S. T. Nameth, J. A. Dodds, and A. O. Paulus
University of California, Riverside

F. F. Laemmlen
El Centro, CA

Cucurbit Viruses of California

Commercial production of melons (*Cucumis melo* L.), squash (*Cucurbita pepo* L.), watermelons (*Citrullus lanatus* (Thunb.) Matsum & Nakai), and cucumbers (*Cucumis sativus* L.) is one of the large agricultural activities in California. Cucurbits are grown in several areas of the state, with melons (cantaloupes, Crenshaw, and casaba) and watermelon accounting for approximately 85% of the total acres harvested and squash and cucumbers accounting for approximately 8 and 6%, respectively.

Virus-related disease problems are a major cause of economic losses in commercial cucurbit production in all parts of the state. Crops in the southern desert and southern coastal regions are most severely affected. At least seven plant viruses are known to cause significant economic damage to cucurbits in California (Table 1): watermelon mosaic virus-1 (WMV-1), watermelon mosaic virus-2 (WMV-2), zucchini yellow mosaic virus (ZYMV), cucumber mosaic virus (CMV), squash mosaic virus (SqMV), squash leaf curl virus (SLCV), and lettuce infectious yellows virus (LIYV). These viruses are continually associated with commercial cucurbit production throughout the state, with specific viruses being more frequent and causing more disease in certain areas. Four of these viruses—WMV-1, WMV-2, CMV, and SqMV—have been reported on cucurbits in the state for the past 20–30 years; the others—SLCV, LIYV, and ZYMV—are relatively new. Recent reports from Florida, New York, and elsewhere suggest that changes in the California cucurbit virus situation reflect events elsewhere in the United States.

The Early Viruses

One of the earliest comprehensive works on virus diseases of cucurbits in California, published in 1959 (6), reported that watermelon mosaic virus (WMV), CMV, and SqMV were the most common. In the southern desert valleys, strains of WMV were most prevalent, CMV was intermediate in prevalence, and SqMV was rare. In northern and central California, CMV and SqMV predominated and WMV was of lesser importance.

A report published 10 years later again described WMV, CMV, and SqMV as the important viruses infecting cucurbits in California (12), with WMV predominating. By this time, WMV was considered to be two distinct viruses, WMV-1 and WMV-2 (18), with WMV-2 more prevalent than WMV-1. CMV and SqMV occurred to a lesser extent than either WMV-1 or WMV-2.

During the next decade, many changes in the methods used to identify plant viruses opened the door for a more complete account of cucurbit viruses in California. New reports confirmed earlier findings (18) that the two previously reported strains of WMV were indeed two serologically distinct viruses of the same group, now known as potyviruses (15). This work, along with the development and refinement of the enzyme-linked immunosorbent assay (ELISA) for use in plant virus identification, set the stage for a comprehensive account of the cucurbit virus situation in California, particularly in the southern desert regions.

During the spring of 1981, ELISA was used to survey 10 cantaloupe fields in the Imperial Valley of California (2). The fields were selected prior to or at the time of planting, before any virus symptoms were present, thus avoiding a natural tendency to sample in fields with plants showing strong mosaic symptoms like those caused by WMV-1, SqMV, and CMV. One thousand samples were analyzed for the presence of WMV-1, WMV-2, SqMV, and CMV. Of the samples collected from plants showing mosaic symptoms, 98% reacted positively for the presence of WMV-2 and 2% reacted positively for SqMV; WMV-1 and CMV were not found.

The survey confirmed previous conclusions that the most important virus associated with mosaic diseases of cucurbits was WMV-2, at least in the southern California desert areas, and that a small percentage of samples were infected with SqMV (probably attributable to seed transmission). Why WMV-1 and CMV were absent is not known, since both were reported in the two previous surveys (6,12) and their aphid vectors abound in the areas surveyed. The survey confirmed an apparent stability in the cucurbit virus situation in California that had persisted for 10–15 years. But no sooner was the survey completed than three previously undescribed cucurbit viruses were found.

The New Viruses

The somewhat stable situation described held true until 1977. That summer, a new disease of squash and other cucurbits called squash leaf curl was reported to be causing severe damage to commercial squash plantings, particularly in the southern desert valleys (5). (In the fall of 1981, squash leaf curl became a severe economic problem to melons, lettuce, and cucumbers as well as to squash and drew national attention to desert vegetable production.) That fall, the sweet potato whitefly (*Bemisia tabaci* Genn.) reached extremely high populations in the Imperial Valley of California and in other desert growing areas of the southwestern United States. Both squash leaf curl (Fig. 1A and B) and lettuce infectious yellows (Fig. 1C and D), another new disease of melon (cantaloupe, honeydew, and casaba), caused severe economic damage to the southern California cucurbit industry (4).

Squash leaf curl and lettuce infectious yellows were later shown to be caused by new viruses. Squash leaf curl, vectored by the sweet potato whitefly, was the first reported disease caused by a whitefly-transmitted geminivirus in the United States (1,3). The virus causing lettuce infectious yellows is also vectored by the sweet potato whitefly but is a long flexuous rod with morphological characteristics resembling virus particles of the closterovirus group of plant viruses (4). Both viruses were responsible for millions of dollars worth of damage to cucurbit production in 1981.

In the spring of 1982, another virus disease of cucurbits new to California was identified. This disease, not associated with a whitefly, caused a severe mosaic on squash, melon, and other cucurbits and under severe conditions caused deforma-

An Ever-Changing Problem

tion and cracking of infected fruit (Fig. 2). The cause was later identified as zucchini yellow mosaic virus, first reported and described in Italy and France in 1981 (10). The virus is an aphid-transmitted long flexuous rod with morphological characteristics and other properties that place it into the potyvirus group of plant viruses—the same group to which WMV-1 and WMV-2 belong. Mosaic symptoms caused by ZYMV on melons are much more severe than those caused by WMV-1 or WMV-2 (Fig. 3). Specific antisera can be made against ZYMV that do not react with either WMV-1 or WMV-2. The biology of ZYMV on selected host plants is similar to, but distinct from, that of both WMV-1 and WMV-2 (Table 2).

The California isolate of ZYMV caused severe damage to the southern California desert melon and squash crops during the spring and summer of 1984 (14). In that year, about 40% of the samples collected with mosaic symptoms tested positive for the presence of ZYMV—about a 30% increase in virus incidence over the previous 2 years. In addition, WMV-1 was found to be associated with mosaic disease of cucurbits for the first time in at least 5 years, and the incidence of WMV-2 was still very high (85%).

All three new viruses—SLCV, LIYV, and ZYMV—have been consistently associated with virus disease problems in southern California desert cucurbit production since they were first identified. In a typical growing season, ZYMV, WMV-1, WMV-2, and SqMV cause mosaic diseases of cucurbits in the spring and SLCV and LIYV cause problems in the fall.

Control Techniques

Over the past 20 years, many attempts have been made to control or manage cucurbit virus diseases in California. Most methods have been targeted at the aphid-borne or mosaic-type viruses WMV-1, WMV-2, CMV, and SqMV. The more recently identified whitefly-transmitted viruses, SLCV and LIYV, which are common in tropical and subtropical parts of the world, probably can be managed with some of the same techniques, and such tests are in progress.

Reflective mulches and oil sprays. Because the aphid-borne viruses (WMV-1, WMV-2, CMV, and ZYMV) are transmitted in a stylet-borne, nonpersistent manner, controlling disease by controlling the vectors is difficult if not impossible. The use of insecticides is not feasible because of the frequency of applications needed for adequate control. Two of the most common methods used to protect cucurbits from aphids have been reflective mulches and oil sprays.

The theory behind reflective mulch is that the insect becomes confused and disoriented above the mulch and keeps flying instead of landing on the plant to feed. Aluminum foil mulch reduced aphid numbers by as much as 96%, coinciding with reductions in virus incidence of 85–90% (17). Oil sprays also reduce aphid populations. Since it was first shown that a thin layer of paraffin oil sprayed on plants impeded aphid transmission of potato virus Y, experiments have been done to determine the effect spraying cucurbits with oil has on common aphid-transmitted viruses such as WMV-1 and WMV-2. Application of oil twice a week to summer squash reduced aphid populations by 17–33%, resulting in a 23–26% reduction in WMV-2 incidence over an entire season (17).

Although these methods produce good to excellent results in controlling aphids and virus spread, both have major drawbacks that have prevented their widespread adoption in California. Reflective mulch is expensive, slows the initial growth of seedlings, loses reflective qualities as plants grow larger, and must be disposed of at the end of the season. The method could be considered more

Table 1. Major curcurbit viruses in California

Virus	Year[a]	Group	Distribution in state	Vector	Hosts
Watermelon mosaic-1, watermelon mosaic-2	1959	Potyvirus	Cultivated southern desert areas, south coast, San Joaquin Valley	Aphid	All commercially grown cucurbit crops
Zucchini yellow mosaic	1983	Potyvirus	Cultivated southern desert areas, southern and central coastal areas	Aphid	All commercially grown cucurbit crops
Cucumber mosaic	1942	Cucumovirus	Throughout; predominates in Sacramento Valley and central coast	Aphid	All commercially grown cucurbit crops but not important on watermelon
Squash mosaic	1949	Comovirus	Throughout; common in Sacramento Valley	Seed and beetle	All commercially grown cucurbit crops except watermelon
Squash leaf curl[b]	1981	Geminivirus	Cultivated southern desert areas	Whitefly	All squash and watermelon; less severe on cantaloupe, mixed melon, and cucumber
Lettuce infectious yellows	1982	Closterovirus(?)	Cultivated southern desert areas	Whitefly	All cantaloupe, cucumber, squash, and mixed melon

[a] When first identified on cucurbits in California.
[b] May be divided into two strains (SLCV and SLCV-2), depending on host range.

seriously if disposal methods were improved or if mulches were biodegradable or photodegradable. In Florida, where all commercial cucurbit production is done under plastic or aluminum mulches, the mulches are burned at the end of the season. Strict antipollution laws prohibit disposal by burning in most areas of California, however. Strawberry growers in southern California rely heavily on plastic mulch and must bury it at the end of the season. Burial sites are beginning to fill or are unavailable, so this method of disposal is rapidly becoming inadequate.

One disadvantage of oil sprays is the frequency of application needed to maintain complete coverage of the target plant surfaces, particularly the young growing tips. Also, formulation, application pressure, and spray nozzle size must be exact, and plant injury from use of oil under the high temperatures of the southwest deserts is a potential problem.

Both methods may show more promise when used in combination and with other techniques.

Cultural practices. Practices such as weed control that remove primary sources of the virus and overwintering hosts for the insect vectors need to be studied in greater detail. Weed hosts have been shown to be important sources of inoculum for such cucurbit viruses as WMV-1, WMV-2, CMV, and SqMV. Recent attempts in France to manage aphid-borne CMV in muskmelon were successful when weed control in and around the edges of fields was combined with mulching. In some instances, virus incidence was lower in weeded, mulched fields of CMV-susceptible muskmelons than in nonweeded, nonmulched fields of CMV-resistant varieties (8). Weed control was a critical part of this disease management program.

A cucurbit-free period could also be explored as a means of controlling those viruses that primarily infect cultivated cucurbits instead of weeds. This would be difficult in the southern California desert valleys, however, where some type of cucurbit is under cultivation throughout the year.

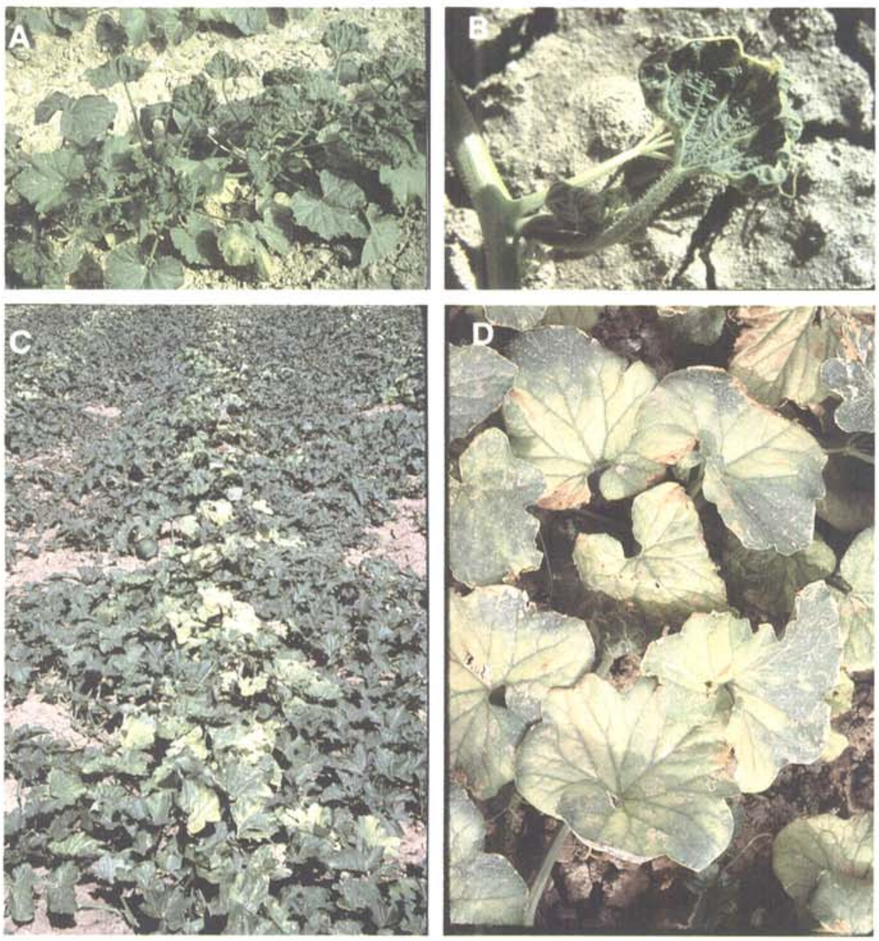

Fig. 1. Leaf symptoms on (A and B) squash infected with squash leaf curl virus and (C and D) Crenshaw melon infected with lettuce infectious yellows virus.

Resistant varieties. The most commonly grown cantaloupe varieties in California, Topmark and PMR 45, show no substantial resistance to any specific virus. Topmark shows some tolerance to WMV-1 and WMV-2, however, enabling production of commercially acceptable quality and yield. For the better known viruses such as WMV-1 and CMV, reasonable efforts have been made to develop resistant or tolerant varieties of cucurbits. Cinco, resistant to WMV-1, is available but is not adapted to or horticulturally acceptable in California (16). In some cases, resistance or tolerance has been found or developed against the aphid vector as well as the virus. Melon varieties AR-Hale's Best Jumbo, AR-5, and AR-Topmark show a high degree of resistance to the melon aphid (*Aphis gossypii* Glover), a secondary vector of WMV-1, WMV-2, and ZYMV (11). This resistance is so effective that the aphid population needed to achieve 50% infection of Hale's Best Jumbo had to be increased 12-fold to achieve 50% infection of AR-Hale's Best Jumbo (A. N. Kishaba, *personal communication*).

Recent work involving *Cucumis melo* breeding line 91213 showed that plants infected with WMV-2 had a lower virus titer than other varieties of *C. melo* such as Hale's Best Jumbo and Topmark (13). Virus titer was quantified using ELISA and a local lesion assay. Because of the lower titer, virus was less likely to be vectored from plant to plant by aphids and virus spread was decreased; this decrease was maintained under field conditions. Similarly, resistance found in *C. melo* breeding line PI 161375 (SC) suppressed the transmission efficiency of CMV by the green peach aphid (*Myzus persicae* Sulz.) and the melon aphid (7).

Fig. 2. (A) Leaf symptoms on Crenshaw melon infected with zucchini yellow mosaic virus and watermelon mosaic virus-2. (B) Fruit symptoms on Crenshaw melon infected with zucchini yellow mosaic virus.

Very little genetic material resistant to WMV-2 and the newer cucurbit viruses such as ZYMV and SLCV is available. Fortunately, plant breeders throughout the world are actively seeking good sources of genetic resistance to these viruses. Resistance and tolerance to

Table 2. Symptom reaction of selected host plants[a] to mechanical inoculation with California strain of zucchini yellow mosaic virus (ZYMV-Ca), watermelon mosaic virus-1 (WMV-1), and watermelon mosaic virus-2 (WMV-2)

Host	Reaction[b]		
	ZYMV-Ca	WMV-1	WMV-2
Luffa acutangula	SM	SM	NR
Phaseolus vulgaris cv. Black Turtle 2	NR	NR	SM
Chenopodium amaranticolor	LL	NR	LL
Cucumis melo cv. Topmark	SM	SM	SM
Cucurbita pepo cv. Early Prolific	SM	SM	SM

[a] Normally used to distinguish between WMV-1 and WMV-2.
[b] SM = systemic mosaic and ELISA-positive; NR = no local or systemic reaction and ELISA-negative; LL = local lesion and ELISA-positive.

ZYMV have been identified in some varieties of watermelon, muskmelon, cucumber, and squash. Resistance in muskmelon PI 414723 is controlled by the single dominant gene *Zym*. Long-term usefulness of this gene for California is doubtful, however, because isolates of ZYMV from France, Israel, Italy, and Spain inoculated into PI 414723 have caused systemic chlorotic spotting and/or yellowing, stunting, mosaic, and leaf deformation (9).

Resistance to SLCV has not been reported, but a high level of tolerance has been observed in *Cucurbita moschata* 'Mediterranean,' which is grown on a relatively small acreage in Imperial Valley and in Mexicali Valley, Mexico. Apparently comparable levels of tolerance have been found in three related wild species: *C. ecuadorensis*, *C. lundelliana*, and *C. martinezii* (J. D. McCreight, *personal communication*). Development of resistant cultivars of *C. maxima*, *C. mixta*, and *C. pepo* will be slow because of incompatibility barriers among these related species.

The Dynamics of the Problem

The cucurbit virus situation in California is constantly changing and fluctuating, and new destructive viruses have been identified in recent years. The task of managing or controlling these viruses is critical to cucurbit production. Such management techniques as reflective mulches and oil sprays show promise but at present may not be economically or environmentally sound. Such cultural practices as weed control and altered planting dates work well against a particular virus in a particular area but not against all viruses in all situations. The major weed reservoirs for SLCV, LIYV, and ZYMV have not been identified, and information is insufficient for planning management experiments. Even for the more established cucurbit viruses, such as WMV-1, WMV-2, and CMV, weed reservoirs and overwintering sources of the virus have been hard to identify. The new, more sensitive diagnostic techniques such as ELISA and dot-spot hybridization may help locate the alternate hosts of these viruses.

Fig. 3. Leaf symptoms on cantaloupe caused by (left) watermelon mosaic virus-2, (center) zucchini yellow mosaic virus, and (right) watermelon mosaic virus-1.

A more intense breeding program for resistance in cucurbits is needed, particularly resistance to such destructive viruses as ZYMV and SLCV. ZYMV is probably the greatest single threat to the cucurbit industry in California. Sources of resistance to this virus found recently in melon have already broken down under pressure from new, more virulent strains (H. Lecoq, *personal communication*).

The dynamics of the cucurbit virus situation in California today make it clear that management of virus diseases cannot rely on a single method and that complete control will not be possible. An integrated program employing any or all combinations of available methods should be explored. Use of resistant or tolerant lines plus such cultural practices as altered planting dates and weed control offers some hope for virus suppression. The body of knowledge concerning virus reservoirs must be expanded if sound cultural practices are to be developed.

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Literature Cited

1. Cohen, S., Duffus, J. E., Larsen, R. C., Liu, H. Y., and Flock, R. A. 1983. Purification, serology, and vector relationships of squash leaf curl virus, a whitefly-transmitted geminivirus. Phytopathology 73:1669-1673.
2. Dodds, J. A., Lee, J. G., Nameth, S. T., and Laemmlen, F. F. 1984. Aphid- and whitefly-transmitted cucurbit viruses in Imperial County, California. Phytopathology 74:221-225.
3. Dodds, J. A., Nameth, S. T., Lee, J. G., and Laemmlen, F. F. 1982. Aphid and whitefly transmitted cucurbit viruses in Imperial County, California. (Abstr.) Phytopathology 72:963.
4. Duffus, J. E., and Flock, R. A. 1982. Whitefly-transmitted disease complex of the desert southwest. Calif. Agric. 36:4-6.
5. Flock, R. A., and Mayhew, D. E. 1981. Squash leaf curl, a new disease of cucurbits in California. Plant Dis. 65:75-76.
6. Grogan, R. G., Hall, D. H., and Kimble, K. A. 1959. Cucurbit mosaic viruses in California. Phytopathology 49:366-376.
7. Lecoq, H., Cohen, S., Pitrat, M., and Labonne, G. 1979. Resistance to cucumber mosaic virus transmission by aphids in *Cucumis melo*. Phytopathology 69: 1223-1225.
8. Lecoq, H., and Pitrat, M. 1983. Field experiments on the integrated control of aphid-borne viruses in muskmelon. Pages 169-176 in: Plant Virus Epidemiology. R. T. Plumb and J. M. Thresh, eds. Blackwell Scientific Publications, Oxford, England.
9. Lecoq, H., and Pitrat, M. 1984. Strains of zucchini yellow mosaic virus in muskmelon (*Cucumis melo* L.). Phytopathol. Z. 111:165-173.
10. Lisa, V., Boccardo, G., D'Agostino, G., Dellavalle, G., and d'Aguillo, M. 1981. Characterization of a potyvirus that causes zucchini yellow mosaic. Phytopathology 71:667-672.
11. McCreight, J. D., Kishaba, A. N., and Bohn, G. W. 1984. AR Hale's Best Jumbo, AR 5, and AR Topmark: Melon aphid-resistant muskmelon breeding lines. HortScience 19:309-310.
12. Milne, K. S., Grogan, R. G., and Kimble, K. A. 1969. Identification of viruses infecting cucurbits in California. Phytopathology 59:819-828.
13. Moyer, J. W., Kennedy, G. G., and Romanow, L. R. 1985. Resistance to watermelon mosaic virus II multiplication in *Cucumis melo*. Phytopathology 75:201-205.
14. Nameth, S. T., Dodds, J. A., Paulus, A. O., and Kishaba, A. 1985. Zucchini yellow mosaic virus associated with severe diseases of melon and watermelon in southern California desert valleys. Plant Dis. 69:785-788.
15. Purcifull, D. E., and Hiebert, E. 1979. Serological distinction of watermelon mosaic virus isolates. Phytopathology 69:112-116.
16. Thomas, C. E., and Webb, R. A. 1982. 'Cinco' muskmelon. HortScience 17: 684-685.
17. Toscano, N. C., Wyman, J., Kido, K., Johnson, H., and Mayberry, K. 1979. Reflective mulches foil insects. Calif. Agric. 33:17-19.
18. Webb, R. E., and Scott, H. A. 1965. Isolation and identification of watermelon mosaic viruses 1 and 2. Phytopathology 55:895-900.

S. T. Nameth

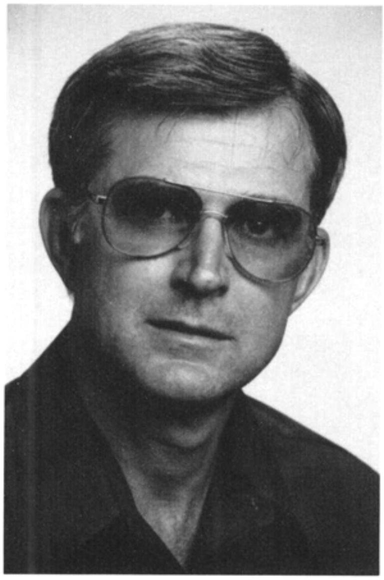
Dr. Nameth received his Ph.D. degree in plant pathology from the University of California at Riverside, where he was graduate research assistant in the Department of Plant Pathology. He received his B.S. degree in agronomy from California State Polytechnic University in Pomona. He is currently assistant professor and extension specialist in the Department of Plant Pathology at Ohio State University, Columbus.

A. O. Paulus

Dr. Paulus is an extension plant pathologist in the Department of Plant Pathology at the University of California, Riverside. He received his Ph.D. degree from the University of Wisconsin, Madison, in 1954. His research activities focus on diseases of vegetables, small fruit, ornamentals, and field crops.

J. A. Dodds

Dr. Dodds is associate professor in the Department of Plant Pathology at the University of California, Riverside. He obtained a B.Sc. degree in botany from Leeds University, England, and M.Sc. and Ph.D. degrees in plant pathology from McGill University, Montreal, Canada. His research interests include virus diseases of vegetables and citrus, virus diagnosis, viruses of fungi and algae, and mixed virus infections, including cross-protection.



F. F. Laemmlen

Since 1980, Dr. Laemmlen has been a member of the University of California Cooperative Extension, serving as a farm advisor in Imperial County. He obtained an M.S. degree in entomology from Purdue University, Lafayette, Indiana, in 1966 and a Ph.D. degree in plant pathology from the University of California at Davis in 1970. His interests and responsibilities include plant problem diagnosis and research on diseases and nematodes associated with vegetable and field crop production in irrigated desert agriculture.