grown in the 2 % soil oxygen than in plants supplied with 21 % soil oxygen. Low soil moisture reduced dry weights of leaves, 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.

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