Verticillium wilt of pistachio

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Proper nutrition reduces infection in low-inoculum soils and improves yields

Pronounced differences in vegetative vigor among pistachio trees became noticeable within five years after they were planted in the San Joaquin Valley. The differences were observed shortly after trees began to bear significant crops of nuts. The most common type of unthrifty tree, in the absence of Verticillium wilt, had a reduced foliage canopy, sparse foliage, small and rather brittle leaves, and prominent shoot dieback. Such trees, however, often were infected with the causal fungus, *Verticillium dahliae.*

Unthrifty trees and Verticillium wilt were in some instances preferentially associated with particular sources of the common rootstock, *Pistacia atlantica.* A planting containing two sources of *P. atlantica* could thus have greater numbers of unthrifty trees and tree losses to Verticillium wilt in one than another part of the planting.

The role of nutrition in the occurrence of unthrifty trees was not suspected until 1982, when unusual development of Verticillium wilt of unthrifty pistachio trees was recognized in plantings that had low levels of the wilt fungus. The low level detected, about 0.1 microsclerotium per gram of soil (4,000 microsclerotia per cubic foot), was inconsequential to thrifty trees. In fact, no infection of trees that made growth during mid-summer was observed during 1982-85. On the other hand, infection among unthrifty trees ranged from 13 to 73 percent, depending on location. Low levels of the fungus were associated with plantings made on previously uncropped desert soils and on previously cropped soils that had been mulched with polyethylene tarps after trees were planted (*California Agriculture,* May-June 1982).

Nutrient deficiencies

We found two major elemental deficiencies to account for unthriftiness of trees: potassium and phosphorus. Mature thrifty trees characteristically had dense foliage canopies, large succulent dark green leaves, and shoot growth continuing throughout the growing season. Mature leaves of vegetative shoots of these trees had 1.1 to 2.2 percent potassium and 0.11 to 0.25 percent phosphorus in mid-July.

Potassium-deficient trees in the absence of Verticillium wilt had sparse foliage, small brittle leaves, and shoot dieback. Leaves of such trees had 0.5 to 0.9 percent potassium during mid-summer, and underlying soils had reduced levels of exchangeable potassium (60 to 70 ppm) below a depth of 2 feet in badly affected plantings (table 1).

We recharged the soil with exchangeable potassium using 12 percent potassium chloride solution injected either through fertilizer shanks or through the drip irrigation system. Exchangeable potassium in soil stabilized quickly when treatment was through the drip irrigation system, but more time was required when potassium was injected with fertilizer shanks (table 2).

There was no evidence of chloride toxicity to leaves at the rates of 12 percent potassium chloride used in our tests. Nor did toxic levels of chloride appear to accumulate in treated soils, since the same range of levels (0.1 to 0.6 meq chloride per liter of saturated soil extract) occurred in untreated and treated soils two months after treatments were made.

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

Location No.	Unthrifty trees*	Sampling depth	Exchangeable potassium
	%	ft.	ppm
1	2	0-1	275
		1-2	129
		2-3	92
		3-4	86
2	28	0-1	286
		1-2	100
		2-3	61
		3-4	64
3	31	0-1	268
		1-2	103
		2-3	71
		3-4	61

*Percent of total trees.

One soil treatment in the spring of 1983 was adequate for at least three growing seasons. That is, levels of exchangeable potassium in treated soils were still greater than 150 ppm through a depth of 6 feet after the 1985 growing season. Also, potassium levels in leaf tissue of treated trees remained relatively high (1.4 to 2.2 percent) during the summer of 1985.

Only the highest treatment rate, 6.6 pounds potassium per tree, improved nut yield during the treatment year, but both the 3.3- and 6.6-pound rates reduced incidence of Verticillium wilt and tree losses due to Verticillium (table 3). The lower effectiveness of 2.2 pounds potassium per tree was related to the amount of time required for the treatment to stabilize (table 2). There was no evidence of improved vegetative vigor of treated trees during the year potassium was applied.

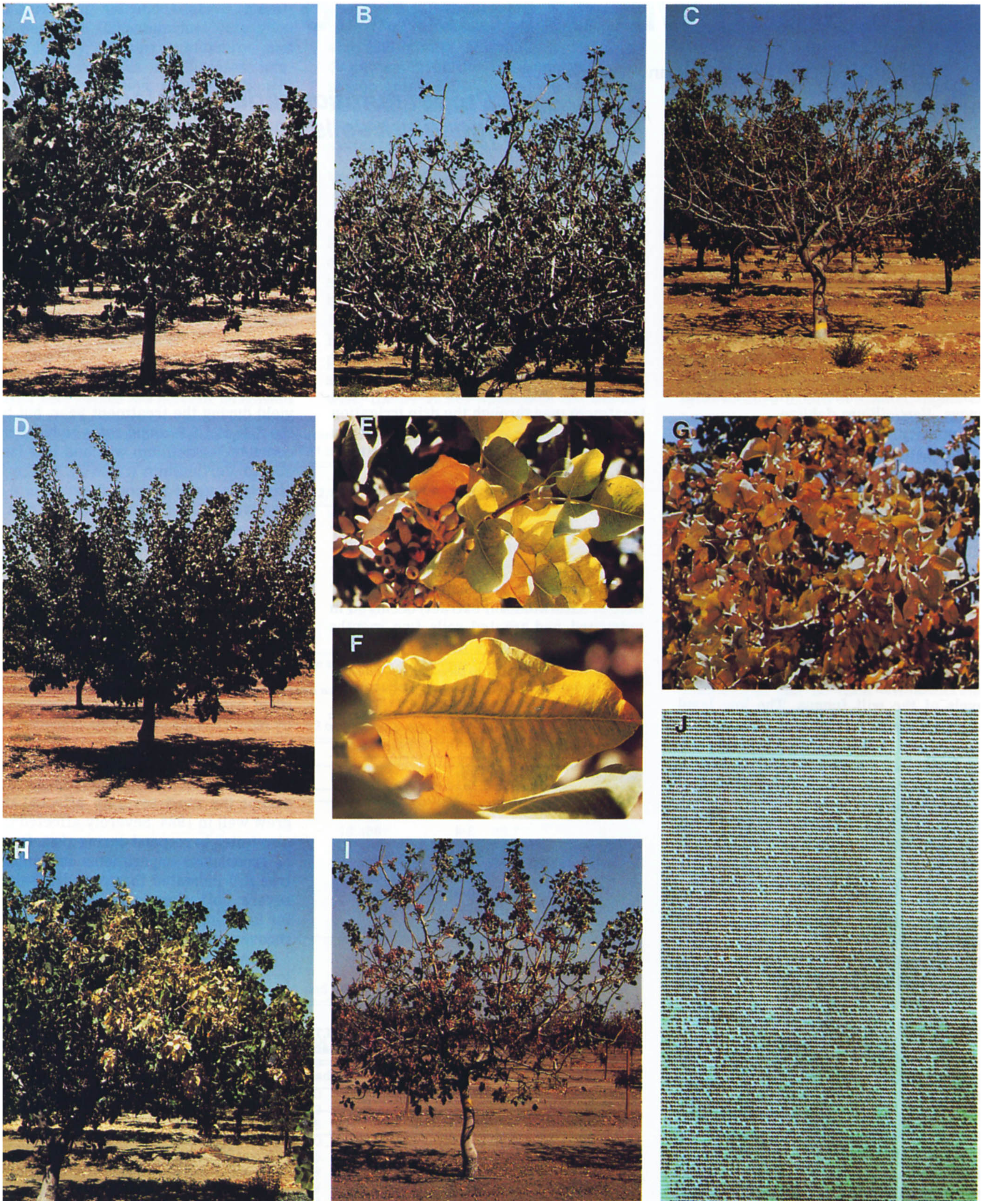
Shoot growth was unaffected during the year treatments were made but was significantly improved in the next year, 1984. Measurements in several plantings indicated that shoot growth had diminished each year since 1981. New growth by May 21, 1984, generally exceeded total growth made in 1983 (fig. 1), and the appearance of most thrifty trees was markedly different in 1983 and 1984. All trees, except the most severely affected ones, grew well in 1984. Severely affected trees also failed to respond during 1985. Results of greenhouse experiments in pathogen-free soil indicated that root death due to severe potassium deficiency accounted for inability of severely deficient trees to recover under field conditions.

Amounts of Verticillium wilt and tree losses were further reduced in 1984 in response to potassium treatments made in

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

Sampling depth	Exchangeable potassium in soil					
	2 months			12 months		
	2.2*	3.3	6.6	2.2	3.3	6.6
ft	ppm					
0-1	273	384	431	-	-	-
1-2	99	328	394	178	232	230
2-3	69	259	425	192	256	241
3-4	63	250	375	220	248	195
4-5	-†	-	-	137	119	145
5-6	-	-	-	127	116	137

* Pounds of potassium per tree; 2.2-pound treatment was injected into the soil with fertilizer shanks, while other treatments were applied through the drip irrigation system.
† Not measured.



(A) A relatively thrifty pistachio tree, typical mid-summer appearance before potassium application. (B) Moderately potassium-deficient tree. (C) Tree with severe potassium deficiency. (D) Typical thrifty tree with abundant shoot development one year after potassium treatment. (E) Phosphorus-deficient terminal. (F) Interveinal chlorosis typical of early phosphorus deficiency. (G) Drying following chlorosis. (H) A moderately phosphorus-deficient tree. (I) New growth after treatment of tree with severe phosphorus deficiency. (J) Differential loss of trees from Verticillium wilt in a planting with two different sources of *Pistacia atlantica* rootstock.

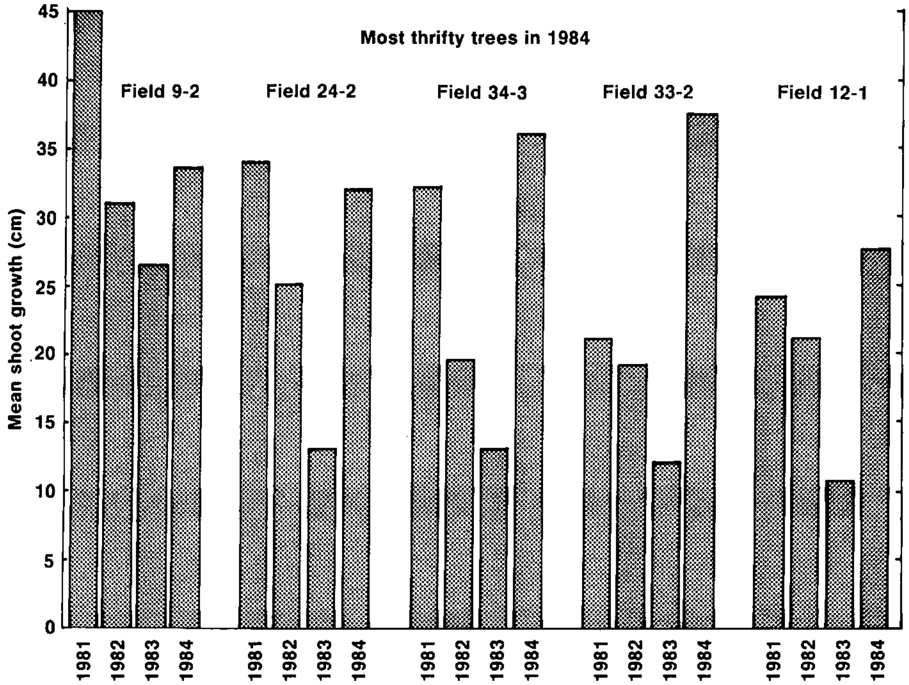


Fig. 1. Shoot growth in five pistachio plantings declined from 1981 to 1983, then increased in 1984 after a potassium application the year before.

1983 (table 4). Nut yield, however, was adversely affected. Yield decreases were associated with increased prevalence of a symptom observed as early as 1982 and now known to be phosphorus deficiency.

Leaves with bright yellow chlorosis, which did not appear during 1984 until mid-July, had relatively high levels of all essential elements, according to guidelines for other fruit and nut crops, with the exception of phosphorus. Such leaves had 0.02 to 0.09 percent phosphorus during July-August 1984, while normal green foliage of thrifty trees had 0.11 to 0.25 percent phosphorus. The chlorosis symptom was not confined to unthrifty-appearing trees but was common among those that performed well until mid-July, coinciding with the onset of nut kernel growth. At that time, all or portions of trees turned bright yellow, followed by drying and early defoliation of affected portions.

TABLE 3. The influence of potassium treatments upon nut yields and Verticillium wilt during 1983.

Potassium treatments	Yield	Verticillium wilt: Infection	Verticillium wilt: Tree losses*
lb/tree	*lb/acre*	*%*	*No./row*
2.2	1,600	18.8	33
3.0	1,687	13.8	23
6.6	2,081	9.7	15
LSD, P = 0.05	180	4.2	-

* 174 tree sites per row.

Results of soil analyses also suggested that symptoms were caused by phosphorus deficiency. Soils of severely affected plantings had 6 to 8 ppm phosphorus (0- to 4-foot depth) instead of the 11 or more ppm considered adequate.

The first soil treatment with phosphorus was in August 1984, when 75 percent phosphoric acid was injected through drip irrigation systems at two locations. Other treatments were made in March 1985. The treatment rate was approximately 2.6 pounds phosphorus per tree. The phosphorus content of leaves of untreated trees remained at 0.06 percent but increased to 0.15 percent within five days in trees treated in August 1984. Our results agree with observations of others on phosphorus deficiency of grape (*California Agriculture,* May-June 1983). Also, as in grapevines, there was evidence of preferential regrowth of treated versus untreated trees within six weeks after soil treatment in August 1984.

Phosphorus deficiency symptoms were less prevalent and less severe in 1985, a light crop year, than in 1984, a heavy crop year. Nevertheless, phosphorus treatment reduced prevalence from about 57 percent of untreated trees to about 29 percent of treated trees in 1985. Overall chlorosis was absent from treated trees in 1985; instead, when present, chlorosis was confined to leaves terminal to nut clusters, which differentially accumulated phosphorus at the expense of those leaves. The nuts had 0.25 percent phosphorus, while chlorotic leaves had 0.07 to 0.09 percent and normal leaves had 0.12 to 0.15 percent phosphorus. The phosphorus threshold level below which chlorosis occurred appeared to be about 0.09 to 0.1 percent during mid-summer.

Nut yield and size were both improved by phosphorus treatment in a planting where Verticillium wilt was absent (table 5). In this case, treatment done in August 1984 increased the phosphorus level of soil from 7 ppm to 10 to 11 ppm through a depth of 4 feet. In a planting severely affected by Verticillium wilt, incidence of wilt was approximately 44 percent less where treatment was made in August 1984 than where treatment was in March 1985 (table 5). Phosphorus in soil at this location was at a deficiency level (6 to 7 ppm through a depth of 4 feet) following the 1985 growing season, suggesting that more must be applied to soil to attain an adequate level. Yield was increased from 500 to 572 pounds per acre and Verticillium wilt was reduced from 7.1 to 4.3 percent by phosphorus treatment in a third experiment, begun in the spring of 1985, supporting results of the other experiments. In this case, the phosphorus level of soil following the 1985 growing season was adequate (14 ppm), but the relatively low response to treatment was due to differences in effectiveness of late-summer versus early spring treatment.

Conclusions

Our data showed that pistachio trees deficient in phosphorus, potassium, or both were very susceptible to Verticillium

TABLE 4. Influence of potassium treatments made in 1983 on Verticillium wilt and interaction of potassium treatments and phosphorus deficiency during 1984

Potassium treatments	Verticillium wilt: Infection	Verticillium wilt: Tree losses	Yield	Severe phosphorus deficiency
lb/tree	*%*	*No./row*	*lb/tree*	*% of trees*
2.2	12.7	22	29.0	47
3.0	8.3	17	25.5	65
6.6	7.5	12	23.1	69
LSD, P = 0.05	3.3	-	1.8	10

TABLE 5. Influence of phosphorus treatments on Verticillium wilt and yield of pistachio trees

Time of treatment	Planting 1 (No Verticicillium wilt): Nut	Planting 1 (No Verticicillium wilt): Yield	Planting 2: Verticillium wilt
	lbs/A	*No. nuts/lb.*	*%*
None	703	391	-
Aug 1984	961	327	12.8
Mar 1985	838	344	22.8
LSD, P = 0.05	155	22	3.7

wilt (13 to 37 percent infection) in soils that had low levels of the fungus (about 0.1 microsclerotium per gram of soil). We conclude that acute deficiency of any essential element may have the same effect, since neither phosphorus nor potassium had exclusive control of susceptibility.

Results of a greenhouse experiment with potassium offered possible explanations for changes in susceptibility observed in the field. There, death of lateral and fine roots was pronounced among deficient trees grown in pathogen-free soil. This could have two important effects: (1) encouraging germination of dormant microsclerotia in soil as nutrients from dead roots leak into soil and (2) providing unusual avenues of entry for the fungus.

We caution, however, that nutrition is of no practical significance where high levels of *Verticillium dahliae* occur in soil. For instance, we observed 75 percent infection of young, thrifty *Pistacia atlantica* trees during 1985 at the University of California West Side Field Station, where the fungal level was about 20 microsclerotia per gram of soil. Similarly, 85 percent of young, thrifty trees were killed during a six-year period where the *Verticillium* level was about 5 microsclerotia per gram of soil.

Our results are important to California pistachio growers for three reasons: First, they provide a basis for renovation of older pistachio plantings whether or not Verticillium wilt is present. Besides reducing Verticillium wilt, treatment improved yields. For example, 4,000 acres of trees, treated with potassium in 1983, yielded 79 percent more nuts in 1984 than in the previous high-yield year, 1982. Second, our results explain the occurrence of Verticillium wilt in areas such as eastern Madera County where, until recently, the disease was essentially absent, Third, they explain why unacceptable amounts of Verticillium wilt continued in some plantings after *V. dahliae* was reduced to low levels as a result of mulching with polyethylene tarps.

We believe the information from our tests in pistachios may also apply to olives, where discrepancies between levels of *V. dahliae* in soil and infection of mature olive trees were recognized 10 to 12 years ago. Despite low levels of the fungus in the soil of mature olive plantings tested, annual Verticillium wilt incidence varied from less than 1 percent to about 30 percent. Nutrition thus may also play an important role in the Verticillium wilt problem of olive, especially in Tulare, Kings, and Kern counties.

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Root-knot nematode resistance in processing tomatoes

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Cultivars with the* Mi *gene for resistance showed excellent tolerance of root-knot nematode injury

Root-knot nematodes can cause severe yield reductions in processing tomato crops. Infestations occur in all major growing regions of California, although nematode problems are generally found in fields or areas of a field with coarse-textured sand soils.

Management of root-knot nematodes (*Meloidogyne* spp.) in processing tomatoes has relied almost entirely on preplant soil-fumigation treatments with nematicides. Telone II (1,3-Dichloropropene), the primary fumigant nematicide currently in use, is a very effective nematode control agent.

Several machine-harvestable tomato cultivars with the *Mi* gene for resistance to root-knot nematodes have recently become commercially available. The *Mi* gene confers resistance to three common root-knot species — *Meloidogyne incognita, M. javanica* and *M. arenaria* — but not to a fourth — *M. hapla*. In addition, some populations of *M. incognita* and *M. javanica* have occasionally been reported to circumvent *Mi*-gene resistance, reproducing on and injuring otherwise resistant plants. These populations have been reported to occur both naturally, with no prior exposure to the *Mi* gene, and as a result of repeated selection on resistant plants in greenhouse experiments.

To evaluate the potential of resistant cultivars for root-knot nematode management, we conducted experiments in tomato fields infested with *M. incognita*. Our purpose was to determine in resistant cultivars (1) the tolerance to nematode injury as assessed by yield and (2) the ability to prevent nematode reproduction and thereby limit population density increases during the season. In greenhouse studies, we also tested selected lines and cultivars for resistance to a diverse collection of California isolates of *M. incognita* and *M. javanica* to determine the potential for broad-scale use of resistant cultivars in California.

Yield evaluations

During three seasons in 1982 to 1984, we evaluated selected advanced tomato lines and cultivars from various breeding programs on five field sites infested with *M. incognita*. Replicated blocks were split into randomly assigned preplant fumigated (with DD [1,3-Dichloropropene, 1,2-Dichloropropane] or Telone II) and nonfumigated treatments, and the lines and cultivars were randomized across each block.

In 1983, we compared five lines and cultivars with susceptible UC82. Four were resistant to root-knot and showed excellent tolerance to nematode infection, as indicated by the comparison of yield for each entry on nontreated and treated plots (fig. 1). The four resistant entries showed no significant yield differences between nontreated and treated plots, while susceptible UC82 and XPH5041 yielded 48 and 55 percent less, respectively, on nontreated than on treated plots.