more than 22 percent mortality at any dose tested, including the extraordinary doses of 32, 64, 128, and 256 pounds formulated Cosan per 100 gallons water. Thus, resistance was extremely high in this R colony, but no accurate LC_{50} value could be estimated, because the R colony did not exhibit a linear response to sulfur. To our knowledge, an acquired resistance to sulfur never has been demonstrated in any other phytoseiid predator, or in any other biological control agent.

Both sets of F_1 progeny were quite resistant to sulfur (fig. 1A). The two types of F_1 progeny had different survival rates, as expected in a species with males that are parahaploid (adult males have only one functional set of chromosomes, which they inherit from their mothers; females have two sets). Thus, the F_1 progeny with R mothers had greater resistance than the F_1 progeny with S mothers. Their mortality was close to that exhibited by the R colony, especially in the dose range between ½ and 8 pounds. This response strongly suggests that sulfur resistance is determined by a dominant or semidominant gene. The increased mortality at the higher doses could indicate that additional, smaller (modifying) genes also contribute to the sulfur resistance. The high level of R in the reciprocal F_2 progeny (fig. 1B), and the reciprocal backcross progeny (fig. 1C) support the hypothesis that sulfur resistance is predominantly determined by a single dominant or semidominant gene in this R colony of *M. occidentalis*.

Benlate, Bayleton, and the experimental fungicide CGA-64251 were tested to determine if alternative fungicides could be used selectively in California vineyards, although Bayleton and CGA-64251 are not registered for use in vineyards. We also tested Mesurol, registered as a bird repellent, and Kryocide, used to control lepidopteran pests in vineyards.

Bayleton and CGA-64251 were not toxic to any *M. occidentalis* colonies tested (table 2). Thus, these materials, if registered for use in vineyards, could be used without substantially disrupting this predator's effectiveness.

Benlate was not toxic to adult females of any *M. occidentalis* colony tested, but it did permanently sterilize the females and they deposited few eggs. The Sevin-Guthion-resistant colony was apparently cross-resistant to Benlate, and females deposited eggs at a nearly normal rate. Immatures of the Sevin-Guthion strain developed to adulthood on Benlate-treated leaf discs, whereas no larvae of the Berkeley blackberry colony survived. Thus, Benlate could be used with less disruption of predator populations if the Sevin-Guthion predator strain were established in vineyards. However, the Sevin-Guthion colony showed no cross-resistance to Mesurol, although both Sevin and Mesurol are carbamates. Kryocide was not toxic to any colonies of *M. occidentalis* tested and thus could be useful as a selective insecticide in integrated pest management (IPM) programs.

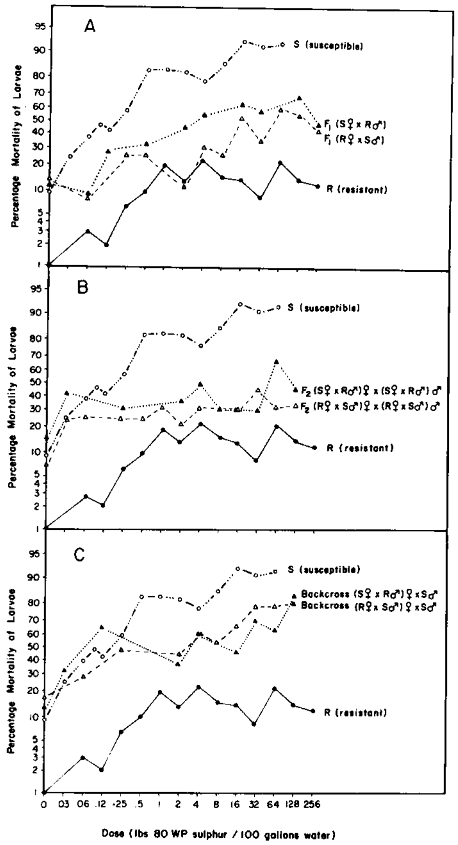

Fig. 1. Concentration response curves on logit paper of larvae of sulfur-susceptible (S) and resistant (R) *M. occidentalis* and their reciprocal: (A) F_1 progeny; (B) F_2 progeny; and (C) backcross progeny.

The responses of *M. occidentalis* to genetic selection for pesticide resistance are impressive. Different populations of this predator have responded to selection in the field, becoming resistant to organophosphorus insecticides, such as Cygon, Guthion, and diazinon, and to sulfur. In addition, laboratory selection has been successful using two different groups of insecticides: a carbamate (Sevin) and a pyrethroid (permethrin or Ambush/Pounce). This wide array of resistance is unique in a biological control agent and offers promise for increasing the effectiveness of this predator in IPM programs in California's deciduous orchards and vineyards.

Marjorie A. Hoy is Associate Professor and Associate Entomologist, and Kathlyn A. Standow is a student, University of California, Berkeley. *Appreciation is expressed to Mary Ann Sall, Department of Plant Pathology, University of California, Davis, for her advice and for providing materials for testing. This project was supported by the Raisin Advisory Board, California Table Grape Commission, California Experiment Station Project No. 3522-H, and the State IPM Project. We thank R.T. Roush and N.F. Knop for their assistance.*

Until 1977 DBCP (1,2-dibromo-3-chloropropane) was widely used as an effective, economical nematicide on many crops including established vineyards. The chemical was especially suited for treatment of grapes, because it was easy to apply as a liquid formulation by chisel applicators or as an emulsifiable formulation in irrigation water; low in phytotoxicity; active as a fumigant, able to spread through the soil profile; highly nematicidal; persistent for long periods in the soil.

Unfortunately the chemical was found to have carcinogenic/mutagenic properties hazardous to public health, and its use has been suspended. Since no other chemical has even approached the capability of DBCP, the grape industry has been left without a replacement or alternative.

Although no nematicides are registered for use on growing vines, a number of nonfumigant materials have been used experimentally by University of California researchers for several years. In 1976 aldicarb (Temik) was applied to Cardinal vines near Lodi, California. Improvements in growth and yields were encouraging, and the trial was continued in 1977 with retreatment of half the vines in each replicate. Phenamiphos (Nemacur) was added to the test program, and several new plots also were established. In 1978 carbofuran (Furadan), ethoprop (Mocap), and Nemamort also were included.

These nonfumigant materials are carbamates or organophosphates, which act systemically to varying degrees. They are generally formulated as granular preparations containing 10 to 15 percent of the active ingredients; some are available also as emulsifiable or water-soluble formulations. The chemicals are low in phytotoxicity and can be applied to established, living plants. However, because of their low volatility, they move through the soil slowly or not at all. To reach nematodes, the chemicals must be mechanically mixed into the soil or carried through the soil profile dissolved in irrigation water.

These nematicides kill target nematodes in the soil by contact action and, in some cases, by systemic action when nematodes feed on root tissues near the point of toxicant absorption.

Carbamates and organophosphates kill insects by inhibiting activity of acetylcholinesterase and cholinesterase, which are involved in synapsis. The inhibition results in abnormal transmissions of impulses through the nervous system. Evidence of cholinesterase-

Dewey J. Raski □ Norman O. Jones □ Saad L. Hafez □ James J. Kissler □ Donald A. Luvisi

Systemic nematicides tested as alternatives to DBCP

like activity has been reported on different species of nematodes.

Some reports have shown that direct contact of nematodes by some carbamates and organophosphate insecticides or nematicides, or their metabolites, in soil or plants can influence behavioral responses and development. Phenamiphos inhibited hatching of *Meloidogyne arenaria* eggs and penetration of field bean roots by *Ditylenchus dipsaci.* Exposure to carbofuran disrupted *Pratylenchus penetrans* orientation to tomato roots and *Tylenchorhynchus claytoni* penetration of corn seedling roots. Reproduction and development of *Aphelenchoides rutgersi* were inhibited by phenamiphos and carbofuran, and similar effects were demonstrated on carbofuran-treated *Acrobeloides nanus.*

Aldicarb, carbofuran, and phenamiphos are degraded in all biological systems to relatively nontoxic end-products that do not accumulate in the environment. The length of time that these compounds remain effective in soil depends on a number of interrelated conditions, including soil moisture, temperature, planting schedule, cultural practices, and application rates. The half-life of aldicarb in soil ranges from 7 to 28 days; that of phenamiphos is 3 to 6 weeks, and of carbofuran about 60 days. All these systemic nematicides have a high mammalian toxicity, are hazardous to humans and domestic animals and must be used with extreme caution.

Experimental applications

Eleven trials were set out: Two near Lodi were infested with *Xiphinema index,* and the other nine predominantly infested with root-knot nematodes, either *Meloidogyne incognita* or *M. javanica.* Five grape varieties were included: Tokay, Mission, Alicante, Cardinal, and Muscat of Canelli. Granular chemicals were sprinkled by hand over the designated area and raked into a thin layer of topsoil. Water sufficient for penetration to about 3 to 4 feet was applied as soon as possible by furrow or basin.

Water-soluble or emulsifiable forms were mixed in a 2-gallon watering can or in a small portable sprayer and then distributed as evenly as possible over the designated area. Irrigation followed.

Each replicate comprised either 50 or 100 percent of the area occupied by a single vine. Applications were made in furrows (single or double furrows on each side of the vine) or bands. In one trial, cross-furrows about 18 inches from each vine were treated in addition to the double furrows. In band treatments, materials were applied evenly over the entire area of the bands.

The most effective and economical dosages have not yet been established, but experiments have set some fairly reliable guidelines within which applications for registration probably will be made. In general the active ingredient ranges between 4 and 20 pounds per acre.

In these trials, applications have been primarily in spring as soon as possible after winter rains end and the soil dries enough to permit preparation—normally late March. Conditions in 1976 and 1977 allowed treatments as early as the first part of February, but 1979 and 1980 trials could not begin until the first week of April. Postharvest treatments were tried once in late November-early December, but were made difficult by the unpredictability of rains, presence of cane growth, and complications with other harvest operations. When winter treatments were compared with spring applications, no substantial differences were found.

Accumulation of toxic residues in mature fruit can also affect application time: Aldicarb treatments at 4 pounds active ingredient per acre must be completed 120 days before harvest to avoid such residues.

Single applications were made in most treatments, but a number were made with two or three repetitions of lower rates, usually totaling the same as single rates.

Samples were collected before treatment and at approximately 30, 60, 90, 120 and/or 270 days after treatment. Root-knot nematode survival was measured by larval counts from soil washings, host-plant evaluations by tomato root indices, or by gall counts on host indicator plants. Counts of *Xiphinema index* were made from washings of 250 cc soil. Tables 1 and 2 present representative counts from two trials.

In every instance weights of fruit from individual vines were recorded. Average weights from each replicate in tables 3 and 4 are representative of the more successful increases in yields due to treatments. Results varied: Many other tests showed smaller increases, and other tests showed yields in treated vines similar to and no greater than those in untreated vines. Observations were made for three years wherever possible.

Discussion

In vineyards great variability in growth and nematode distribution from vine to vine is typical, making it difficult to get consistent results in small plots. Nevertheless, some trends seem to emerge.

Reductions of nematode populations were noted 30 days after treatment and lasted 150 to 200 days before building up again. Small numbers of nematodes survived even the best treatments.

Improvements in vine growth and yields were evident in some trials but not in others. In the Cardinal trial vine growth improved the first year of treatment. Even greater vigor resulted from treatment of Mission and Alicante plots, but not until the third year after treatment. In other trials effects on vine growth were not outstanding at any time.

Statistically significant yield increases occurred in 20 percent of the tests but generally were not obtained the first year after treatment. More often, significant increases were found the second and third years. In another 65 percent of the aldicarb and phenamiphos treatments, average yields characteristically were higher in treated vines but not sufficiently high to be statistically significant. In the remaining 15 percent, yields from treated vines were the same as from untreated checks.

Phenamiphos gave best results at 20 pounds active ingredient per acre but is being further evaluated at that rate and at 6 and 9 pounds in each of three applications, 60 days apart. The optimum aldicarb dosage is 4 pounds, although 6 pounds is being given further attention. Carbofuran at 10 pounds and ethoprop

TABLE 1. Control of *Meloidogyne javanica* on Tokay Grape Following Sidedressing with Aldicarb

Treatments (March 1978)	Before treatment		Control at time of sampling on following days after treatment									
			30		60		90		120		270	
	L	RGI	L	RGI	L	RGI	L	RGI	L	RGI	L	RGI
Aldicarb 15 G, 8 lb ai/acre	812	4.00	6	0.30	4	0.20	0	0.50	7	0.60	810	0.60
Aldicarb 15 G, 4 lb ai/acre	615	4.25	32	0.30	132	1.00	32	2.00	38	2.50	1,184	4.20
Untreated control	575	3.60	1,405	4.60	367	5.00	390	4.25	132	4.00	2,740	4.60

NOTE: Treatments rated by number of second-stage larvae (L) in the soil and root-gall index (RGI) on tomato test plants. RGI based on 0 to 5 rating (5 heavily galled).

at 20 to 40 pounds are the most likely economical and effective dosages for those chemicals. Further tests are under way with all these materials.

Analyses of fruit for toxic residues show no accumulations of phenamiphos or its breakdown products at any of the dosages under consideration (18 to 20 pounds active ingredient per acre). Fruit treated with aldicarb at 4 pounds indicate that residues will not exceed 0.4 ppm, and are often below the detectable level, if treatments are completed 120 days or more before harvest.

Prospects

Many hurdles remain before any of these chemicals may be registered and available for commercial use. At least three are being advanced for larger scale testing, and applications are being, or have been, prepared for submission to the U.S. Environmental Protection Agency for an Emergency Use Permit or an Emergency Exemption Status. Furadan 10 G was granted Emergency Exemption Status for 1981, effective up to February 28. This establishes temporary tolerances so that larger tests of up to 10 acres could be made without the high cost of destroying the fruit from treated vines.

Larger scale testing under commercial conditions is needed to confirm our results from test applications by hand, which are more precise than might be possible by machine.

Similar and continued favorable results of increased vigor and yields together with unequivocal data proving that residues are not a complicating problem should enable registration and availability to the industry of one or more of these materials.

Dewey J. Raski is Nematologist, and Norman O. Jones is Staff Research Associate IV, Division of Nematology, University of California, Davis; Saad L. Hafez was Research Assistant, Division of Nematology, U.C. Davis (now Post Graduate Research Nematologist, University of Kansas, Manhattan); and James J. Kissler and Donald A. Luvisi are Farm Advisors, U.C. Cooperative Extension, San Joaquin County and Kern County, respectively.

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TABLE 2. *Xiphinema index* Populations after Treatment of Tokay Grape by Sidedressing with Nonfumigant Nematicides

Treatment			*X. index*/250 cc soil on following days after treatment	
Chemical	Rate and date	Area treated	37	146
	lb ai/acre	%		
CARBAMATES				
Aldicarb 15 G	8 lb, Feb 1978	50	13.2**	4.6**
Carbofuran 10 G	10 lb, Feb 1978	50	16.4**	2.4**
Carbofuran 10 G	10 lb, Feb 1978	100	12.6**	1.6**
ORGANOPHOSPHATES				
Phenamiphos 15 G	20 lb, Feb. 1978	50	22.6*	24.8*
Phenamiphos 15 G	20 lb, Feb 1978	100	14.0**	21.0*
Phenamiphos 15 G	10 lb each, Feb & May 1978	50	23.0*	19.5*
Phenamiphos 3 EC	20 lb, Feb 1978	50	14.0**	5.4**
Phenamiphos 3 EC	5 lb each, Feb, Mar, May 1978	50	19.4**	13.6**
Ethoprop 10 G	10 lb, Feb 1978	100	21.0*	47.8
Ethoprop EC	10 lb, Feb 1978	100	31.0	59.6
Untreated control	—	—	40.2	42.6

NOTE: Average *X. index* population in pretreatment sampling was 40.4 for all treatments.
*Differences statistically significant at 5% level.
**Differences statistically significant at 1% level.

TABLE 3. Average Yields of Tokay Grapes per Vine Treated with Phenamiphos†

Block	Check	Treatment 1		Treatment 2		Treatment 3		Treatment 4	
		a	b	a	b	a	b	a	b
	lb	lb	lb	lb	lb	lb	lb	lb	lb
1	17.38	54.50	35.50	53.38	36.50	47.00	42.63	39.13	34.00
2	20.63	23.75	30.75	33.50	38.75	59.13	39.50	32.75	35.63
3	28.57	30.00	15.75	35.13	41.88	52.50	49.25	52.13	39.63
4	31.44	40.25	37.63	44.88	51.17	41.88	31.50	33.33	49.75.
5	29.63	53.75	42.88	54.75	43.50	44.50	35.88	43.38	42.25
Average	25.52	40.45*	26.00	44.33**	42.36**	49.00**	39.75*	40.14*	40.25*

*Differences statistically significant at 5% level.
**Differences statistically significant at 1% level.

†Treatment	Year	lb ai/acre	Treatment	Year	lb ai/acre
1a	1979	4 + 4 + 4	3a	1979	10 + 10 + 10
	1980	6 + 6 + 6		1980	18
1b	1979	4 + 4 + 4	3b	1979	10 + 10 + 10
	1980	None		1980	None
2a	1979	8 + 8 + 8	4a	1979	40
	1980	9 + 9		1980	40
2b	1979	8 + 8 + 8	4b	1979	40
	1980	None		1980	None

TABLE 4. Average Yields of Tokay Grapes per Vine Treated with Aldicarb

Block	Check	Treatment 50% coverage†					
		4 lb ai/acre		8 lb ai/acre		5 + 3 lb ai/acre	
		1 yr	2yr	1 yr	2 yr	1 yr	2 yr
	lb	lb	lb	lb	lb	lb	lb
1	49.88	30.25	19.83	33.63	21.83	57.00	45.75
2	30.94	47.63	52.63	56.88	63.00	60.63	64.38
3	36.38	66.25	63.75	54.63	56.00	73.25	71.63
4	57.07	53.13	61.13	69.88	70.63	51.25	52.00
5	44.88	52.75	56.13	56.75	68.13	58.75	57.00
Average	43.83	50.00	50.69	54.35	55.92	60.18*	58.15*

†1 yr = treated in 1979 only; 2 yr = treated in 1979 and 1980.
*Differences statistically significant at 5% level.