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.

The yield of the different entries in treated plots (without nematodes) also varied, indicating inherent differences and maturity characteristics of tomato genotypes that are independent of the nematode resistance trait.

Results of the 1984 trial confirmed these findings of good tolerance to nematode infection in resistant tomatoes (fig. 1). Eight resistant entries showed no significant reduction in yield in nontreated compared with treated plots. Yields of susceptible UC82 and NS201 were significantly reduced by nematode infection; they were 56 and 55 percent less, respectively, in nontreated than in treated plots.

The yield suppressions of more than 50 percent in susceptible tomatoes in each year resulted from the presence of high *M. incognita* initial population densities of 79 second-stage juveniles and eggs per 250 cubic centimeters of soil in 1983 and 259 in 1984.

Yields varied widely among resistant and susceptible entries in treated plots, again revealing basic differences in yield and maturity traits of the tomato genotypes. For example, GS27 was the highest yielding resistant entry in both years.

Nematode reproduction

We also assessed root galling symptoms and populations of *M. incognita* second-stage juveniles and eggs in roots at harvest in the field trials (table 1). The soil fumigation treatments in both years prevented significant galling and reproduction in roots of susceptible tomatoes. In nontreated plots, however, susceptible UC82 and XPH5041 (1983) and UC82 and NS201 (1984) supported considerable nematode reproduction, as indicated by densities of 6,141 to 11,866 *M. incognita* eggs and second-stage juveniles per gram of fresh root at harvest. In comparison, roots of resistant tomato entries in both years supported only trace levels of reproduction in nontreated plots, with *M. incognita* densities ranging from 0 to 696 per gram of fresh root at harvest. It is important to note that, in our trials, no resistant tomatoes have shown immunity (no nematode reproduction on roots).

Galling symptoms (scale 0 to 4) are generally related to the nematode population densities in roots. Susceptible and resistant entries in treated plots and resistant entries in nontreated plots had little or no galling on roots (gall indices from 0 to 0.3). Susceptible entries in nontreated plots were severely galled (indices from 2.9 to 3.1).

Results from soil samplings at harvest (not shown) in these trials revealed a trend in *M. incognita* population densities in soil similar to the root sampling results. Soil populations were low following resistant tomatoes, soil fumigation treatments, or both, but high following susceptible tomatoes in nontreated plots.

Root-knot isolates

We inoculated 15 *M. incognita* and *M. javanica* isolates onto susceptible check tomato cultivar UC82 and selected root-knot-resistant advanced lines and cultivars in greenhouse pot experiments. Pots containing one-month-old seedlings were inoculated with a suspension of nematode eggs in water, and two months later, the nematode egg and second-stage juvenile numbers per gram of fresh root were counted. We summarized the data as relative resistance indices, expressing nematode reproduction in roots of a resistant tomato entry as a percentage of reproduction in the susceptible check (table 2).

Resistant tomatoes were all highly resistant to each of eight *M. incognita* isolates (resistant indices from 0.1 to 4.8), with the exception of two isolates on CX8202 (indices of 21.6 and 39.7) that represent moderate resistance. Some reproduction occurred in all entry-isolate combinations, indicating that no resistant tomato was immune to any *M. incognita* isolate.

The resistant tomatoes were moderately or highly resistant to the seven *M. javanica* isolates tested and, although no susceptible reactions occurred, the isolates varied in ability to reproduce on re-

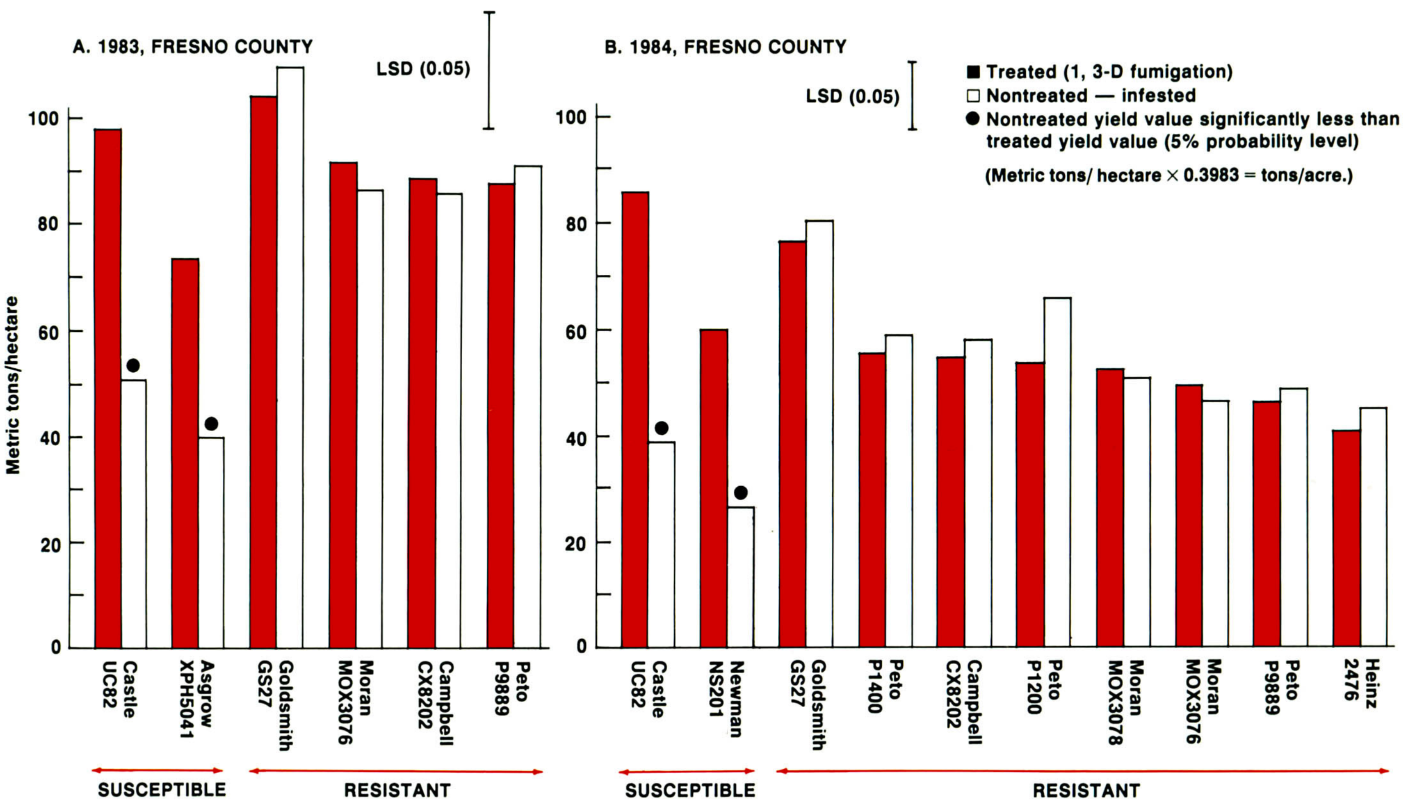

Fig. 1. Yields in two trials comparing resistant and susceptible tomatoes in treated (no nematodes) or nontreated (infested) plots. **Resistant tomatoes showed good tolerance of nematode infection, although some variation occurred among entries.**

TABLE 1. Root-knot nematode population densities in roots and root galling at harvest of processing tomatoes in nematicide-treated and nontreated plots, Fresno County, California, 1983-84

Entry	Reaction to nematodes†	*M. incognita* /gram root‡ Treated	*M. incognita* /gram root‡ Nontreated	Root gall index§ Treated	Root gall index§ Nontreated
1983					
Castle UC82	S	3	6,141*	0.1	3.1*
Asgrow XPH5041	S	1	8,259*	0	3.1*
Peto P9889	R	2	1	0	0.1
Moran MOX3076	R	0	3	0	0.3
Campbell CX8202	R	2	1	0	0.3
Goldsmith GS27	R	1	8	0	0.1
LSD (P = 0.05)		2,657		0.36	
1984					
Castle UC82	S	25	11,866*	0.2	3.0*
Newman NS201	S	93	11,541*	0.2	2.9*
Peto P9889	R	0	15	0	0.1
Peto P1200	R	0	3	0.1	0.1
Peto P1400	R	<1	13	0	0.1
Moran MOX3076	R	0	696	0.1	0.2
Moran MOX3078	R	0	0	0	0
Heinz 2476	R	<1	<1	0	<0.1
Campbell CX8202	R	0	140	0	0.2
Goldsmith GS27	R	<1	67	<0.1	0.1
LSD (P = 0.05)		1,777		0.23	

* The difference between values in nematicide and no-nematicide treatments for that entry is significant (P = 0.05).
† S = susceptible; R = resistant
‡ *Meloidogyne incognita* eggs and second-stage juveniles per gram of root.
§ Gall index, 0 to 4, where 0 = no galls, 4 = root system completely galled.

TABLE 2. Relative resistance of processing tomatoes to different isolates of root-knot nematodes in greenhouse tests

Entry	Reaction to nematodes	*M. incognita** Mean (8 isolates)	*M. incognita** Range	*M. javanica** Mean (5 isolates)	*M. javanica** Range	*M. javanica*‡ Isolate MJ-1	*M. javanica*‡ Isolate MJ-6
UC82	S	100.0	—	100.0	—	100.0 a	100.0 a
VFN8	R	0.7	0.1 - 1.5	0.2	0.1 - 0.4	7.2 c	8.6 c
GS27	R	1.1	0.3 - 2.2	0.4	0.2 - 0.8	24.2 b	15.1 bc
Hy9889	R	0.4	0.2 - 1.1	0.3	0.1 - 0.6	23.8 b	37.8 b
XPH671	R	0.6	0.2 - 1.3	0.2	0.1 - 0.3	5.3 c	12.3 bc
CX 8202	R	9.1	0.1 - 39.7	21.5	0.1 - 43.8	—	7.7 c
MOX3076	R	0.2	0.1 - 0.4	0.3	0.1 - 0.6	—	3.8 c
MOX3078	R	1.2	0.1 - 4.8	5.1	0.1 - 28.9	—	28.9 bc

NOTE: Relative resistance: Eggs and second-stage juveniles per gram of fresh root produced on a resistant line or cultivar expressed as a percentage of those produced on susceptible UC82.
* Values for *M incognita* and *M. javanica* are means and ranges for the given number of specific isolates. Relative resistance values of all isolates on all resistant tomatoes were significantly less (P = 0.05) than their values on susceptible UC82.
‡ Within a column, values followed by same letter are not significantly different (P = 0.05).

sistant tomatoes. The resistant tomatoes were all highly resistant to five *M. javanica* isolates (indices of 0.1 to 1.9) except for moderate resistance reactions on CX8202 and, with one isolate, on MOX3078. Isolates MJ-1 (from Orange County) and MJ-6 (from Tulare County), however, were each able to reproduce moderately on most resistant lines. Resistance values ranged from 5.3 to 24.2 for isolate MJ-1 on four resistant tomato lines and from 3.8 to 37.8 for isolate MJ-6 on seven resistant tomato lines. No reactions to *M. javanica* indicated tomato immunity.

Conclusions

In three years of field tests at different locations, processing tomato lines and cultivars with the *Mi* gene for resistance had excellent tolerance to root-knot nematode injury, even on sites where severe infestations caused more than a 50 percent reduction in yield of susceptible tomatoes. In fact, the ability of these resistant tomatoes to produce yields on infested ground is so promising that they can be grown safely without additional nematode management inputs such as nematicides. Omitting nematicides would offer cost savings that more than offset the expense of hybrid seed and would eliminate concern about the effect of soil conditions, weather problems, and timing of application and planting on fumigation results.

In our field and greenhouse tests, nematode reproduction was extremely low on resistant tomatoes, and final nematode population densities in soil were much smaller after resistant crops than after susceptible crops. Some variability, however, was apparent in nematode reproduction on resistant tomatoes. Reduced root-knot population densities following a resistant crop are more manageable; they may require less nematicide fumigation and may be more amenable to control with nonfumigant, organophosphate and carbamate nematicides. Furthermore, the selection of a following crop that has some tolerance to root-knot, such as cotton, may permit effective use of resistant tomatoes as a control tactic in annual rotations.

The root-knot isolates used in our greenhouse tests were a broad representation of populations from different growing regions of California. The highly resistant reactions in most combinations of root-knot isolate and tomato entry suggest that resistant cultivars should be generally useful for *M. incognita* and *M. javanica* control in the different tomato growing areas. Some test combinations showed moderate rather than high tomato resistance, especially to two *M. javanica* isolates. Since soil nematode populations would not be reduced as much in these situations, soil sampling after growing a resistant crop would be important in making subsequent management decisions.

No combination was fully susceptible in our greenhouse or field tests, although other researchers in California have reported *M. incognita* populations able to develop fully on resistant VFN8 tomato. Because of this possibility, it is advisable to try some test beds of resistant tomatoes on infested sites before making large-scale plantings. Tests would also pinpoint fields that contain *M. hapla*.

A consideration for effective long-term use of resistant tomato cultivars on infested fields is the avoidance of plantings to resistant tomatoes without rotation. Repeated plantings could encourage the selection of resistance-breaking root-knot populations, a phenomenon known to occur experimentally. Because root-knot resistance in tomato genotypes is conferred by the same gene, the substitution of one resistant cultivar for another may not be helpful.

The variation among resistant lines in yield potential, maturation, and fruit quality factors is a primary challenge for tomato breeders. As improved cultivars with resistance become available, resistant processing tomato cultivars will become a primary tool in managing root-knot nematode infestations. Their long-term, effective use will depend on their appropriate integration into planned rotations with selected nematicide treatments, for which nematode soil sampling programs will be an important component.

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