Nutritional Diseases of Pistachio Trees: Potassium and Phosphorus Deficiencies and Chloride and Boron Toxicities

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ABSTRACT

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Potassium (K) and phosphorus (P) deficiencies accounted for unthriftiness and poor yields of pistachio trees. K-deficient trees had sparse foliage canopies, small leaves without chlorosis, and pronounced shoot dieback. The threshold K level of leaves for deficiency appeared to be 0.7–0.9% in midsummer. P-deficient trees had normal dense foliage canopies, normal-sized leaves, and leaf chlorosis. Chlorosis of P-deficient trees appeared first on leaves terminal to nut clusters but later involved part or all foliage of the affected trees. Chlorosis was first interveinal, but leaves later became bright yellow, desiccated, and dehisced prematurely. The threshold P level for deficiency appeared to be 0.09–0.1%. Vegetative growth resumed within 2 mo following treatment with P and within 1 yr following treatment with K. A leaf scorch symptom was associated with high Cl^- levels in leaves (1.9%). Normal leaves, free of scorch symptoms had 0.4–0.8% Cl^- during midsummer. Boron (B) toxicity was characterized by marginal necrosis of mature leaves near the end of the growing season and was nearly universally present in the San Joaquin Valley of California. Necrosis-free leaf tissue, without and with marginal necrosis, had 220–235 ppm B while necrotic marginal tissue had about 1,000 ppm B.

Additional key words: elemental toxicities.

The pistachio nut tree, *Pistacia vera* L., has been grown commercially in California for over 40 yr, but large-scale planting began only about 1970. There are now about 19,000 ha of nonbearing and bearing trees, mainly in the San Joaquin Valley. Our interest in nutritional problems of pistachio arose from observations made on Verticillium wilt (caused by *Verticillium dahliae* Kleb.) to which the cultivar Kerman (5) and its common rootstock, *P. atlantica* Desf. (1) are susceptible. Other than our recent brief report on the relationship of K nutrition to Verticillium wilt (2), little is known about the nutritional requirements of the pistachio tree, except for zinc (17).

Three general types of unthrifty trees were observed: some trees had severely reduced foliage canopies with normal green color, reduced leaf size, and prominent shoot dieback; other trees had normal foliage canopies with leaves of normal size which had interveinal to overall bright yellow chlorosis which was at first confined to leaves terminal to nut clusters but spread to part or all of the foliage by mid-August and caused affected leaves to dry up and dehisce prematurely; still other trees had all these symptoms. Foliar symptoms occurred whether or not trees were infected with *V. dahliae* (2).

We report here on the causes and the control for the symptoms described above and on the toxicity of Cl^- and B to pistachio trees. A discussion of the relationship of K nutrition to susceptibility of the pistachio tree to infection by *V. dahliae* will follow in a separate report (3).

MATERIAL AND METHODS

Leaf tissue analyses. Samples were air-dried then milled to pass a screen with 2-mm-diameter holes. Phosphorus and boron analyses were made on 2 g samples ashed at 450 C (7). A molybdenum-blue colorimetric procedure (7) was used to determine P and the azomethine-H colorimetric procedure (15) was used to determine B. Except for organic N and Cl^-, analyses of all other essential elements and salts were made with an atomic absorption

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spectrophotometer on extracts of 1-g samples that had been refluxed for 25 min in 16 N HNO_3 until the tissue was digested (11). Organic N analyses were made on 1-g samples digested in 9 g K_2SO_4, 12 ml H_2SO_4, and 0.22 g $CuSO_4 \cdot 7H_2O$ for 45 min at 410 C, in an aluminum block heater. Digested samples were diluted to 250 ml with H_2O and N was determined as HN_4^+ with an ion-specific electrode (15). Chloride and NO_3^- also were determined with an ion-specific electrode following overnight extraction of 1-g samples with dilute HNO_3 (7) for Cl^- and with water for NO_3^-. Values obtained with these procedures on standard leaf tissue samples furnished by the National Bureau of Standards were within 10% of the NBS values (Standard Reference Material 1571).

Soil analyses. Soil samples were air-dried then milled to pass a screen with 2-mm-diameter holes. Organic nitrogen was determined on 5-g samples digested with 9 g K_2SO_4, 15 ml H_2SO_4, and 0.22 g $CuSO_4 \cdot 7H_2O$; otherwise the analysis was as for leaf tissue. Inorganic N (NO_3) and Cl^- were determined with an ion-specific electrode after 50-g samples were diluted 1:2 with H_2O and allowed to stand overnight. For P, 2.5-g samples were extracted with $NaHCO_3$ and determinations were made by using $SnCl_2$ as the color indicator (7). The azomethine-H colorimetric procedure (15) was used for B analyses of hot-water extracts (7). All other analyses were made with an atomic absorption spectrophotometer following extraction. Exchangeable K was determined by using 10-g samples extracted with 1 M CH_3COONH_4 (7) and 0.1 N HNO_3 was used for total K (7). Other elements were determined on 5-g samples refluxed for 25 min in 16 N HNO_3 (10). Conductivity measurements were made on 50-g samples diluted 1:4 with H_2O.

Inoculum densities of *V. dahliae* were established for all soils by using a wet-sieving procedure to concentrate microsclerotia (MS) in soil residues which then were quantitatively cultured on a selective substrate (12).

Nutritional status of thrifty and unthrifty trees. Tests were made to determine geographical variations of the nutritional status of thrifty and unthrifty trees since nutrient levels were not known except for Zn (17). Three composite leaf samples were collected from relatively thrifty trees at nine locations and from unthrifty trees at five locations in July–August 1982. Thrifty trees had dense foliage canopies, well expanded dark-green leaves, and shoot die-back was absent. Vegetative growth of such trees was present or absent during midsummer, 1982. Unthrifty trees had sparse foliage canopies; their leaves were smaller than those of thrifty trees, and leaves were dark green to variably chlorotic. All unthrifty trees had pronounced shoot dieback and vegetative growth was absent during midsummer, 1982. Phosphorus determinations were made on leaves at one location, but all other essential elements, except Cl^-, were determined at all locations.

Exchangeable K was determined for soils under three thrifty and three unthrifty trees at three locations in December 1982. Soils were sampled to a depth of 1.2 m in 30-cm increments and at 0, 1.2, and 3.1 m from water emitters located in tree rows.

Potassium treatments of soil. Soil treatments were made in a 13-yr-old planting during March-April 1983. A 12% solution of KCl was injected into the drip-irrigation system to deliver 1.5 and 3.0 kg of K per tree during 15–25 March 1982. There were six two-row replicate blocks of 174 trees per row. In another treatment, a 12% KCl solution was injected to a depth of about 20 cm at a distance of 1.3 m from trees with fertilizer injector shanks delivering 1.0 kg of K per tree during 15–25 April 1983. There were six replicated two-row blocks of 174 trees per row.

Exchangeable K levels in the soil were determined for three bulked core samples per replication, taken to a depth of 1.2 m at a distance of 0.6 and 1.3 m from the trees before treatment and 2 mo following treatment. Samples were taken to a depth of 1.8 m at a distance of 1.3 m from trees 1 yr following treatment.

Potassium levels in leaves of untreated trees. Five composite leaf samples from an untreated planting having many unthrifty trees were analyzed for K content in 1982, 1983, and 1984 to determine the influence of high (1982 and 1984) and low (1983) productivity upon K levels of leaves. This yield pattern, e.g., a year of high productivity followed by a year of low productivity (alternate-bearing) is typical of mature pistachio trees. Leaf collections were made during mid-July each year.

Treated trees. One composite leaf sample per replicate was analyzed for K content six times following treatment in 1983. Sampling dates were 14 May, 27 May, 10 June, 8 July, 19 July, and 26 Oct. During 1984, leaves were analyzed following collections made on 5 May and 30 Aug.

The influence of potassium treatments on performance of trees. Total yields of nuts were determined when all trees were mechanically harvested on 30 September 1983 and 25 September 1984.

Vegetative shoot growth measurements were made on 21 May 1984. In addition, shoot growth measurements were made on trees of several other plantings that were treated with 1.5 kg of K per tree during summer, 1983. Growth made by these trees by 21 May 1984 was compared with increments of growth made during 1981, 1982, and 1983. Measurements were made on five vegetative shoots on 20 trees each of thrifty, moderately deficient, and severely deficient trees, as available, at each location.

Phosphorus deficiency. Leaf samples were collected from several locations on 26 July 1984, when mild to severe chlorosis of K-treated trees was observed. Twelve composite samples of near-terminal leaves were collected from a planting of thrifty, vigorously growing, trees having few if any chlorotic leaves. Other samples were collected from 20 individual trees at a location where severely affected trees were absent and at a location where chlorosis was confined to leaves terminal to nut clusters, and from 20 trees from a planting suffering overall severe chlorosis. Leaves of each composite sample and tree were analyzed separately.

Soil of one half of a 65-ha planting of K-treated trees was treated with a 76% P_2O_5 solution during 14–15 August 1984. The material was injected into the drip irrigation system in quantities to deliver 1.2 kg of P per tree, followed by a 48-hr irrigation to cause diffusion of P into root zones of trees. Phosphorus contents of near-terminal leaves of vegetative shoots of untreated and treated trees were determined on three or five composite leaf samples per treatment, 0, 5, 11, 26, and 60 days following treatment.

A count of untreated and treated trees having new terminal growth was made on 3 October 1984. Two classes of trees were counted in 20 rows, 86 trees per row, in both untreated and treated portions of the planting: trees with severe chlorosis, and trees with mild-moderate chlorosis, which were marked with paint on 1 September 1984.

Chloride toxicity. In July 1983, soil of trees adjacent to a pumping station used for injection of KCl solutions was flooded with 12% KCl solution when a storage tank leaked. Chloride determinations were made on three composite leaf samples from scorched trees and from nearby unaffected trees. Three soil samples, collected 0–30 cm deep from unaffected and scorched tree sites, also were analyzed for Cl^-.

Leaf tissue from trees that were scorched when Cl_2 escaped from a tank of the gas used for algae control, was analyzed for Cl^-. Soil collected 0–30 cm deep also was tested for Cl^-. Results for scorched trees and tree sites were compared with results for unaffected trees and tree sites.

Boron toxicity. Tissue of normal mature leaves, collected 25 July 1984 from 27 locations and on 15 October 1984 from one location, were analyzed for all essential elements and salts. There were three composite samples from each location. These results were compared with results for marginally necrotic leaves collected on 15 October 1984 from three locations. Before the leaves with marginal necrosis were dried, the necrotic tissue was removed which allowed separate analysis of normal tissue and necrotic tissue.

RESULTS

Infestations by *Verticillium dahliae*. Inoculum densities ranged from 0.02 to 0.20 MS/g of soil.

Observations on potassium deficiency. *The nutritional status of thrifty and unthrifty pistachio trees.* Exploratory analyses were made on leaves of 15 plantings in the San Joaquin and Sacramento Valleys during July–August 1982, since the nutritional requirements of pistachio were not known except for Zn (17). Leaf samples from thrifty (Fig. 1A) and unthrifty trees (Fig. 1B and C), described earlier, were analyzed for all essential elements except Cl^-. Chloride was not determined since it was generally abundant in water and soil of California valleys (9). Minimal attention was given to P since it was rarely deficient in tree crops in California (16) and leaves of thrifty and unthrifty trees in a single test had 0.12% P in July, an amount considered adequate for other tree crops (16). All other essential elements, except K, were present in amounts adequate for other tree crops (16), in both thrifty and unthrifty trees. Potassium levels in leaves of thrifty trees ranged from 1.1 to 2.2% while K levels in unthrifty trees ranged from 0.5 to 0.8% (Fig. 2). The amounts of K detected in leaves of thrifty trees were adequate while the amounts detected in leaves of unthrifty trees were inadequate for tree crops grown in California (16), except for olive for which the threshold level for deficiency was reported to be 0.4%.

Soil analyses of exchangeable K were made for three plantings where the amounts of unthrifty trees were 2, 28, and 31%. Exchangeable K levels were adequate (6) at 0-60 cm depths at all locations (Table 1). Soil was marginally deficient (6) below a depth of 60 cm where 2% of trees were unthrifty and was deficient (6) below a depth of 60 cm where 28–31% of the trees were unthrifty (Table 1).

Potassium and chloride in soil following treatment. There was no detectable difference in exchangeable K in untreated soils (Table 1) and amounts detected 2 mo after 1 kg of K per tree was injected into soils via fertilizer shanks (Table 2). Potassium levels in soil collected 0.6 m from the trees (*unpublished*) was similar to levels in soil collected 1.3 m from the trees (Table 2). On the other hand, exchangeable K levels of soils treated with 1.5 and 3.0 kg of K per tree were considerably higher after 2 mo (Table 2) than before treatment (Table 1). Increasing K treatment from 1.5 to 3.0 kg of K per tree did not, however, cause a major change in K levels after 2 mo (Table 2). One year following treatment, similar amounts of exchangeable K was detected in all treatments.

After 2 mo, chloride levels in soils were similar at all depths, ranging from 0.1 to 0.6 meq of Cl^- per liter of saturated soil.

Potassium content of leaves of untreated trees during three years. Tests were made during 1982–1984 to establish the influence of alternate bearing on the K content of leaves. In a year of low productivity (e., g., 1983), the K contents of leaves of both relatively thrifty and unthrifty trees were considerably greater than in years of high productivity (e. g., 1982 and 1984), and the K content of leaves was lower in 1984 than in 1982 (Fig. 3A).

Potassium content of leaves of treated trees. Following soil treatment with KCl, leaf tissue was analyzed for K content six times during 1983. The data for 19 July showed that leaves of relatively thrifty trees (Fig. 3C) had greater amounts of K than leaves of unthrifty trees (Fig. 3B) and that these amounts were adequate for other fruit and nut trees grown in California (17). While K content of leaves during 1983 (a low production year) appeared adequate regardless of K treatments, they were much lower in 1984, a year of high productivity (Fig. 3D). In 1984, the K content of leaves of trees treated with 1.0 kg of K per tree was inadequate (less than 1% K) while the K contents of leaves of trees treated with 1.5 or 3.0 kg K/tree (Fig. 3D) were within the adequate range of levels reported for other trees (17).

The leaf chloride content was not determined since the Cl^- contents of untreated and treated soils were similar after 2 mo, as indicated earlier in this report. Also, there was no evidence of leaf-burn that could be attributed to potential Cl^- toxicity (Fig. 1K).

The influence of potassium treatments upon vegetative growth of trees. There was no evidence of enhancement of shoot growth of trees during the year treatments were made. In fact, shoot growth ceased by 1 July 1983. In 1984, however, shoot growth by 21 May was 11.7, 19.2, and 19.4 cm per shoot respectively, for the 1.0, 1.5, and 3.0 kg of K per tree treatments (LSD [P=0.05] = 2.8 cm). The difference in appearance of relatively thrifty trees before treatment (Fig. 1A) and thrifty trees following treatments (Fig. 1D) was apparent until mid-July, 1984. Following mid-July, changes in trees occurred that will be discussed under P deficiency.

Shoot growth made by 21 May 1984 was compared with total shoot growth made during 1981, 1982, and 1983 in five other plantings treated with 1.5 kg of K per tree in 1983. Results of measurements showed that annual shoot growth diminished each year between 1981 and 1983, but that growth made by 21 May 1984 generally exceeded the total growth made in 1983 (Fig. 4A and B). A few trees failed to respond to treatment (Fig. 4C). Essentially, all trees of plantings 9-2 and 24-2 responded to K treatment while significant numbers of severely deficient trees remained in plantings 33-2 and 12-1 during 1984 (Fig 4C).

The influence of potassium upon the yield of nuts. Nut yield with the 3.0 kg of K per tree treatment was considerably greater, 2,338 kg/ha, than with the 1.0 kg of K (1,798 kg/ha) or the 1.5 kg of K treatment (1,896 kg/ha) in 1983 (LSD [P= 0.05] = 202 kg). In 1984, however, yields were similar, regardless of treatment; 2,785 kg/ha, 2,802 kg/ha, and 2,818 kg/ha, respectively, for the 1.0, 1.5, and 3.0 kg K per tree treatments. This question will be discussed under phosphorus deficiency. In addition to this experiment, other plantings totalling 1,620 ha treated with 1.5 kg K per tree during the summer of 1983 had an average yield of 3,696 kg/ha in 1984 compared with 2,072 kg/ha in 1982, the high-yield growing season just before the K treatments were applied.

Observations on phosphorus deficiency. Trees of all plantings treated with K in 1983 grew well in 1984 until mid-July when chlorosis of leaves terminal to nut clusters (Fig. 1E, F) was observed. Chlorosis was absent from isolated trees in plantings which earlier were decimated by Verticillium wilt (Fig. 1H); it was at first more prevalent in 14- than in 10-yr-old plantings. By mid-September, nearly all trees of 10-yr-old plantings having near-complete stands also were severely affected. Trees suffered partial (Fig. 1I) to overall chlorosis followed by drying of leaves (Fig. 1G) and premature defoliation. All of the symptoms described above were part of the syndrome observed in 1982 and 1983.

Nutritional status of normal and chlorotic leaves. Analyses of essential elements and salts from samples of near-terminal normal leaves collected in a planting where chlorosis was generally absent were compared with results from two other plantings. Chlorosis was confined to leaves terminal to nut clusters in one planting and moderate and severe overall chlorosis occurred in the other planting. All elements except phosphorus and B occurred in the chlorotic foliage at levels acceptable for other fruit and nut trees grown in California (16). Normal leaves had 0.24% P while the P content in chlorotic leaves was 0.09% in a moderately affected planting, and was 0.02% in a severely affected planting (Table 3). These levels were low compared with needs for other fruit and nut trees (16). Relatively high levels of B were observed (126–173 ppm).

Soil treatment with phosphoric acid and uptake of P by trees. A 76% solution of P_2O_5 was injected into the drip irrigation system in quantities sufficient to deliver 1.2 kg of P per tree during 14–15 August 1984. Analyses made 5 days after treatment showed that leaves of untreated trees had 0.06% P while leaves of treated trees had 0.15% P, an amount considered adequate for other fruit and nut trees (16). These differences persisted 11 and 26 days after treatment (Fig. 5); 60 days after treatment P levels were 0.14% and 0.07% for, respectively, treated and untreated trees. Phosphorus levels in leaves of treated trees did not reach the level (0.24%) observed earlier in normal leaves of thrifty trees (Table 3).

Evidence of recovery from phosphorus deficiency. A count of untreated and treated trees having new terminal growth was made on 3 October 1984. Among severely affected trees, 4.7% of untreated and 17.6% of the treated trees had new terminal growth (Fig. 1J). Among moderately affected trees (Fig. 1I), 9% of untreated and 26% of treated trees had new terminal growth. Differences were significant at P = 0.01.

Relationship of phosphorus deficiency to reduced yields in potassium treatments. In 1983, the 3.0 kg of K per tree treatment yielded significantly more than either the 1.0 or 1.5 kg of K per tree treatments, for which yields were similar. The differences in yield were accounted for by the mean yield of individual trees (Table 4).

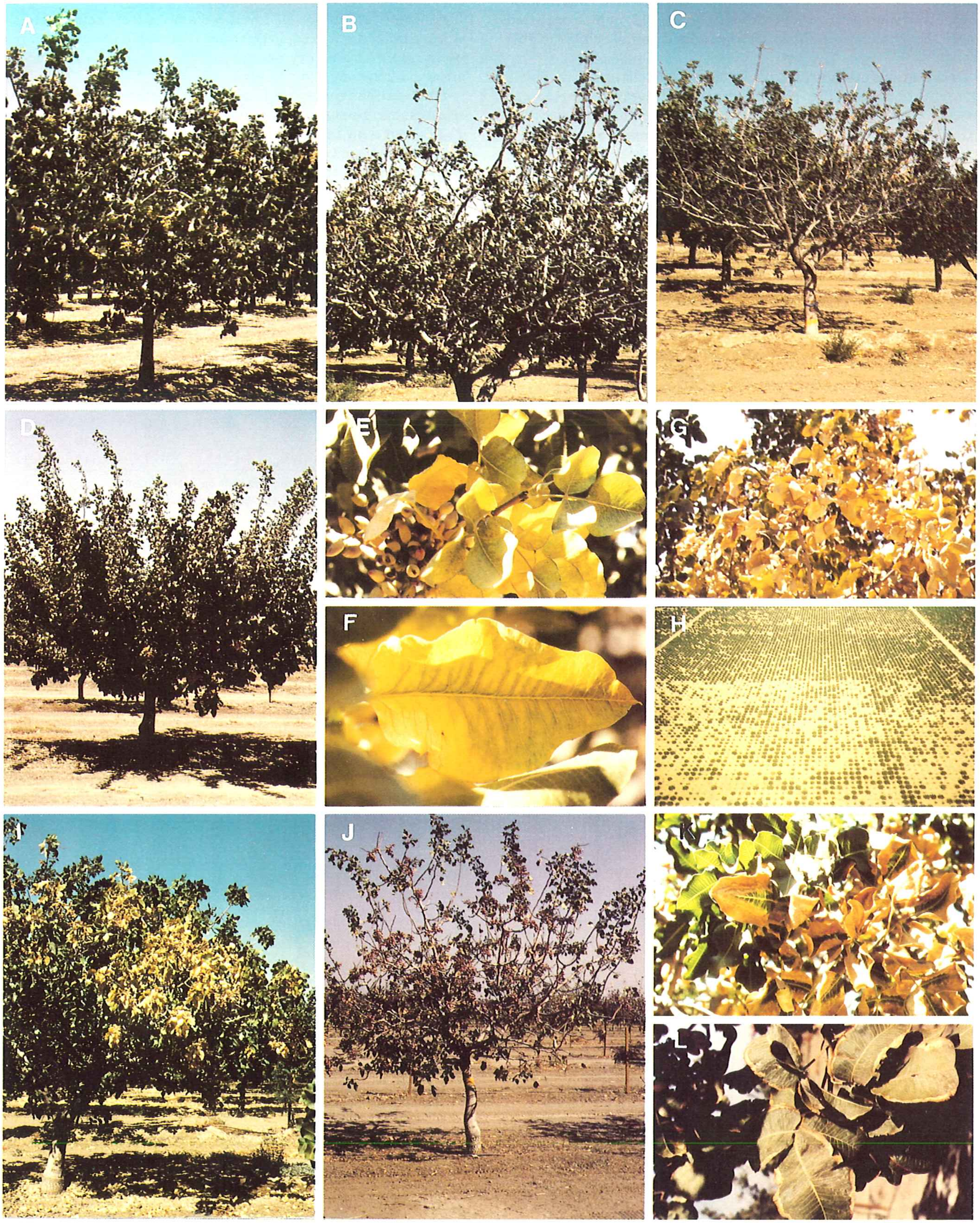

Fig. 1. A, A relatively thrifty pistachio nut tree, typical midsummer appearance before potassium (K) was applied; **B,** a moderately K-deficient tree, and **C,** a tree with severe K deficiency. **D,** A typical thrifty tree with abundant shoot development 1 yr following K treatment. **E,** A P-deficient terminal. **F,** Interveinal chlorosis typical of early P deficiency. **G,** Desiccation symptom that followed chlorosis. **H,** Aerial view of a pistachio planting decimated by Verticillium wilt. **I,** A moderately P-deficient tree. **J,** New growth following treatment of a tree that had severe P deficiency. **K,** Symptoms of Cl^- toxicity. **L,** Symptoms of B toxicity.

In 1984, however, there was a negative relationship between yield per tree and increasing amounts of K applied to soil in 1983. Reduced yield per tree in 1984 appeared to be related to increased numbers of trees with severe P deficiency (Fig. 1J), which occurred where the greatest amounts of K were added to soil in 1983 (Table 4).

Observations on chloride toxicity. Interveinal to nearly complete scorching of mature (Fig. 1K) and immature leaves of pistachio was observed during July 1983, where soil had been flooded with 12% KCl solution when a storage tank leaked. Normal leaf tissue from nearby trees had 0.4% Cl^- while scorched leaf tissue had 1.9% Cl^-. Normal leaf tissue from 26 other locations collected in July, 1984 had 0.4–0.8% Cl^-. Soil in the KCl spill site had 43 meq Cl^-/L while nearby soil had 2.5 meq Cl^-/L, both from samples collected 0–30 cm deep.

An identical leaf scorch developed among trees adjacent to a Cl_2 storage tank that leaked; in this case, however, damage appeared to be caused by transitory presence of the gas since unaffected and scorched leaves had low levels of Cl^- (0.2–0.5%).

Observations on boron toxicity. By September, in all growing seasons, marginal necrosis of mature leaves of pistachio trees (Fig. 1L) is common in San Joaquin Valley plantings. During 1984, however, marginal necrosis of leaves was absent in a small block of trees that had been deliberately under-irrigated for several years.

TABLE 1. The relationship between prevalence of unthrifty pistachio trees and reduced amounts of exchangeable potassium in soils

Location No.	Unthrifty trees (% of total trees)	Sampling depth (cm)	Exchangeable potassium (ppm)
1	2	0–30	275
		30–60	129
		60–90	92
		90–120	86
2	28	0–30	286
		30–60	100
		60–90	61
		90–120	64
3	31	0–30	268
		30–60	103
		60–90	71
		90–120	61

TABLE 2. Exchangeable potassium in soil 2 and 12 months following application of potassium to soil in a planting of pistachio trees

Sampling depth (cm)	Exchangeable K (ppm) in soil					
	2 months			12 months		
	1.0[a]	1.5	3.0	1.0	1.5	3.0
0–30	273	384	431	...	...	...
30–60	99	328	394	178	232	230
60–90	69	259	425	192	256	241
90–120	63	250	375	220	248	195
120–150	...[b]	...	...	137	119	145
150–180	...	...	...	127	116	137

[a] Kilograms of potassium per tree; 1.0 kg K treatment was injected into the soil with fertilizer shanks while other treatments were applied through the drip irrigation system.

[b] Not measured.

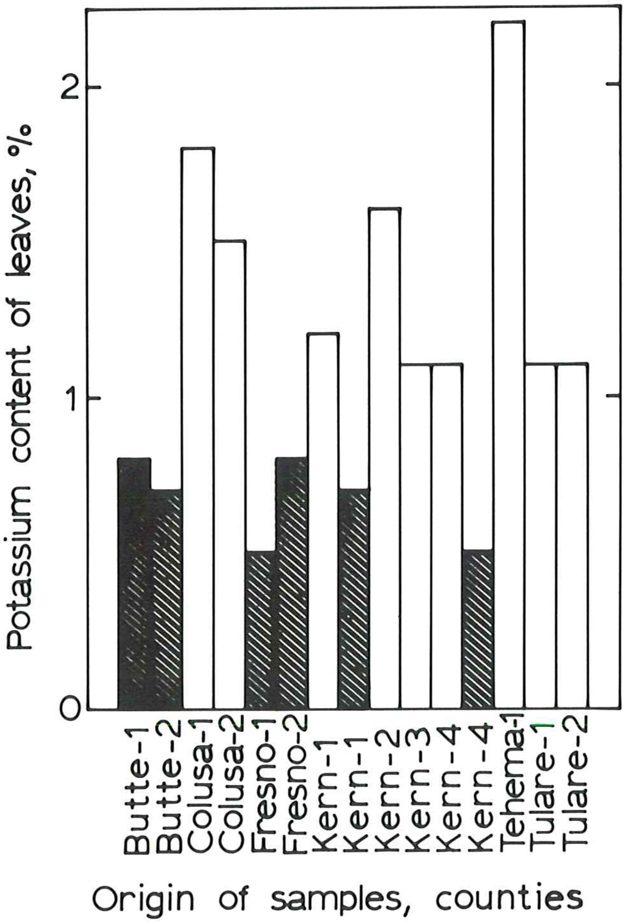

Fig. 2. Potassium content of unthrifty (shaded bars) and thrifty (open bars) pistachio trees.

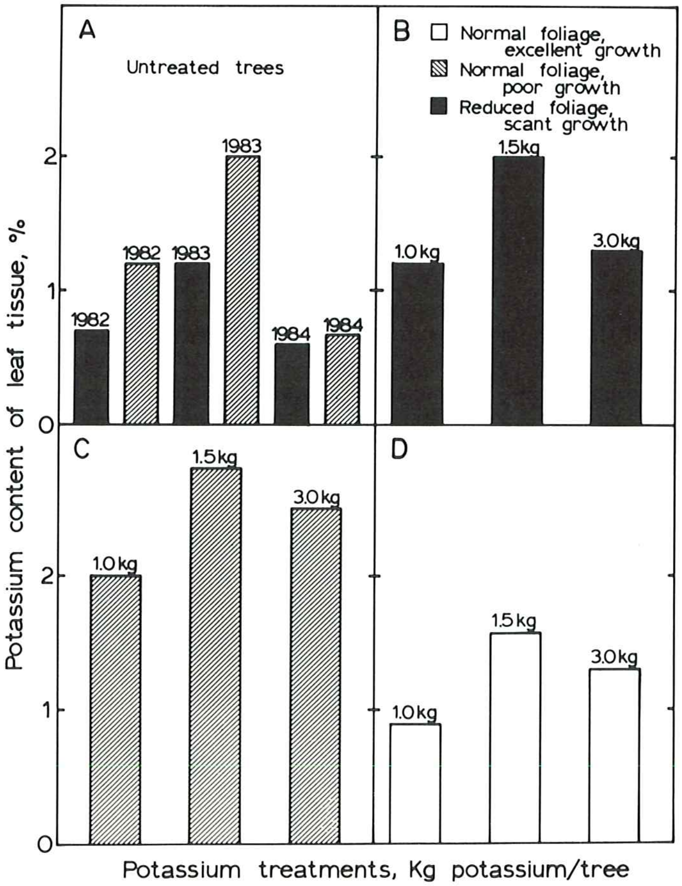

Fig. 3. Seasonal levels of K in leaves of pistachio trees: **A,** untreated trees during years of high productivity (1982 and 1984) and in a year of low productivity (1983); **B to C,** levels in July 1983 following treatment with 1.0, 1.5, and 3.0 kg of K per tree; and **D,** levels in leaves of treated trees 1 yr following treatment.

They had been watered with one 4 L/hr emitter whereas adjacent trees, and trees at 26 other locations in which marginal necrosis was universally present, were watered with either four or five 4 L/hr emitters. All trees received water for equal periods of time during the growing seasons.

The principal differences in accumulations of substances in necrotic leaf margin tissue versus normal leaf tissue were in NO_3 and B. The level of NO_3 (Table 5) was not unusual since 10,000 ppm NO_3 in normal leaf tissue is common (16). However, about 4.5 times more boron (1,073 ppm) was detected in necrotic tissue than in normal tissue (220–235 ppm) (Table 5). Boron levels in normal leaves collected at five locations in the upper Sacramento Valley in July 1982 were about the same (143–230 ppm) as levels in healthy leaf tissue collected in the San Joaquin Valley.

DISCUSSION

Potassium deficiency was associated with trees having reduced foliage canopies (Fig. 1B); slight (Fig. 1A), moderate, to severe shoot dieback (Fig. 1B and C); and a low K content of leaves

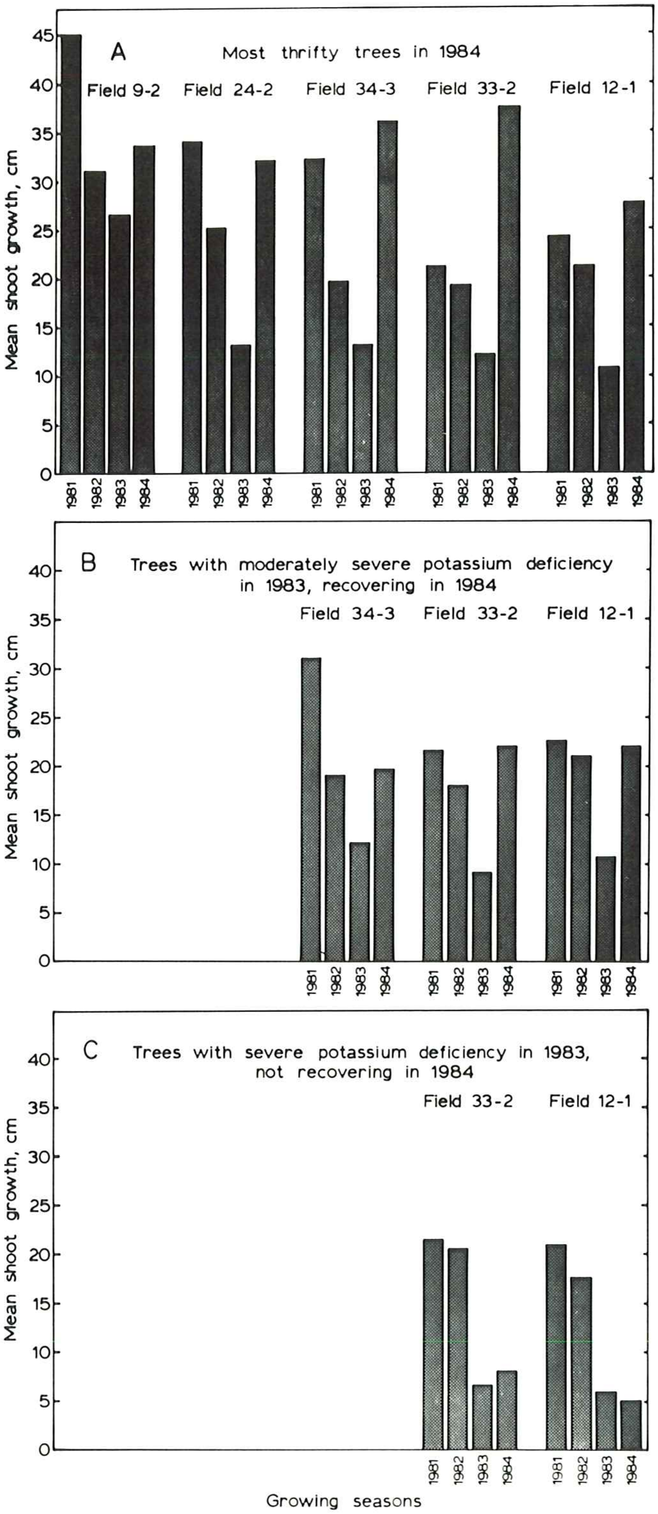

Fig. 4. Mean annual shoot growth of pistachio trees in several plantings during 1981, 1982, and 1983 compared with shoot growth made by 21 May 1984 following treatment with 1.5 kg of K per tree in 1983.

TABLE 3. Elemental analysis of normal and chlorotic leaves of pistachio trees

	Concentration	Normal leaves	Chlorotic leaves	
Element	Units	Location 1	Location 2	Location 3
Nitrogen (NH_4)	%	2.5	2.5	2.5
Potassium	%	1.4	2.5	2.1
Phosphorus	%	0.24	0.09	0.02
Calcium	%	3.1	3.0	4.6
Magnesium	%	4.8	6.0	5.3
Zinc	ppm	22.0	20.0	16.0
Iron	ppm	319.0	326.0	344.0
Copper	ppm	7.5	5.5	5.5
Manganese	ppm	51.0	41.0	47.0
Boron	ppm	90.0	110.0	100.0
Sodium	ppm	131.0	173.0	126.0
Chloride	%	0.7	0	0.6

TABLE 4. Influence of potassium treatments upon yields of pistachio nuts and the occurrence of severe foliar phosphorus deficiency

		1984	
Potassium treatments (Kg/tree)[a]	1983 Nuts/tree (kg)	Nuts/tree (kg)	Severe P deficiency[b] (percentage of trees)
1.0	8.0	13.2	47.7
1.5	7.9	11.6	64.5
3.0	9.1	10.5	68.9
LSD, $P = 0.05$	1.1	0.8	9.7

[a] Applied in 1983.

[b] Pistachio trees were considered to be severely deficient in P if level of foliar $P \leqslant 0.09\%$.

TABLE 5. Nutritional and salt status of pistachio. Normal leaves and leaves with marginal necrosis during 1984

			Mature leaves with marginal necrosis	
	Normal mature leaves		Normal tissue	Necrotic tissue
Elements	25 July	15 October	15 October	15 October
Nitrogen,				
NH_4, (%)	2.5	1.6	1.3	1.4
NO_3 (ppm)	···	2,100	1,270	4,170
Phosphorus (%)	0.15	0.07	0.11	0.13
Potassium (%)	1.2	1.6	2.0	1.0
Calcium (%)	3.4	2.6	3.2	2.3
Magnesium (%)	0.5	0.8	0.9	0.9
Zinc (ppm)	13	23	28	19
Iron (ppm)	107	258	116	165
Manganese (ppm)	53	70	44	29
Copper (ppm)	8	6	12	11
Boron (ppm)	101	220	235	1,073
Sodium (%)	0.09	0.07	0.13	0.16
Chloride (%)	0.5	0.7	1.0	0.6

(0.5–0.8%). Soils of K-deficient tree sites were low in exchangeable K below a depth of 60 cm (Table 1), according to criteria for California soils established by Brown et al (6). A probable explanation follows: Low rainfall (about 12 cm/yr) and the nature of the irrigation system (drip-type) resulted in soil 0–60 cm deep being too dry for root activity except for a short time each year. Exchangeable K levels of deficient soils were readily restored by injecting 12% KCl solution through the drip irrigation system. Recharging of the soil in this manner was measured after 2 mo and acceptable levels persisted after 1 yr (Table 2). However, 1.0 kg of K per tree, injected directly into soil with fertilizer shanks, appeared at first to be immobilized since no increase in the exchangeable K level was detected after 2 mo (Tables 1 and 2), although acceptable levels of exchangeable K were detected after 1 yr (Table 2).

Changes in the K content of leaves in the first year of treatment (1983) were apparent (Fig. 3B and C) but partly masked due to the reduced needs of trees in a year of low production (Fig. 3A), i.e., attributed to alternate bearing by trees. One year after treatment, however, differences in the K content of leaves were obvious. There was no advantage to applying 3.0 kg of K per tree compared to the 1.5 kg of K per tree treatment (Fig. 3D). The K content of thrifty trees was 1.1—more than 2% K. The threshold level of deficiency for pistachio appeared to be 0.7–0.9%, agreeing with values reported for other fruit and nut crops (16) except olive for which 0.4% was reported to be the threshold level (11).

Although K did not affect shoot growth during the year treatments were made (1983), shoot growth of trees treated with 1.5 and 3.0 kg of K per tree was excellent the following year, 1984 (Fig. 1D; 4A and B) until July. At that time, moderate to severe leaf chlorosis appeared and shoot growth stopped. The onset of leaf chlorosis coincided with the period of rapid growth of nut kernels which extended from about 15 July–1 October, based on measurements made during two growing seasons (L. J. Ashworth, Jr., *unpublished*).

Nut yields were improved about 20% over the 1.0 kg of K per tree treatment by the 3.0 kg of K per tree treatment during the year treatments were made. Differences between the 1.0 and 1.5 kg of K per tree treatments and the 1.5 and 3.0 kg of K per tree treatments were not significant. One year after K applications, yield per tree was lower in the 1.5 and 3.0 kg of K per tree treatments than in the 1.0 kg of K per tree treatment. Reduced yields per tree in these treatments were associated with the occurrence of trees with severe P deficiency (Table 4). Severe P deficiency appeared to be induced by depletion of available P in soil as a result of increased vegetative vigor of trees receiving 1.5 and 3.0 kg of K per tree in 1983 (Fig. 4).

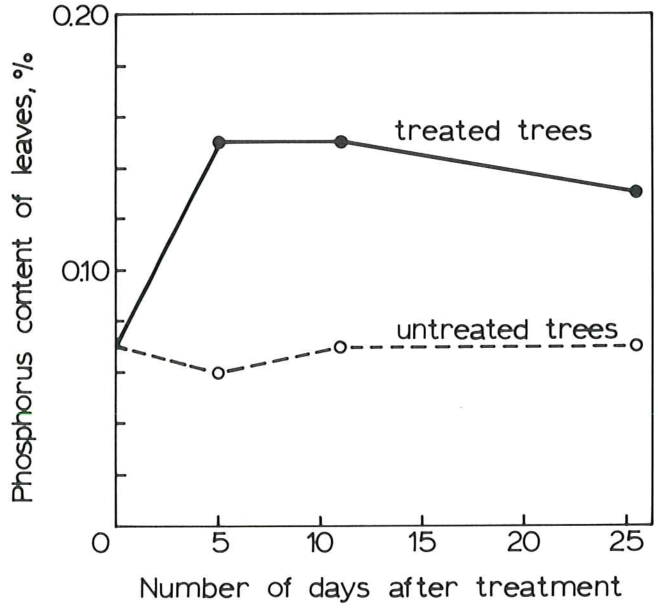

Fig. 5. Effect of P treatment on P content of untreated and treated pistachio trees 5, 11, and 26 days following P treatments in 1984.

Regardless, the yield from 1,620 ha treated during the summer of 1983 was 78% greater in 1984 than in the previous high-yield growing season (1982) before the K treatment was applied.

P-deficient trees had normal dense foliage canopies and chlorotic leaves of normal size, with chlorosis developing first in leaves terminal to nut clusters (Fig. 1E, F, and I). Severely chlorotic leaves desiccated (Fig. 1G) and dehisced prematurely. Shoot dieback was not associated with P deficiency. The P content of deficient leaves ranged from 0.02–0.08% while the P content of normal leaves ranged from 0.12 to 0.25%. The threshold level of P deficiency appeared to be about 0.1%, which agrees with values reported for other fruit and nut crops (16).

P-deficient trees responded quickly to P application (Fig. 5), and renewal of growth (Fig. 1J) occurred within 2 mo. Our observations agree with recent observations made on treatment of P-deficient, drip-irrigated grapes by Cook, et al (8).

Although no evidence of Cl^- toxicity was observed in trees treated with 1.0, 1.5, or 3.0 kg of K per tree, using 12% KCl solution, toxicity was observed in trees affected by a spill of KCl. Scorched leaves (Fig. 1K) had 1.9% Cl^- while normal leaf tissue had 0.4% Cl^-. Soil (0–30 cm depth) at the spill site had 43 meq Cl^-/L while nearby unaffected soil had 2.5 meq Cl^-/L. The Cl^- level detected in scorched leaves was greater than most minimal levels for toxicity of 41 species reported by Eaton (10). Likewise, the amount of Cl^- detected in soil of affected trees was well above the minimal level expected to cause toxicity to Cl^--tolerant species (16). Identical symptoms were observed among trees adjacent to a leaking Cl_2 cylinder, however, tissue concentrations were not changed.

Leaves of pistachio trees appeared to accumulate levels of B in normal tissue (220–235 ppm) by the end of the growing season that would be toxic to tolerant crops such as olive and walnut, and 2-3 times the minimal levels damaging less tolerant crops such as almond and peaches (16). Tissue of necrotic leaf margins of pistachio (Fig. 1L) had 1,073 ppm B, about the same amount observed in damaged leaves of rough lemon (13) and barley (4,14), both relatively tolerant to B.

Only trees suffering severe water stress were free from boron toxicity while all trees receiving 4–5 times as much water exhibited symptoms of B toxicity. Soil moisture determinations with a neutron probe, showed that roots of severely water stressed trees were limited to the upper 1 m of the soil profile while roots of nonstressed trees grew throughout the soil profile to a depth of 2.7 m (L. J. Ashworth, Jr., *unpublished*). Our observations agree with those of Oertli (13) who suggested that B uptake was passive in nature. Translocation of B was in xylem and accumulated at vessel endings at leaf margins late in the growing season. Toxic accumulations of B apparently do not accumulate in roots of pistachio because trees grow well in the Central Valley of California. Accumulation of toxic amounts near vessel endings occurred only late in the growing season, which may be an expression of B tolerance.

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