John N. Simons JMS Flower Farms, Inc., Vero Beach, FL
Thomas A. Zitter Cornell University, Ithaca, NY

Use of Oils to Control Aphid-Borne

Almost 20 years have passed since Bradley et al (2) first reported that mineral oil on a leaf surface interferes with aphid transmission of a nonpersistent virus. Surprisingly, in view of the lack of adequate control procedures for this large and destructive group of viruses, only a modest effort has been made in the United States to exploit this discovery. Research effort has been significant in Europe and Israel, where oils are used commercially on such crops as seed potatoes, lilies, peppers, and cucumbers. Even there, however, oil use is limited, primarily because of phytotoxicity but also because of ineffectiveness.

Little work has been done to tailor oils to virus control, and commercially available oil formulations generally have been used for testing. In this article, we discuss oil formulations and application techniques specifically designed to control aphid-borne virus diseases—both persistently and nonpersistently transmitted–with minimum phytotoxicity to plants and relatively low cost to growers.

0191-2917/80/06054205/$03.00/0

Mechanism of Oil's Action

The mechanism by which oil prevents aphids from transmitting viruses is not understood. Both acquisition and inoculation of virus are affected by oil on the leaf (1), with activity apparently greater against acquisition than against inoculation. This may be related to the fact that with virus acquisition the aphid's stylets have a chance to contact oil both during penetration of the epidermis and during withdrawal, whereas with inoculation the only contact is during the penetration stage of probing. Oil appears to have little effect on the probing and feeding behavior of aphids. Simons et al (5) found that green peach aphids required a greater preprobe time on oil-treated plants, although the delay was less than a minute. They also found that electronically monitored sap ingestion seemed to be reduced when aphids fed on oil-treated leaves.

Oil does not appear to denature virus particles. Transmission of viruses with differing morphologies (flexuous rods, spherical particles, bacilliform) seems equally suppressed by oil. The oil's effect could involve adherence of the virus to the aphid's stylets (1) or interference with

Fig. 1. Rotary mowing machine cutting back pepper plants in Florida. A second crop of fruit is produced on the regrowth.

sap ingestion in the food canal or possibly sap egestion, if this occurs. Efforts to elucidate the exact mechanism of action have not been successful. Vanderveken's recent review (6) covers this subject in considerable detail.

That oil interferes with the transmission of both nonpersistent and semipersistent aphid-borne viruses is well established (6), and the literature consistently reports that oil does not reduce transmission of persistent aphid-borne viruses (6). During the past 2 years, however, we have obtained evidence that oil can interfere with transmission of a persistent virus. The tomato yellows virus (TYV) causes a destructive disease in Florida. TYV is very similar to potato leaf roll virus (PLRV) in host range and symptomatology. We have observed control of TYV in commercial tomato plantings by weekly applications of oil, and experimental work in small field plots has verified this (7). Recently completed vector-virus relationship studies (T. A. Zitter and J. H. Tsai, *unpublished*) also point to similarities between TYV and PLRV. In view of the rather numerous reports that oil does not affect transmission of persistent viruses, these findings should stimulate reinvestigation. Our work was done under field conditions, whereas the work reported in the literature was done in the laboratory. Use of apterous aphids and/or long inoculation feeding periods may explain apparent discrepancies.

Fig. 2. High-clearance spray machine applying oil on stake tomatoes in Florida.

Epidemiologic Aspects

In most field situations, the majority of virus transmissions are among crop plants (secondary spread), and a relatively small part of the diseased population is comprised of plants infected with virus brought in from the outside (primary spread). Thus, a treatment that interferes significantly with introduction of virus should prove highly efficacious under field conditions. This has been the case with JMS Stylet-Oil; small plot field trials on pepper, cucumbers, and squash have consistently shown threefold to eightfold reductions in virus spread (8), whereas almost total suppression of disease has been common under commercial field conditions. One major difference between small experimental plots and large fields has been that the small plots were established with primary inoculum and the commercial fields were essentially free from virus at the time oil treatment was begun.

Where pepper growers have left unsprayed blocks to monitor the effectiveness of the oil treatment, we have observed the following: 1) virus-infected plants did not appear in the unsprayed areas until several weeks later than would normally be expected and 2) once disease was established in the unsprayed area, spread was rapid and ultimately 100% of unsprayed plants became infected. The delay in disease appearance was undoubtedly associated with locating the unsprayed blocks in the middle of large areas of oil-treated blocks of plants, which provided protection several weeks longer than normal. Interestingly, the plants in the oil-sprayed blocks on either side of the unsprayed blocks remained almost completely free from virus many weeks after the unsprayed blocks had become totally infected. This could only be attributable to strong suppression of primary spread by the oil and emphasizes the need for growers to initiate oil treatments as soon as winged aphids appear rather than waiting for disease to appear.

Oil obviously has a significant effect on reducing secondary spread of virus, otherwise we would not have observed the level of control seen in small plots. Since most spread under field conditions is secondary, it is essential that oil be effective in limiting plant-to-plant spread.

Inoculum Potential

Our observations indicate that oil sprays lose effectiveness as inoculum potential increases. We do not know what the level of infection in a field must be before oil sprays become ineffective, but under Florida conditions the level of infected plants is probably between 10 and 20%. Such factors as the number of winged aphids, titer of transmissible virus in infected plants, and plant density (stand) are all important. Disease incidence probably increases at a slow rate until a 1–2% infection level is reached, then spread can be rapid, often reaching twofold to threefold each week. We observed one instance with pepper and tobacco etch virus in which oil sprays were initiated after disease incidence had reached about 3.5% and where incidence increased to only 8% after 10 weeks; unsprayed control areas in the same field became 100% infected in about 6 weeks.

Some of the most striking evidence for the importance of suppressing inoculum potential involves the double cropping of peppers in Florida. The use of oil on peppers has been so effective in controlling virus that producing two crops of fruit from the same plants has become feasible. The first pickings are made in November-December, the plants are cut back to a height of about 15 cm (Fig. 1) in late December to early January, and a second crop of fruit is produced on the regrowth for harvest in March-April. This results in a roughly 50% increase in yield, with the second crop costing only about 15% as much to grow as the first crop. The technique succeeds largely because plastic mulch is used to control weeds and plant beds are fumigated in late summer to control soil diseases. Supplemental fertilizer is generally used for the second crop.

Inoculum potential is particularly important where seedborne virus diseases are involved. Two crops that suffer significant losses from seedborne virus diseases but whose cash value is too low to warrant oil applications on production plantings are peanut (peanut mottle virus) and cowpea (cucumber mosaic virus). J. W. Demski in Georgia (*personal communication*) is investigating the possibility of protecting the seed crops with oil and providing growers with virus-free seed. Transmission of peanut mottle virus in commercially available seed occurs at a rate of 0.1–1% (4); this low level should be controllable by oil sprays.

Oil sprays may prove less effective where levels of inoculum potential are higher, as with seed potatoes. Because seed potatoes are generally grown where aphids are not abundant, oil sprays may be of value. Considerable work has been done in Europe using oils to control potato virus Y (PVY). Virus spread has been reduced significantly where oils have been used at 3–4% concentrations. Unfortunately, phytotoxicity has been a major problem and yield reductions up to 20% have been reported. Work in Maine with JMS Stylet-Oil has been encouraging, however. This oil can be used at a lower concentration (0.75%), and phytotoxicity has not been a serious problem, yield reductions generally being about 3%. D. F. Hammond (*personal communication*) tested the oil on several potato cultivars and found that weekly applications effectively reduced PVY spread (Table 1). Interestingly, when the oil was used in combination with aldicarb (Temik), a systemic insecticide applied at planting time, the oil was not as effective.

Oil Plus Insecticides

The use of insecticides to control nonpersistent aphid-borne viruses is ineffective, primarily because insecticides do not act quickly enough to prevent transmission of virus. What is not generally recognized, however, is that insecticides that are ineffective against aphids can actually enhance virus transmission. This phenomenon was described nearly 30 years ago with DDT and spread of PVY (3), but little attention has been given to the subject in recent years. Many insecticides that were once very effective against aphids are no longer as useful. Most of the older organophosphate insecticides as well as the chlorinated hydrocarbon materials are in this category. Presumably, administration of sublethal doses of insecticides to alate aphids results in hyperactivity and more probing and flying. Where quick-acting, highly toxic, and short residual aphicides are used, the danger of aggravating virus spread is probably slight. During the past year a number of additional reports of this phenomenon (*personal communications*) have come to our attention, including the use of endosulfan (Thiodan) on cantaloup (cucumber mosaic) and of aldicarb on sweet corn (maize dwarf mosaic).

The use of oil to control PVY with a systemic insecticide to control potato leaf roll was reported to be more effective than either treatment alone (9). Although such a combined approach may have merit, the potential for certain insecticides to cause hyperactivity in alate aphids should not be overlooked. Certainly, the use of aphicides should be associated with the presence of winged aphids, and the value of placing a systemic insecticide in the soil at planting time when no aphid activity is expected for 6–8 weeks seems dubious unless other insects are a problem.

Table 1. Results of spray trials with JMS Stylet-Oil for control of potato virus Y in seed potatoes in Maine[a]

	Percent infection				
Cultivar	Oil at 7 days	Oil at 14 days	Temik + oil at 7 days	Temik + oil at 14 days	Control
Russet Burbank	2.97	5.57	10.63	9.99	7.26
Pungo	1.59	5.25	7.28	4.86	4.31
Ontario	0.96	6.05	2.17	1.89	4.75
Atlantic	0.91	2.04	4.77	3.33	3.71
Norchip	1.11	3.90	2.09	4.67	2.15
Mean	1.51	4.56	5.39	4.95	4.87

[a] Oil was used at 0.75% concentration and sprayed at 400 psi with TX-5 nozzles. Temik was applied to the soil at planting time.

Influence of Plant Density

In Florida, oil is used to control virus spread in pepper, tomato (Fig. 2), and squash. These crops are all highly susceptible to nonpersistent aphid-borne viruses, and outbreaks frequently reach 100% infection. Virus spread in squash (zucchini or crookneck) can be particularly rapid, with total infection (watermelon mosaic virus 1) of fields observed within 4 weeks of the initial infection. In the laboratory, watermelon mosaic virus 1 is transmitted readily by aphids but not as efficiently as PVY or tobacco etch virus. Yet these latter two viruses generally require at least 6–8 weeks to totally infect a pepper planting. Spread of watermelon mosaic virus 1 is even more rapid in watermelon than in squash. The green peach aphid is the principal vector species in all cases.

In the laboratory, oil is highly effective in preventing inoculation of the virus to all three crops, yet under test plot conditions, oil is most effective on pepper, less effective on squash, and almost ineffective on watermelon. Differences in aphid behavior may account for these variations in oil effectiveness, but differences in plant stand more likely are involved. Pepper is planted at about 44,000 plants per hectare, squash at 15,000–18,000 plants per hectare, and watermelon at 1,200–1,800 plants per hectare. When one is dealing with a plus and minus phenomenon (infection or no infection), as is the case with systemic virus infections, there is going to be strong interaction between the number of available suscepts and the probability of obtaining infection in a given suscept. When the procedure used to limit the spread of virus is marginally effective and only protectant in nature, which is the case with oil, the aspect of plant stand can be a very important component in the epidemiologic picture.

Spray Coverage

The effectiveness of any protectant spray material is closely related to the thoroughness of coverage. Oil applications deal with areas of plant canopy subject to probing by alate aphids; apterous aphids are of little importance as vectors. Since alate aphids generally probe only on the outer surface of a plant, coverage on the underside of leaves and deep within the plant canopy is not necessary.

Oil persists on sprayed leaves for at least 10–14 days (5). Weekly sprays or, with rapidly growing plants such as cucurbits, twice-weekly sprays are needed to protect new foliage. Spray booms should be designed to provide thorough coverage to the uppermost surfaces of plants. Nozzles should be placed about 25 cm apart, and doubling of overhead nozzles (those spraying straight down) by

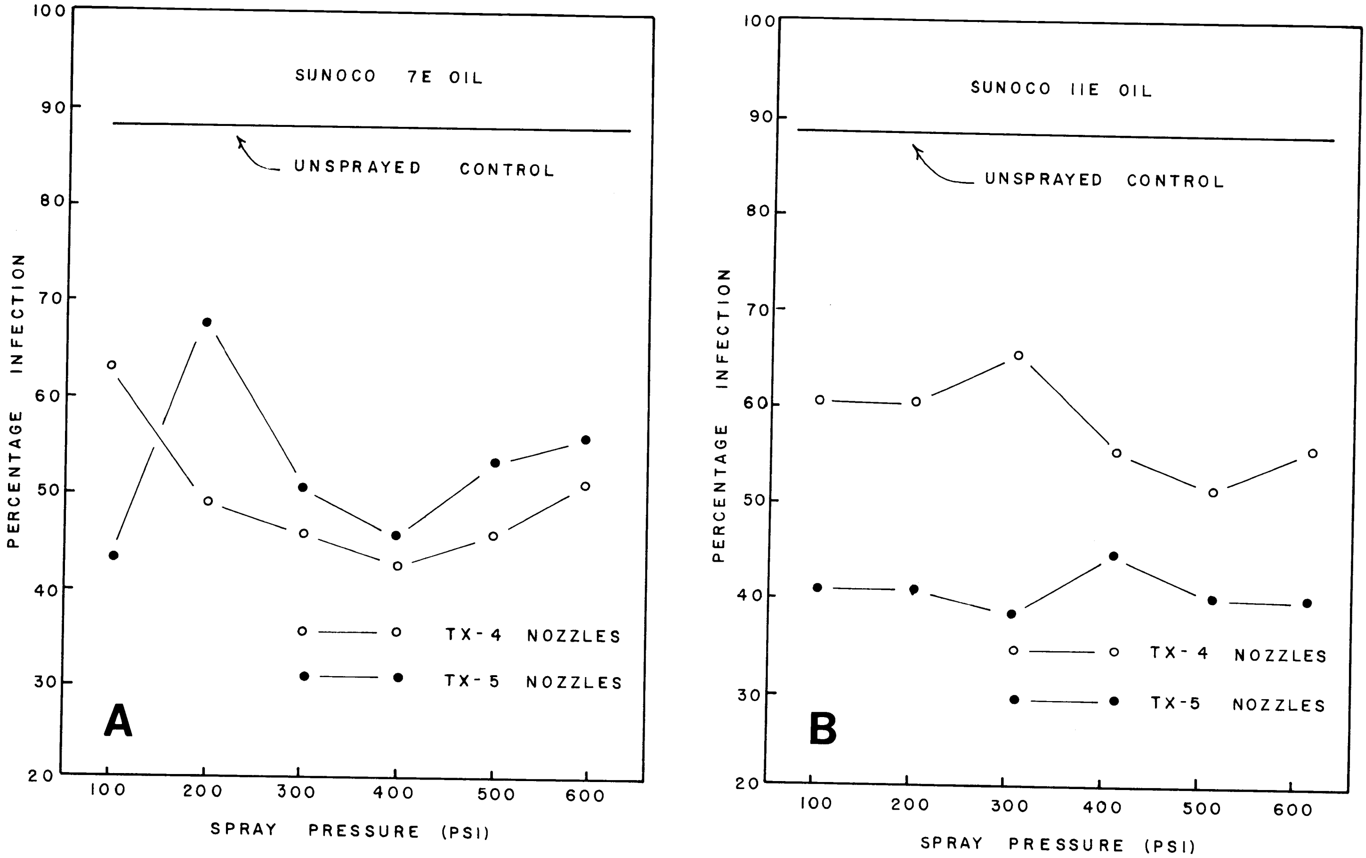


Fig. 3. Effect of nozzle orifice and spray pressure on effectiveness of (A) Sunoco 7E oil and (B) Sunoco 11E oil used on pepper at 0.75% concentration. Plants were inoculated by green peach aphids the day after treatment. Amount of spray applied was kept constant at each spray pressure and with each spray nozzle. Results are based on six replicates of 10–15 plants per treatment.

using tees and two short nipples placed at a 45° angle to the spray boom is helpful. Nozzles should be adjusted to spray 30–40 cm from the plant canopy. Adequate coverage can be obtained using enough nozzles to spray 40 gal per acre on young plants and 100 gal per acre on mature plants. Sprayers should not be driven faster than 3 mph. Because volume and coverage are essential for control, low-volume aerial applications field-tested in Florida have been ineffective.

Oil should not be sprayed on wet foliage, as coverage will be poor. In addition, application of oil to wet leaves can redistribute protectant chemicals, causing loss of their efficacy. The surfactant systems used in formulating other chemicals interfere with distribution of oil in a specially formulated virus control product. We recommend applying oil first, then waiting at least 24 hours before spraying other chemicals. Oils are not washed from leaves by small amounts (< 1 cm) of rain.

Developing an Oil for Virus Control

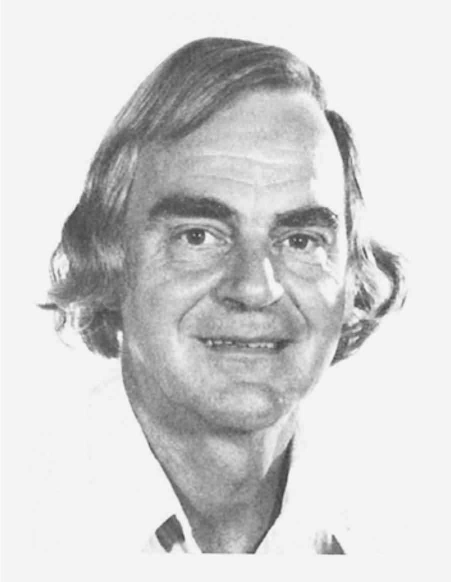
Mineral oils for use on plants are generally characterized by: 1) viscosities of 60–110 sec SUS (Saybold Universal Second), 2) unsulfonated residues of 90–96%, 3) API gravity of 33–35, and 4) emulsifiers (0.75–1.25% by volume). When used with standard application equipment, the oils form quick-breaking emulsions that separate on leaf surfaces, leaving a somewhat discontinuous film over the leaf. Generally, concentrations of 2–4% are used to assure as complete coverage as possible. Unfortunately, many tender vegetable crops do not tolerate these high concentrations, and the somewhat discontinuous film produced does not provide the maximum protection possible.

Aphids generally initiate probes intercellularly rather than directly through the periclinal wall of epidermal cells. This suggests that only the deep grooves separating the cells in which aphids normally initiate probes, and not the entire leaf surface, need to be covered with oil to prevent virus transmission. If this were possible, high concentrations of oil would not be necessary for maximum virus control, since these grooves occupy a very small portion of the total leaf area. Using less oil and placing it in a relatively biologically inert part of the leaf (such as over the anticlinal walls) should minimize problems with phytotoxicity. Also, oil in the grooves should have more persistent antitransmission effects; as leaf cells expand, the oil would continue to exist as discrete rivulets, decreasing in depth but not in continuity, as would a general surface film on the leaf.

Two obvious ways to approach this hypothetical scenario are: 1) test oils with differing emulsification systems and 2) investigate various aspects of application technology. We have done considerable work in both areas and have found that both are important in developing an oil with maximum potential for virus control.

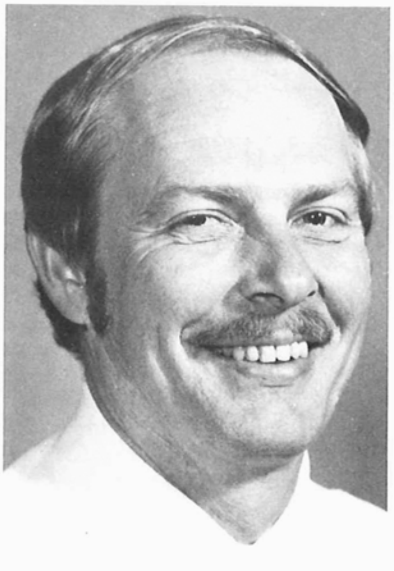
We tested a number of commercially available emulsifiers, using various concentrations and oils of different viscosities. Our results indicated that significant effects relate to both kind and quantity of emulsifier used and that optimal concentrations of emulsifier exist. Increasing the amount of emulsifier improves performance, but once the optimal concentration is reached, there is no plateau in performance. Instead, further increases reduce the efficacy of the formulation. The reasons are not known, but it seems likely that distribution of the oil on the leaf surface is affected somehow.

In our studies on application technology, we investigated a series of nozzles differing only in orifice size in conjunction with the effect of various spray pressures. The work was done on peppers and tomatoes (PVY) and zucchini squash (watermelon mosaic virus 1) using green peach aphids as vectors. Oils were



John N. Simons

Dr. Simons is president of JMS Flower Farms, Inc., in Vero Beach, FL. After receiving his Ph.D. from the University of California at Berkeley in 1953, he conducted research on epidemiology and control of viruses of vegetables at the University of Florida for 7 years. The next 10 years were spent at Stanford Research Institute, where he was employed as senior entomologist. In 1969 he joined the research staff of the Ciba-Geigy Corporation in Vero Beach as a senior scientist in charge of a plant virus screening program. In 1977 he began work with commercial application of mineral oil for control of virus diseases and is currently self-employed in this endeavor.



Thomas A. Zitter

Dr. Zitter is an associate professor in the Department of Plant Pathology at Cornell University, Ithaca, NY. He received his Ph.D. at Michigan State University in 1968. He was located for 11 years at the University of Florida Agricultural Research and Education Center at Belle Glade, working on the epidemiology and control of insect-transmitted plant virus diseases. He is continuing this research at Cornell.

sprayed at a concentration of 0.75% the day before virus inoculation. Plants were grown outdoors so that the leaf surfaces would be similar to those of field-grown plants. A specially built machine with precisely controlled spray boom speed was used to insure that equal amounts of spray material could be applied regardless of nozzle type or spray pressure used. The spray boom was mounted on a track about 8 m long, and up to 25 plants could be sprayed in a single pass. Rate of travel of the boom was controlled by a servomotor and could be varied between 0 and 3 mph.

Results of some of these trials using pepper and PVY are shown in Fig. 3. Differences in effectiveness related to oil viscosity, spray pressure, and nozzle orifice are clearly shown. Interestingly, a reversal in effectiveness was associated with nozzle orifice according to whether Sunoco 7E or Sunoco 11E oil was used; these two oils were formulated similarly with respect to emulsifier and differed only in viscosity. Efficacy also generally improved as spray pressure was increased, with a pressure of 400 psi required for optimal effectiveness in most instances.

The reasons for these differences are not known, but we suspect interactions among the oils and the spray parameters result in differences in oil droplet size that are associated with distributional effects on leaf surfaces. We recently obtained evidence that the oil droplets within the emulsion droplet are very small, averaging 0.2 μm in diameter. The emulsion droplets have an average diameter of 40 μm. Oil droplets this small do not coalesce readily and probably have considerable mobility on the leaf surface, accumulating in the grooves around the borders of the epidermal cells.

We also found interactions between spray nozzle orifice and leaves of different plant species. In general, the Teejet TX-4 nozzles provided better protection on smooth-surface leaves such as on pepper and the TX-5 nozzles gave better protection on more pubescent leaves such as on tomato and squash. Differences in effectiveness ranged from 10 to 20% and were consistent, again indicating some subtle distributional effects.

Incompatibility Between Oil and Other Chemicals

We have not observed any phytotoxicity problems using oil specifically formulated for virus control, regardless of the plant species sprayed. JMS Stylet-Oil has been applied separately from other pesticides by recommended application procedures: 0.75% concentration, appropriate nozzles, and spray pressure of 400 psi. When oil is used in combination with other pesticides as part of normal production practices, serious problems of incompatibility can arise. Most involve fungicides, including sulfur, chlorothalonil (Bravo), and dichlone (Phygon). Aerially applied chemicals can be more of a problem than dilute materials applied with ground sprayers because aerial applications often spatter rather large deposits of chemicals on foliage. We have also observed that most chemicals incompatible with oil tend to be rather phytotoxic and the oil tends to aggravate the phytotoxicity. Plant injury is more severe when air temperatures are above 30 C.

Additional studies on the effects of oil on transmission of aphid-borne viruses should be conducted to elucidate the mechanism(s) by which oil works.

Literature Cited

1. BRADLEY, R. H. E. 1963. Some ways in which a paraffin oil impedes aphid transmission of potato virus Y. Can. J. Microbiol. 9:369-380.
2. BRADLEY, R. H. E., C. V. WADE, and F. A. WOOD. 1962. Aphid transmission of potato virus Y inhibited by oils. Virology 18:327-328.
3. FERNOW, K. H., and S. H. KERR. 1953. Leaf roll control by use of insecticides. Am. Potato J. 30:187-196.
4. KUHN, C. W., and J. W. DEMSKI. 1975. The relationship of peanut mottle virus to peanut production. Res. Rep. Ga. Agric. Exp. Stn. 213. 19 pp.
5. SIMONS, J. N., D. L. McLEAN, and M. G. KINSEY. 1977. Effects of mineral oil on probing behavior and transmission of stylet-borne viruses by *Myzus persicae*. J. Econ. Entomol. 70:309-315.
6. VANDERVEKEN, J. J. 1977. Oils and other inhibitors of virus transmission. Chap. 18 in: K. F. Harris and K. Maramorosch, eds. Aphids as Virus Vectors. Academic Press, New York. 559 pp.
7. ZITTER, T. A., and P. H. EVERETT. 1979. Use of mineral oil sprays to reduce the spread of tomato yellows virus disease in Florida. Univ. Fla., Immokalee ARC Res. Rep. SF79-1. 7 pp.
8. ZITTER, T. A., and H. Y. OZAKI. 1978. Aphid-borne vegetable viruses controlled with oil sprays. Proc. Fla. State Hortic. Soc. 91:287-289.
9. ZSCHIEGNER, H. J., W. KRAMER, O. SASS, R. FRITSCHE, and H. DOBNIK. 1971. Successful restriction of the spread of nonpersistent viruses by methods of virus vector control. Pages 319-323 in: Proc. Br. Insectic. Fungic. Conf., 6th.