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CROP AND INSECT RESPONSE TO HORTICULTURAL MINERAL OIL ON TOMATO AND PEPPER

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Abstract. **Horticultural mineral oil (HMO) is an inexpensive, environmentally safe pest management alternative, and acceptable in some cases for products labeled for organic production. However, there has been insufficient information on efficacy and direct impact to vegetable crops, including tomatoes (*Lycopersicum esculentum* Mill.) and peppers *Capsicum annuum* L. under commercial conditions in south Florida. We conducted a series of field trials in Immokalee on pepper and tomato during two fall seasons and one spring season. Highly refined HMOs were tank mixed with fungicides, insecticides or sprayed alone at rates ranging from 0.5% to 2% at weekly intervals throughout the crop cycle. Pest populations significantly reduced in response to these sprays included silverleaf whitefly (*Bemisia argentifolii* Bellows and Perring), Broadmite (*Polyphagotarsonemus latus* Banks), green peach aphid (*Myzus persicae* Sulzer), and surprisingly, southern armyworm (*Spodoptera eridania* Stoll), and pepper weevil (*Anthonomus eugenii* Cano). It is not certain whether these effects were due to mortality, repellency or a combination of both. Some phytotoxicity and increased bacterial spot were observed with higher rates of oil on fall tomatoes, especially early in the fall season during hot weather. Nevertheless, HMO appears to be a useful and as yet under-exploited pest management tool for vegetable growers.**

Petroleum-derived horticultural mineral oils (HMOs) have been used for pest control for well over a hundred years, initially as dormant oil sprays for deciduous tree crops. Their use as foliar sprays has increased as improvements in purity and surfactants have improved efficacy and reduced risks of phytotoxicity (Davidson et al., 1991). Oils are thought to act directly on insects by blocking the spiracles and causing suffocation (Stansly et al., 1996). An additional effect brought about by coating of olfactory receptor organs may cause interference with host location (Simons, 1982), resulting in repellency to adult aphids and whiteflies (Butler et al., 1989; Larew and Locke, 1990; Liu and Stansly 1995a,b). Finally, there is good evidence that oils slow the movement of non-persistent plant viruses in the field by interfering with the retention of virions on aphid vector stylets (Wang and Pirone, 1996). Although oils may control a wider range of pests than soaps, oils may also be toxic to beneficial organisms, particularly from direct contact with sprays (Davidson et al., 1991; Liu and Stansly, 1996; Rosen, 1967; Stansly and Liu, 1997; Stansly et al., 2002). The field experiments described here were undertaken with the objective of defining practical benefits and limits of using HMOs to control pests of tomato and pepper in Florida.

HMO is the standard treatment in Florida citrus for greasy spot, rust mite and a host of other pests and conditions including loosening of sooty mold. Problems with phytotoxicity in citrus have largely disappeared since the advent of highly refined "narrow range" HMOs. Nevertheless, there has been concern about phytotoxic responses of vegetable crops, even to narrow range oils, although no phytotoxicity was observed on bell pepper during fall, 1995 following weekly applications at rates of up to 2% Sunspray Ultrafine (tank mixed or not) with mancozeb and copper fungicides (Vavrina et al., 1996). Benefits from weekly sprays on tomato would largely be felt in spring when the threat of whitefly and TYLCV is greatest. However, the potential risk of phytotoxicity is greatest in early fall when temperatures are highest and plants are most susceptible to spray burn. Our objectives were to evaluate possible phytotoxic responses to HMOs of tomatoes and peppers during the fall and spring growing seasons, as well as the insecticidal properties of these products to the principal pests of these crops. While we anticipated rates of 0.5% to 1.0% as becoming the norm, higher rates were tested under adverse conditions to evaluate possible plant injury. Insecticidal properties were also compared to various standard and experimental treatments against the principal pests of tomato and pepper in southwest Florida to asses efficacy of HMOs with respect to existent and future control options.

Materials and Methods

Tomato

Fall 2003. Greenhouse-raised 'Florida 47' seedlings were planted 8 Sept. at 18-inch spacing on 2 sets of 3 raised beds each 240 ft long on 6-ft centers covered with whiteface polyethylene film and constituting a replicate. Plants were irrigated and fertilized using drip tape (Netafim®) with 12-inch spacing between emitters. Tissue sap analysis was used to adjust fertigation rates. The center bed of each set of three beds was left untreated to serve as a buffer between treated beds. The treated beds were divided into plots 48 ft long to which five treatments were assigned in a completely randomized block design with four replications. Imidacloprid (Admire® 2F, Bayer CropScience, Research Triangle, N.C.) was applied at 16 oz/acre as a drench 11 Sept. except in one treatment of the two treatments of 1% HMO. A narrow-range HMO with mid-range boiling point of 435°F and unsulfonatable residues = 99% (Purespray Green®, Petro-Canada, Calgary, Alberta, Canada) was tank mixed with the fungicides maneb and copper hydroxide (Kocide) and sprayed weekly beginning 12 Sep. through 26 Nov. for 12 applications total. Sprays were applied with a high clearance sprayer using yellow ceramic nozzles (Albuz®) mounted on two vertical drop booms operating at 200 psi. Output varied from 44 gpa to 88 gpa as nozzles were added in response to plant growth.

Evaluations for foliar injury from phytotoxicity were made weekly for 8 weeks beginning 20 Sept., and for 6 weeks on the

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severity of bacterial spot beginning 7 Oct. A rating scale of 0-4 was used where 0 = no phytotoxicity or disease, 1 = 0-15 spots per leaflet with no significant damage, 2 = 15-30 spots with some damage and spots of dead tissue, 3 = 30 plus spots with blotching and significant damage to the leaf, 4 = severe leaf damage and loss of functional ability. Numbers of adult whiteflies were recorded by striking 20 plants with 9 × 12 inch black pie pan coated with a 9:1 mixture of vegetable oil and household liquid detergent. Whitefly nymphs were evaluated 3 Dec. from a leaf removed from the 6th node of 6 centrally located plants in each plot. All whitefly stages were counted that appeared in a 2 cm^2 ring placed once on the 3 terminal leaflets from each leaf. Two plants were sampled from each plot at first bloom, during the early fruiting cycle and post harvest on 14, 28 Oct. and 3 Dec. to evaluate dry weight. Fruit was harvested twice from 20 plants per plot, on 17 Nov. and 1 Dec. Culls were removed and classified as worm damaged or not. Marketable fruit was sorted by size on a commercial grading table, and weights and numbers in each size category were noted.

Spring, 2004. Seedlings of the same variety as above were transplanted 31 Mar. into 8 drip irrigated beds, 240 ft long on 12 ft centers. The beds were divided into consecutive 2 bed sets to make 4 replications each divided into 12 plots 40 ft long and assigned to treatments in a completely randomized block design. Imidacloprid, thiamethoxam (Platinum® 2SC, Syngenta Crop Protection, Inc., Greensboro, N.C.) and acetamidprid (Assail® 70 WP, Cerexagri, Inc., King of Prussia, Pa.) treatments were applied as soil drenches on 2 Apr. in 10 ml of solution. Additionally, imidacloprid was applied as a soil drench at 16 oz/acre on 13 Apr. to plants receiving one of three rates of mineral oil (PureSpray Green). Spiromesifen (Oberon® 2 SC, Bayer CropScience) was first applied 11 May, for 3 weekly applications to one set of the imidacloprid plots after the whitefly had become established. Acibenzolar-methyl (Actigard, Syngenta Crop Protection, Inc., Greensboro, N.C.) was applied weekly for 4 weeks beginning 4 May at 0.33 lb./acre and increased incrementally to 0.75 oz/acre and pymetrozine (Fulfill 50WG, Syngenta Crop Protection, Inc., Greensboro, N.C.) was applied in 2 weekly applications beginning 11 May and tank mixed with an organo-silicone adjuvant (Kinetic®, Helena, Collierville, Tenn.) at 0.1% v/v. to one set of the Platinum plots. The two horticultural mineral oils, (PureSpray Green and Sunspray Ultrafine Spray Oil (Sun Oil Company, Philadelphia, Pa.), mid-range boiling point of 415°F and unsulfonatable residues = 92% were tank mixed individually with the weekly fungicide applications. Normal cultural practices were followed to control other pests and diseases.

Eight weekly evaluations of whitefly adults were made beginning 8 Apr. by beating 1 side of four plants at three locations per plot as above. Immature stages were monitored 26 Apr., 11 and 24 May, and 1 Jun using one leaf removed from the 6th node of four centrally located plants in each plot and evaluated as above. All plants were visually assessed five times from 29 Apr. to 24 May for the presence of TYLCV symptoms (dwarfing, chlorosis, downward leaf curling). Fruit was harvested and evaluated as above on 2 June.

Fall, 2004. Greenhouse-raised seedlings of 'Hazera 3073' a cultivar resistant to tomato yellow leafcurl virus (TYLCV) were planted 31 Aug. on 12 raised beds 240 ft long on 6-ft centers, each covered with whiteface polyethylene film as above. The center bed of each set of three beds was planted with alternating tomato and *Amaranthus viridis* L. plants and left untreated to serve as a source of pest inoculum. The treated beds were divided into plots 40 ft long to which 12 treatments were assigned in a completely randomized block design with four replications. imidacloprid 2F and 2 rates of clothianidin (Belay 16 WSG, Arvesta Corp., S.F., Calif.) were applied as soil drenches on 2 Sept. in 10 mL of solution per plant. The treatment receiving the horticultural mineral oil (HMO), PureSpray Green, was tank mixed with the weekly fungicide applications of copper hydroxide and manzate. The initial application of HMO began 7 Sept. at 0.5% v/v and the rate was increased 0.5% every 2 weeks until 2.0% was reached on 19 Oct., the rate used to finish the crop season. The other treatments were applied in two applications on 26 Oct. and 2 Nov. at 88 gpa. Penetrator®, a nonionic adjuvant, was tank mixed with emamectin benzoate and lamda cyhalathrin (Proclaim® and Warrior, respectively, Syngenta® Crop Protection, Greensboro, N.C.) at 0.25% v/v. All sprays were applied using a high clearance sprayer with two vertical booms each fitted with ceramic yellow hollow cone nozzles operating at 200 psi with outputs of 33 gpa, 44 gpa, 66gpa and 88 gpa on 7 Sept., 21 Sept., 6 Oct., and 20 Oct. respectively. An application of Avaunt 30 WG (indoxacarb, Dupont Crop Protection, Wilmington, Del.) at 3.5 oz product was made 2 Nov. to control a developing southern armyworm population in the imidacloprid 2F and clothianidin 16 WSG drench only treatments. Disease was rated significant if 10% or more of the lower ⅓ of the plant was infected. A precount on 22 Oct. showed 3% of 192 plants sampled from six plots per rep across the trial had larvae or egg masses of southern armyworm present. Number of larvae and damage to eight plants per plot was monitored four times weekly starting 29 Oct. Damage was rated as 0 = no damage, 1 = 1% leaflets with damage, 2 = 2 to 5%, 3 = 6 to 15%, 4 = 16 to 30% and 5 = >30%. Weekly evaluations of whitefly adults were made beginning 11 Oct. in the clothianidan, imidacloprid 2F, drench treatments, the HMO treatments and untreated control by beating 1 side of eight plants at two locations per plot with a 9 × 13 inch pie pan painted black and coated with a 9:1 mixture of vegetable oil and liquid detergent. All plants were evaluated for disease and phytotoxicity four times starting 22 Oct. after the rate of the oil was increased to 2.0% and the first incidence of bacterial spot was noted. All fruit of marketable size was harvested from the 16 plants per plot on 15 and 29 Nov. Number and weight of marketable fruit and culls caused by damage from insect, disease or other causes were recorded.

Pepper

Spring, 2004. Two trials were conducted; experiment 1 focused on whitefly and experiment 2 on pepper weevil. For both, greenhouse-raised Jalapeño pepper 'Mitla' plants were transplanted on 31 Mar. at 10 inch spacing in single rows on four sets of three beds 240 ft in length and covered with polyethylene film mulch. Water and fertilizer were provided through drip tape (Netafim®) with 12-inch emitter spacing. The center bed in each set of three was left untreated to serve as the untreated control and a source of pests. Each treated bed was divided into plots 30 ft long to which treatments were assigned in a randomized complete block RCB design with four replications. Applications were made using a high clearance sprayer operating at 200 psi. Spray was delivered through two vertical booms, each fitted with two ceramic yellow hollow cone nozzles for a total of 44 gpa until 25 May when one nozzle was added to each boom for an output of 66 gpa. Applications schedules for the two trials are given in Tables 1 and 2. HMO was applied weekly starting 14 Apr. using a high clearance sprayer operating at 200 psi.

For the first experiment, seven weekly evaluations of whitefly adults were made beginning 19 Apr. by beating one side of four plants at three locations per plot with a 9 × 13 inch pie pan painted black and coated with a 9:1 mixture of vegetable oil and liquid detergent. Immature stages were monitored 11 and 24 May, and 1 June using 1 mature leaf removed from eight centrally located plants in each plot. All whitefly stages were counted that appeared in a 2 cm^2 ring placed twice on each side of the midrib (total 4 cm^2) from each leaf collected.

Weevil infestation was evaluated during the course of the second experiment by monitoring fallen fruit collected weekly, under 27 plants per plot. A piece of wooden lathing was fixed to the beds to prevent fruit from rolling off the plastic. All marketable fruit was harvested on 8 Jun. Weight of marketable fruit was determined by dissecting a random sample of 50 harvested fruit per plot (200 per treatment), to obtain a percentage infested with weevils and adjusting the total weight accordingly.

Fall, 2004. Greenhouse-raised bell pepper plants 'X3R Lancelot' were transplanted on 20 Sept. at 10-inch spacing in single rows on two beds 240 ft in length and covered with polyethylene film mulch. Water and fertilizer were provided through drip tape with 12-inch emitter spacing. Each bed was divided into eight plots 30 ft long making four replications. The treatments were assigned in an RCB design. Sixteen weekly applications of PureSpray Green HMO tank mixed with copper hydroxide @ 2.25 lb/acre and maneb @ 1.75 qt/acre, were made starting 21 Sept. using a high clearance sprayer operating at 200 psi. Spray was delivered through two vertical booms, each fitted with two ceramic yellow hollow cone nozzles for a total of 44 gpa. Seven weekly evaluations of whitefly adults were made beginning 11 Oct. by beating one side of six plants at three locations per plot with a 9 × 13 inch pie pan painted black and coated with a 9:1 mixture of vegetable oil and liquid detergent. Bacterial spot was rated weekly for seven weeks on 25 plants from 4 Oct. to 19 Nov. Ratings of 0-3 were assigned based on the following criteria per plant, 0 = no damage; 1 = 1-2 spots, light damage; 2 = 3-5 spots, moderate damage; 3 = >5 spots, severe damage. Numbers of Southern and beet armyworm larva were recorded on 25 plants in four weekly evaluations from 15 Oct. to 4 Nov. Green peach aphids and broad mite infestations were evaluated in three weekly samplings from 28 Oct. to 18 Nov. on 25 plants per plot. The number of plants with a total of 10 or more aphids from three expanded leaves per plant was recorded. Broad mites were evaluated by recording the number of plants that were showed moderate or severe broad mite damage. On 18 Nov. a count from 25 plants per plot for ladybeetle adults and larvae was made. All fruit larger than 2 inches was harvested from 30 plants per plot on 3 Dec and again on 10 Jan. 2005 from the same plants. Fruit was graded as marketable, or unmarketable due to insect damage, or other.

Analysis. Analysis of variance was used with mean separation using Fisher's LSD ($P < 0.05$) in case of a significant treatment F value. Data from multiple weeks was subjected to repeated measures analysis using the replicate × treatment mean square as an error term.

Results and Discussion

Tomato

Fall, 2003. Dry weight of plants taken on the first two sample dates showed no significant differences among treatments (data not shown). Whitefly numbers were low and no TYLCV was observed during the growing season. Nevertheless, the number of immature whiteflies corresponded to the rate of HMO, with most seen on control plants and significantly fewer on plants treated at all rates including 0.5% (Table 3). Phytotoxicity seen with the higher rates of HMO consisted of brownish interveinal and marginal discoloration on the foliage. These symptoms were most noticeable the first month when mean high temperature averaged 88°F (http://fawn.ifas.ufl.edu). Incidence and severity of bacterial spot followed the same pattern as phytotoxicity. It is likely that necrotic areas caused by the phytotoxic response served as entry points for bacteria. Yield was significantly reduced at the 1% and 2% rates. This was attributed to foliage loss resulting from bacterial spot. These results indicated that the 0.5% rate sprayed weekly in conjunction with fungicides provided whitefly control without significant loss of yield in the absence of virus pressure.

Spring, 2004. Counts of whitefly adults from tomato plants jumped from an average 7.4 ± 1.4 (mean ± SE) per pan on 8 Apr. to 85.0 ± 11.2 on 26 Apr. with lowest counts seen on plants receiving a drench of imidacloprid 2F and sprayed with 1% PureSpray Green Oil (Table 4). Counts of nymphs on that day were lowest on plants receiving a neonicotinoid drench alone or supplemented with HMO. The only weekly evaluation for new virus incidence that showed significant treatment differences occurred on 5 May, when fewest newly symptomatic plants had been drenched with imidacloprid 2F followed by weekly sprays with 1% HMO. Soon afterward, all plants were symptomatic for TYLCV, regardless of treatment. On 11 May, mean adult counts had risen to 183.0 ± 10.3 with no significant differences among treatments, although fewest pupae were again seen with the imidacloprid 2F drench + 1% HMO weekly sprays. Fewest adults and pupae were seen 24 May in response to the imidacloprid 2F drench followed by spiromesifin sprays, although in regard to adults, differences were not significant with any treatment receiving a neonicotinoid drench, nor in regard to pupae, to those including thiamethoxam 2SC (drench) + sprays of either pymetrozine 50WG and acibenzolar-methyl or imidacloprid 2F + sprays of HMO at 0.5% or 1%. Again on 1 June, fewest pupae were seen on plants drenched with imidacloprid 2F followed by sprays of spiromesifen, although differences compared to the imidacloprid 2F drench + sprays of HMO at 0.5% and 1% were not significant. Thus, no treatments provide protection from the onslaught of whiteflies and TYLCV, although significant levels of suppression were observed with most treatments including drenches of imidacloprid 2F or thiamethoxam 2SC, and these in turn were improved by follow-up foliar applications of horticultural mineral oil, spiromesifen (Oberon), or pymetrozine 50WG + acibenzolar-methyl. These results reflected in the yield which was greatest from plants drenched with imidacloprid 2F followed by spiromesifen sprays but not significantly so except when compared to the untreated by some criteria.

Fall, 2004. Fewest adult whiteflies were observed over seven sample dates on plants drenched with imidacloprid 2F or sprayed with HMO, with no differences between these two treatments (Table 5). All treatments provide significant con-

Table 1. Spray schedule on pepper, fall 2004, Experiment 1.

		Spray dates and products applied							
Treatment/formulation	Rate amt form/ac	14 Apr	21 Apr	28 Apr	4 May	11 May	18 May	25 May	1 Jun
1. Novaluron 0.83EC	12 oz			Novaluron	Oxymyl[z]	Novaluron	Oxymyl	Novaluron	Oxymyl
2. Diflubenzuron	6 oz			Diflubenzuron	Oxymyl	Diflubenzuron	Oxymyl	Diflubenzuron	Oxymyl
3. Acetamiprid 30 WD	4 oz				Oxymyl	Acetamiprid 30 WDG	Oxymyl	Acetamiprid 30 WDG	Oxymyl
4. Acetamiprid 70 WP	1.2oz				Oxymyl	Acetamiprid 70 WP	Oxymyl	Acetamiprid 70 WP	Oxymyl
5. Acetamiprid 70 WP	1.7 oz				Oxymyl	Acetamiprid 70 WP	Oxymyl	Acetamiprid 70 WP	Oxymyl
6. Acetamiprid 70 WP HMO 435[y]	1.2 oz + 1.0% v/v				Oxymyl	Acetamiprid 70 WP + HMO	Oxymyl	Acetamiprid 70 WP + HMO	Oxymyl
7. Cryolite	8 lb		Cryolite	Cryolite	Cryolite + oxymyl	Thiamethoxam 25 WDG[z]	Oxymyl	Thiamethoxam 25 WDG	Oxymyl
8. Cryolite	12 lb			Cryolite	Cryolite + oxymyl	Thiamethoxam 25 WDG	Oxymyl	Thiamethoxam 25 WDG	Oxymyl
9. Imidacloprid 1.6F	7 oz				Oxymyl	Imidacloprid 1.6F	Oxymyl	Imidacloprid 1.6F	Oxymyl
10. Thiacloprid 2EC	4.5 oz				Oxymyl	Thiacloprid	Oxymyl	Thiacloprid	Oxymyl
11. HMO 435	0.25% v/v	HMO	HMO	HMO	HMO + oxymyl	HMO + thiamethoxam 25 WDG	HMO + oxymyl	HMO + thiamethoxam 25 WDG	HMO + oxymyl
12 HMO 435	0.5% v/v	HMO	HMO	HMO	HMO + oxymyl	HMO + thiamethoxam 25 WDG	HMO + oxymyl	HMO + thiamethoxam 25 WDG	HMO + oxymyl
13 HMO 435	1.0% v/v	HMO	HMO	HMO	HMO + oxymyl	HMO + thiamethoxam 25 WDG	HMO + oxymyl	HMO + thiamethoxam 25 WDG	HMO + oxymyl
14. HMO 435	2.0% v/v	HMO	HMO	HMO	HMO + oxymyl	HMO + thiamethoxam 25 WDG	HMO + oxymyl	HMO + thiamethoxam 25 WDG	HMO + oxymyl
15. HMO 435[x]	2.0% v/v	HMO	HMO	HMO	HMO + oxymyl	HMO + thiamethoxam 25 WDG	HMO + oxymyl	HMO + thiamethoxam 25 WDG	HMO + oxymyl
16. Thiamethoxam 25 WDG	4 oz				Oxymyl	Thiamethoxam 25 WDG	Oxymyl	Thiamethoxam 25 WDG	Oxymyl
17. Untreated check									

[z]Oxymyl and thiamethoxam 25 WDG applied at 3 pt/acre and 4 oz/acre, respectively.
[y]PureSpray Green®—mid-range boiling point 435 °F.
[x]Sunspray Ultrafine®—mid-range boiling point 415 °F.

Table 2. Spray schedule on pepper, fall 2004, Experiment 2.

Treatment/formulation	Rate amt form/acre	Spray dates and products applied							
		14 Apr	21 Apr	28 Apr	4 May	11 May	18 May	25 May	1 Jun
Untreated check									
Novaluron 0.83 EC	14 oz			Novaluron	Oxymyl	Novaluron	Oxymyl	Novaluron	Oxymyl
Diflubenzuron 25 WP	6 oz			Diflubenzuron	Oxymyl	Diflubenzuron	Oxymyl	Diflubenzuron	Oxymyl
HMO 435	0.25% v/v	HMO	HMO	HMO	HMO + oxymyl	HMO + thiamethoxam 25 WDG	HMO + oxymyl	HMO + thiamethoxam 25 WDG	HMO + oxymyl
HMO 435	0.5% v/v	HMO	HMO	HMO	HMO + oxymyl	HMO + thiamethoxam 25 WDG	HMO + oxymyl	HMO + thiamethoxam 25 WDG	HMO + oxymyl
HMO 435	1.0% v/v	HMO	HMO	HMO	HMO + oxymyl	HMO + thiamethoxam 25 WDG	HMO + oxymyl	HMO + thiamethoxam 25 WDG	HMO + oxymyl
HMO 435	2.0% v/v	HMO	HMO	HMO	HMO + oxymyl	HMO + thiamethoxam 25 WDG	HMO + oxymyl	HMO + thiamethoxam 25 WDG	HMO + oxymyl
HMO 415	2.0% v/v	HMO	HMO	HMO	HMO + oxymyl	HMO + thiamethoxam 25 WDG	HMO + oxymyl	HMO + thiamethoxam 25 WDG	HMO + oxymyl
Acetamiprid 30 WDG	4 oz				Oxymyl	TD2472-01	Oxymyl	TD2472-01	Oxymyl
Acetamiprid 70 WP	1.2 oz				Oxymyl	Acetamiprid 70 WP	Oxymyl	Acetamiprid 70 WP	Oxymyl
Acetamiprid 70 WP	1.7 oz				Oxymyl	Acetamiprid 70 WP	Oxymyl	Acetamiprid 70 WP	Oxymyl

Table 3. Whitefly immatures, phytotoxicity rating, bacterial spot rating, number and weight of marketable fruit and number of unmarketable fruit from 20 tomato plants adjusted to 25 lb boxes per acre in experimental plots in fall, 2003.

HMO (% v/v)	Imidacloprid (16 oz)	Whitefly[z]	Phyto[y]	Bacteria[x]	Yield[w] (bx/ac)	Yield[w] (bx/ac)	Culls[v] (No)
0	Yes	3.0 a[u]	0.0 c	0.6 d	2952 a	1407 a	195 a
0.5	Yes	1.5 b	0.1 c	0.7 cd	2459 ab	1092 b	62 b
1	Yes	1.3 bc	0.4 b	1.2 bc	2207 b	943 b	57 b
1	No	1.2 bc	0.4 b	1.5 b	2139 b	927 b	37 b
2	Yes	0.1 c	1.0 a	2.1 a	1375 c	602 c	95 b

[z]Mean number of nymphs + pupae per 84 cm^2.
[y]8 week summary of ratings.
[x]6 week summary of ratings.
[w]Large plus X-large, both harvests combined.
[v]Worm-damaged.
[u]Means in columns followed by the same letter are not significantly different (LSD, 0.05).

trol of southern armyworm (SAW, *Spodoptera eridania*) larvae, although more were seen on plants treated only with drenches of imidacloprid 2F or clothianidin 16 WSG compared to the remaining treatments. All treatments provided protection from SAW damage compared to the control, with least damage seen on plants treated with HMO, lamda cyhalathrin, indoxacarb, the high rate of methoxyfenozide (Intrepid 2F, Dow AgroScience, Indianapolis, Ind.) or the low rate of E2Y45 though not significantly different from the low rate of methoxyfenozide 2F the high rate of E2Y45 or emamectin benzoate. The highest number and weight of marketable fruit were harvested from plants treated with HMO, though not significantly different from all other treatments except for those made to the soil. Only plants treated with emamectin benzoate, indoxacarb, and HMO yielded significantly fewer unmarketable fruit than the control, with fewest seen on the latter. Thus, HMO provided as good or better protection against both whitefly and SAW as the other products tested that specifically targeted these pests.

Pepper

Spring, 2004—Experiment 1. Fewer whitefly pupae were seen on plants treated with all but the lowest rate of HMO and with novaluron 10 EC on 11 May (Table 6). Fewer adults were seen 17 May on plants treated with 2% HMO compared to the untreated check, with the other oil treatments intermediate. Fewest pupae were seen with 2% HMO, although not less than the lower rates, HMO and novaluron. All treatments resulted in fewer adults than the control on 1 June, with fewest seen on plants treated with 2% HMO. Fewest pupae were seen with the two highest rates of HMO and the acetamiprid (Assail 70 WP Cerexagri + 1% HMO, tank mix, although not significantly fewer than the lower rates, HMO (Sunspray) or novaluron. No phytotoxicity was observed with any treatment. Thus, the horticultural mineral oils added to each spray provided an extra measure of protection against silverleaf whitefly in pepper.

Experiment 2. Significant reduction of fallen peppers due to weevil damage was observed for all treatments except those including diflubenzuron (Dimilin), acetamiprid (Assail®) and imidacloprid (Provado 1.6F) (Table 7). Fewest fallen fruit were observed from all remaining plants treated with 2% HMO (Sunspray Ultrafine®, Sun Oil Company, Philadelphia, Pa.) plus either oxymyl (Vydate® 2L, Dupont Agricultural Products, Wilmington, Del.) or thiamethoxam (Actara® 25 WDG. Syngenta Crop Protection, Greensboro, N.C.), although differences were not significant. Fewest infested fruit were observed from plants treated with 2% PureSpray Green HMO plus either oxymyl 2L or thiamethoxam 25 WDG, although differences with the other treatments, except for the control, were not significant. Most marketable fruit were harvested from plants treated with 0.5% PureSpray Green Oil plus either oxymyl @L or thiamethoxam 25 WDG, although differences were not significant compared to plants treated with novaluron and oxymyl, thiamethoxam 25 WDG + 0.5% HMO and oxymyl, cryolite @ 12 lb + thiamethoxam 25 WDG and oxymyl, thiacloprid (Calypso 4, Bayer Crop Science, Greensboro, N.C.) and oxymyl, or any rate of HMO mixed with thiamethoxam 25 WDG or oxymyl. Thus, the addition of HMO to the standard thiamethoxam/oxymyl spray alternation seemed to provide additional control of pepper weevil.

Fall 2004. Pressure from whiteflies and armyworms was light. No significant treatment effects were observed in numbers of adult whiteflies over all sample dates (Table 8). Most armyworms were observed on untreated plants, with none seen on plants receiving the highest (2%) rate of HMO (PureSpray Green Oil). About 10 times more untreated plants were seen with moderate to heavy broadmite damage than on treated plants, with no significant differences between rates of oil. Fewest aphids were seen on plants treated with the 2% rate of HMO, but there was no difference between the 1% rate and the untreated check. This may have been because the lack of treatment was compensated by a higher ladybeetle population on untreated plants compared to treated plants. Most bacterial spot was seen on plants treated with 2% HMO, with no differences among the other rates or between them and the check. In terms of fruit number, greatest yield came from plants treated with HMO at the 2% rate, and least from plants treated at the 1% rate. In terms of weight, plants treated at 0.5% produced most, but not different from other treatments except 1% HMO. Culls considered unmarketable because of disease were least prevalent from plants treated with 2% HMO. Thus, we again saw pest suppression benefits from weekly sprays of HMO, although there also appeared to be suppression of ladybeetles.

The above field trials produced both expected and unexpected results. We expected to observe little if any phytotoxicity on foliage of tomato or pepper after applying the HMO Purespray green. We observed some phytotoxicity in tomato but only at high rates (2%) and during the hottest period of the early fall season. Phytotoxicity of HMOs has been attributed to transient inhibition of transpiration and subsequent heat stress resulting from obstruction of the stomata and to membrane disruption that is greatly enhanced by photodeg-

Table 4. Whitefly adults per beat sample and immature counts per 6 cm², leaf incidence of new TYLCV infestation for the week of 28 Apr. - 5 May, and yield of 20 plants adjusted to 25 lb boxes per acre, tomato, spring 2004.

		Whitefly adults per beat sample and immature counts per 6 cm² leaf									Yield (boxes/acre)			
		26 Apr		11 May		24 May		1 Jun			2 Jun			
Treatment/formulation	Rate amt form/acre	Adults	Large Nymphs	Adults	Pupa	Adults	Pupae	Adults	Pupae	TYLCV 5 May (%)	X- Large (no.)	X- Large (lbs)	Total (no.)	Total (lbs)
Acetamiprid 70 WP	5.7oz	103.7 ab	0.3 d	193.3 ab	7.6 bc	24.0 b	9.9 abcd	362.5 a	27.8 ab	24.0 b	172 ab	67b	835 ab	335 a
Root Feed I & II[w] + Imidacloprid 2F	5 gal/15 lb 16 oz	79.6 ab	1.9 cd	258.3 a	4.6 cde	17.1 bc	13.5 ab	398.8 a	24.9 abc	17.1 bc	177 ab	67 b	934 ab	344 a
Imidacloprid 2F	16 oz	54.4 ab	0.3 d	147.5 b	1.8 de	20.2 ab	6.1 cde	388.8 a	6.6 ef	20.2 ab	302 ab	120 ab	1210 a	504 a
Imidacloprid 2F + Spiromesifen 2SC[z]	16 oz 8.5 oz	56.5 ab	0.4 d	135.8 b	1.6 de	13.8 bc	1.2 e	75.9 b	0.5 f	13.8 bc	351 a	147 a	1171 a	541 a
Thiamethoxam 2SC	8 oz	76.6 ab	0.6 d	149.2 b	4.0 cde	19.2 b	10.9 abcd	388.8 a	16.2 bcde	19.2 b	256 ab	104 a	913 ab	411 a
Thiamethoxam 2SC + Actigard 50WG[y] + Pymetrozine 50WG[x]	8 oz 0.33 oz 2.75 oz	66.7 ab	0.3 d	165.0 b	2.6 de	14.8 bc	4.3 de	390.6 a	14.1 cde	14.8 bc	290 ab	116 ab	1034 ab	463 a
+ HMO 435 + Imidacloprid 2F	0.25% v/v 16 oz	60.5 ab	0.8 d	154.2 b	3.9 cde	15.3 bc	9.1 bcd	388.8 a	16.8 bcde	15.3 bc	206 ab	85 ab	874 ab	356 a
HMO 435 + Imidacloprid 2F	0.5% v/v 16 oz	65.8 ab	0.1 d	190.0 ab	3.6 de	23.3 ab	4.6 de	391.3 a	13.6 cde	23.3 ab	273 ab	109 ab	1053 ab	465 a
HMO 435 + Imidacloprid 2F	1.0% v/v 16 oz	30.2 b	0.0 d	173.8 b	0.4 e	5.7 c	5.3 de	370.0 a	11.6 de	5.7 c	235 ab	94 ab	947 ab	400 a
HMO 435	1.0% v/v	155.8 a	2.9 bc	201.7 ab	5.6 bcd	6.1 bc	13.4 ab	385.0 a	18.4 abcd	16.1 bc	188 ab	76 ab	78 ab	323 a
HMO 415	1.0% v/v	139.6 a	3.8 b	208.8 ab	9.0 b	21.8 ab	12.5 abc	393.8 a	29.7 a	21.8 ab	159 b	64 b	905 ab	327 a
Untreated Check		130.8 ab	6.4 a	218.3 ab	16.4 a	33.3 a	16.3 a	400.0 a	26.1 ab	33.3 a	174 ab	68 b	743 b	306 a

[z]3 weekly applications beginning 11 May.
[y]4 weekly applications beginning 4 May at 0.33 lb product per acre and increasing incrementally to 0.75 oz per acre.
[x]2 weekly applications beginning 11 May and tank mixed with an organosilicant, Kinetic, at 0.1% v/v.
[w]9-0-0 liquid fertilizer and 5-10-27 soluble fertilizer (Rootfeed I and II respectively, Stoller Enterprises, Houston, TX).

Table 5. Mean number of whiteflies per beat on each of 8 plants per plot over 7 evaluations, 11 Oct, 18 Oct, 25 Oct, 1 Nov, 8 Nov, 15 Nov, and 22 Nov., mean number of SAW larvae per plant over 4 evaluations, 29 Oct, 5 Nov., 10 Nov., and 19 Nov., and number and weight of marketable and insect damaged small, medium, large and X-large fruit from 16 plants over 2 harvests adjusted to number of 25 lb boxes per acre.

					Mean number and weight of fruit			
					Marketable		Unmarketable	
Treatment/formulation	Rate (form/acre)	Whitefly adults[a]	Larvae	Damage	No	Boxes/acre	No	Boxes/acre
Emamectin benzoate 5 SG	2.4 oz		0.02 c	0.52 de	3573 abcd	1385 abcd	524 cde	219 bc
λ-cyhalothrin 1 CS	3.8 oz		0.09 c	0.45 e	4432 ab	1670 ab	518 cde	225 abc
E2Y45 1.7 SC	8.3 oz		0.33 c	0.43 e	4047 abc	1636 abc	641 abcd	277 ab
E2Y45 1.7 SC	33.2 oz		0.15 c	0.52 de	3966 abcd	1532 abcd	742 abcd	240 abc
Clothianidin 16 WSG	15 oz	7.8 a	1.16 b	0.76 cd	2420 cd	1030 cd	972 abc	397 ab
Clothianidin 16 WSG	20 oz	8.5 a	1.41 b	1.10 b	2720 bcd	1100 bcd	1041 a	417 a
Imidacloprid 2F	16 oz	6.8 ab	1.04 b	0.90 bc	2968 abcd	1082 ab	998 ab	382 ab
HMO	0.5%-2.0%	3.3 b	0.10 c	0.30 e	4704 a	1857 e	182 e	68 ab
Methoxyfenozide 2F	6.0 oz		0.08 c	0.79 cd	3856 abcd	1565 abc	807 abcd	344 ab
Methoxyfenozide 2F	8.0 oz		0.27 c	0.52 de	3448 abcd	1474 abcd	566 bcde	244 abc
Indoxacarb 30 WP	3.4 oz		0.04 c	0.40 e	4075 abc	1692 ab	436 de	207 bc
Untreated		4.5 ab	2.45 a	2.00 a	2266 c	952 d	980 abc	352 ab

redation products (Hodgkinson et al., 2002). Each of these processes would be dose and temperature dependent. Toxic photodegredation products are formed from unsaturated impurities or sulfonatable residues which are claimed to be less than 1% in HMO (PureSpray Green oil), but up to 8% in HMO (Sunspray Ultrafine). The duration of these effects is a function of the persistence of the oil, and therefore negatively correlated with volatility. In other words, residues of heavier oils persist longer on the leaf surface than lighter oils and are therefore more phytotoxic. HMO (PureSpray Green) has a midrange boiling point of 435°F compared to 415 °F for HMO (Sunspray Ultrafine). On the other hand, greater persistence results in greater insecticidal activity for the same reasons described above and this, too, was consistent with our observations of the two HMOs. In addition, the leaf cuticle acts as a barrier between the leaf surface and sensitive plant tissues, and therefore cuticle thickness is another determining factor in sensitivity. This is why citrus is more tolerant to HMOs than tomato and older plants are more tolerant than younger plants. Therefore, lower rates of HMOs should be used when temperatures are high and plants are tender.

An unexpected outcome of one of the trials was the exacerbation of bacterial spot, caused by *Xanthomonas compestris* pv vesicatoria that we observed in the fall of 2004 when disease pressure was high due to warm temperatures and windblown rain. Although HMOs have not been specifically linked to bacterial disease in the literature to our knowledge, surfactants have (Gottwald et al., 1997). These authors speculated that invasion of stomata and hydrothodes by the bacteria could be aided by wetting agents contained in certain adjuvants. Thus, the exacerbation of bacterial spot we observed may have been caused by the surfactant used to emulsify the oil rather than the oil itself. In this case, it might be possible to formulate the HMO with less or weaker surfactants for use where and when the risk of bacterial disease is high.

We expected and observed suppression of small, soft-bodied insects including whiteflies, aphids and broadmite. All stages of these organisms are susceptible to oil induced suffocation, and in addition, oviposition may have been suppressed through repellency (Liu and Stansly, 1995b). However, contact with the insect and therefore good coverage is necessary for these mechanisms to function. The white-

Table 6. Whitefly adults and "pupae" on pepper, Experiment 1, Spring 2004.

		[z]Mean adults per beat sample or pupae per 4 cm^2 per leaf					
		11 May	17 May	24 May		1 Jun	
Treatment/formulation	Rate: form/acre	Pupae	Adults	Adults	Pupae	Adults	Pupae
1. Untreated Check		1.0 a	61.9 a	50.3 abc	4.9 a	316.3 a	4.4 a
2. Novaluron 0.83 EC	14 oz	0.2 bcd			0.2 e		1.1 cde
3. Diflubenzuron 25 WP	6 oz	0.7 abc			2.8 bc		2.9 b
4. HMO 435	0.25% v/v	0.8 ab	28.3 ab	41.1 abcd	0.9 de	149.4 cd	1.4 cde
5. HMO 435	0.5% v/v	0.2 bcd	33.6 ab	54.3 ab	1.1 de	117.5 d	1.6 bcde
6. HMO 435	1.0% v/v	0.1 d	26.2 ab	39.2 bcd	0.3 e	128.3 cd	0.3 e
7. HMO 435	2.0% v/v	0.2 cd	14.3 b	34.0 cd	0.1 e	53.4 e	0.3 e
8. HMO 415	2.0% v/v	1.2 a	34.6 ab	53.1 abc	0.6 de	185.6 bc	0.8 de
9. Acetamiprid 30 WDG	4.0 oz			60.0 a	2.0 bcd	229.4 b	1.9 bcd
10. Acetamiprid 70 WP	1.2 oz			24.3 d	3.3 b	145.6 cd	2.4 bc
11. Acetamiprid 70 WP	1.7 oz			49.6 abc	2.1 bcd	136.6 cd	1.7 bcde
12. Acetamiprid 70 WP + HMO 435	1.2 oz + 1.0%			37.6 bcd	1.7 cde	184.3 bc	0.6 de

[z]Total from beating 1 side of 4 plants.

Table 7. Fallen Jalapeño peppers infested with pepper weevil, infested fruit and marketable fruit harvested, adjusted to 25 lb boxes per acre.

Treatment/formulation	Rate form/acre	Fallen pepper[z] 3 Jun	Infested[y] fruit (%)	Marketable fruit (bx/ac)
1. Novaluron 0.83EC	12 oz	16.3 cd	23 bc	500 abc
2. Diflubenzuron 25 WP	6 oz	39.3 abcd	159 b	365 d
3. Acetamiprid 30 WDG	4 oz	34.5 abcd	121 bc	405 bcd
4. Acetamiprid 70 WP	1.2oz	50.0 ab	129 bc	435 abcd
5. Acetamiprid 70 WP	1.7 oz	30.5 abcd	129 bc	395 cd
6. Acetamiprid 70 WP + HMO 435	1.2 oz + 1.0% v/v	25.5 bcd	30 bc	505 cd
7. Cryolite 96	8 lb	13.8 cd	38 bc	515 ab
8. Cryolite 96	12 lb	11.3 cd	83 bc	506 abc
9. Imidacloprid 1.6F	7 oz	45.5 abc	114 bc	374 c
10. Thiacloprid 2EC	4.5 oz	12.8 cd	91 bc	456 abcd
11. HMO 435	0.25% v/v	13.0 cd	45 bc	455 abcd
12. HMO 435	0.5% v/v	13.8 cd	45 bc	523 a
13. HMO 435	1.0% v/v	10.8 cd	30 bc	488 abc
14. HMO 435	2.0% v/v	21.0 bcd	0 c	464 abcd
15. HMO 415	2.0% v/v	7.5 d	15 c	498 abc
16. Thiamethoxam 25 WDG	4 oz	10.8 cd	106 bc	508 abc
17. Untreated check		57.3 a	402 a	241 e

[z]Fallen peppers from 27 plants per plot, also checked on 21 and 28 Jun with no significant difference between treatments.
[y]Percentage of harvested peppers infested with weevil larvae.

Table 8. Whitefly adults, southern armyworm (SAW) larvae, broadmite and aphid infestation, ladybeetle larvae and adults and intensity of bacterial spot on bell pepper, fall 2004.

		Mean over all dates						
Treatment	Rate (per acre)	Whitefly Adults	SAW	Broadmite[x]	Aphids[w]	Ladybeetle larvae[v]	Ladybeetle adults[w]	Bacterial Spot
Untreated		1.2 a	1.7 a	35 a	66 a	0.35 a	0.38 a	0.27 b
HMO 435	0.5% v/v	1.7 a	0.7 b	3 b	33 b	0.02 b	0.02 b	0.26 b
HMO 435	1.0% v/v	1.7 a	0.2 b	7 b	60 ab	0.05 b	0.02 b	0.31 b
HMO 435	2.0% v/v	1.8 a	0.0 b	3 b	18 c	0.00 b	0.02 b	0.56 a

[z]Total from beating 1 side of 6 plants.
[y]Total per plant, total over 4 dates.
[x]Percentage of plants with moderate or more damage, mean over 3 dates.
[w]Percentage of plants with 10 or more aphids, mean over 3 dates.
[v]Number of larva observed from 3 leaves per plant, 18 Nov.
[u]Number of adults observed from 3 leaves per plant, 18 Nov.

fly *Bemisia tabaci* is the key pest of tomato in Florida and elsewhere due to its damage potential and role as virus vector. Management of this pest is greatly dependent on soil-applied neonicotinoid insecticides such as imidacloprid. However, weekly applications of HMO were effective in suppressing whiteflies, rivaling the neonicotinoid when pressure was relatively low. Therefore, HMOs should be included in whitefly management programs, either alone or in combination with conventional insecticides.

Another unexpected outcome was the apparent suppression of southern armyworm and pepper weevil with weekly applications of HMO. It has been reported, however, that HMOs function as oviposition deterrents for many types of insects, including weevils, and that HMOs kill small larvae of Lepidoptera (Khattak, 2000; Mensah et al., 2005). If repellency were the principal mechanism for the suppression of these insects that we observed in our small plots, then it may not translate to a large scale commercial setting where flying to an unsprayed plant is not an option. Therefore, large scale testing is necessary to asses the true potential of HMOs to suppress insect pests of vegetable crops.

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