Imidacloprid Does Not Enhance Growth and Yield of Cantaloupe in the Absence of Whitefly

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Abstract.

Imidacloprid is a new, chloronicotinyl insecticide currently being used to control sweetpotato whitefly (Bemisia tabaci Genn, also known as silverleaf whitefly, Bemisia argentifolii Bellows and Perring). Large growth and yield increases of cantaloupes (Cucumis melo L.) following the use of imidacloprid have caused some to speculate that this compound may enhance growth and yield above that expected from insect control alone. Greenhouse and field studies were conducted to evaluate the growth and yield response of melons to imidacloprid in the presence and absence of whitefly pressure. In greenhouse cage studies, sweetpotato whiteflies developed very high densities of nymphs and eclosed pupal cases on plants not treated with imidacloprid, and significant increases in vegetative plant growth were inversely proportional to whitefly densities. Positive plant growth responses were absent when plants were treated with imidacloprid and insects were excluded. Results from a field study showed similar whitefly control and yield responses to imidacloprid and bifenthrin+ endosulfan applications. Hence, we conclude that growth and yield response to imidacloprid is associated with control of whiteflies and the subsequent prevention of damage, rather than a compensatory physiological promotion of plant growth processes.

Introduction

The sweetpotato whitefly, also known as silverleaf whitefly (Bellows et al. 1994), has recently become a serious economic pest of cantaloupes (Perring et al. 1993). Damage by whitefly species to most crops includes a reduction in plant growth caused by the removal of plant assimilates from the phloem during feeding (Buntin et al. 1993) and the excretion of honey-dew which promotes the growth of sooty mold on harvestable plant parts (Byrne and Miller, 1990). Fruit quality and yield of cantaloupe can decrease when immature whitefly population densities are not properly controlled (Palumbo 1994a).

Imidacloprid (Admire 2F, Miles Inc., Kansas City, KS) is a new chloronicotinyl insecticide that is toxic to many insect pests (Elbert et al. 1990). It has good systemic insecticidal activity in the plant, and performs best when applied to the soil to be absorbed by roots (Mullins 1993). This chemical has demonstrated exceptional control of sweetpotato whitefly populations in cantaloupes (Palumbo et al. 1994). Imidacloprid was first used commercially in the United States in 1993 for sweetpotato whitefly on lettuce (*Lactuca sativa* L.) and cantaloupes in Arizona and California. Because yields improved in most fields following imidacloprid applications (Palumbo 1994b), observers speculated that imidacloprid may have a plant growth regulator (PGR) effect on plants that can increase yield above that expected from insect control alone.

Plant growth and yield enhancement has been attributed to some insecticides by several investigators (Scott et al. 1985, Parrot et al. 1985). However, in many cases more rigorous evaluations have shown that plant growth and yield responses are associated entirely with a reduction in insect pressure. For example, early reports that chlordimeform enhanced cotton, *Gossypium hirsutum* L., growth (Campbell et al. 1979) were latter shown to be largely associated with a reduction in insect damage (Cathey and Bailey, 1987; Youngman et al. 1990). Because imidacloprid is applied to crops as a prophylactic control measure at planting, the potential for the overuse of this compound is highly possible if growers suspect a plant growth-insecticide interaction. However, if no stimulatory effects on plant growth can be associated with imidacloprid, growers are likely to use the chemical more judiciously. Therefore, the objective of this study was to evaluate the plant growth and yield responses of cantaloupes to imidacloprid in the presence and absence of whiteflies.

Materials and Methods

Greenhouse studies All plants used in the greenhouse tests were direct seeded 'Topmark' cantaloupes in a 3:3:1 soil-perlite-peat mixture in 1.5-liter pots. Each pot contained 500 g of soil mixture and was planted with 4-5 seeds. Seedlings were grown during March and April 1994 in a glasshouse under natural light with adequate water and nutrients for maximum growth. Upon emergence, seedling plants were thinned to one per pot. Pots were then placed in wooden frame exclusion cages (1.7m width by 1.2m long by 0.6m high) screened with fine organdy cloth to exclude whitefly adults and other insects. The cages were maintained in the glasshouse at 28 ± 4 C. Whitefly adults used in these studies were of mixed age and from a population originally collected from melons at the Yuma Valley Agricultural Center. The colony was maintained on cantaloupe plants in an outdoor insectary under ambient conditions. Samples of our whiteflies that were maintained in the insectary were b-strain sweetpotato whitefly or silverleaf whitefly.

The effects of imidacloprid and whitefly feeding on seedling growth and vigor was investigated in two separate cage studies. In the first trial, imidacloprid was applied to 60 seeded pots by drenching the soil of each pot with 0.00, 0.02, 0.04 or 0.08 g AI in 18 ml of water per pot (Mullins 1993). Immediately following application, each pot was hand watered to provide adequate moisture and initiate germination of the seed. The experiments were conducted as a randomized complete block design with five replications. Each exclusion cage served as a replication. Within each cage, three pots of each rate were randomly assigned a position within the cage for a total of 12 plants per treatment. In the second trial, imidacloprid was applied at 0.00, 0.005, 0.010 or 0.020 g AI as indicated above.

When plants reached the one true-leaf stage, 1200 whitefly adults (100/plant) were collected from the insectary and released into each cage to allow for oviposition and nymphal development. Adults and nymphs were allowed to feed and develop for 35 days and then removed from the cages for assessment of whitefly densities and plant growth. Whitefly densities were estimated by counting the number of eggs, nymphs, and pupal cases from a random 2.5-cm^2 area of the six oldest leaves on each plant. Plant growth responses were based on the dry weights (mg) of leaves, petioles, and stems of each plant that had been dried at 70 C for 48 h in a forced-draft. Leaf area (cm^2) was measured with a LI-3100 leaf-area meter (LiCor, Lincoln, NE). The dry weight and leaf area measurements were used to calculate mean relative growth rate (R) and mean net assimilation rate (E) according to Hunt (1978).

Plant growth response to imidacloprid in the absence of whitefly was evaluated in exclusion cage studies using the same design as noted above. Imidacloprid was applied to 60 seeded pots by drenching the soil of each pot with 0.00, 0.02, 0.04 or 0.08 g AI in 18 ml of water per pot. The experiment was conducted three times under similar greenhouse conditions. Plant growth responses were assessed as explained above. We calculated mean whitefly densities per cm^2 per leaf, R, and E. Data from all greenhouse studies were analyzed by subjecting mean whitefly densities, mean dry weights, leaf areas, E, and R to trend analysis using General Linear Models procedure of SAS (SAS Institute 1988).

Field Study 'Top Mark' cantaloupes were established on 22 Feb, 1994 in 8m by 30m long plots in a randomized complete block design with four replicates. Treatments included 1) an untreated control, 2) a single side-dress application of imidacloprid (0.28 kg AI/ha) when the stand was thinned (3-4 leaf stage), and 3) weekly foliar applications of bifenthrin (Capture 2E, FMC Corp., Philadelphia, PA) at 0.1 kg AI/ha combined with endosulfan (Gowen Endosulfan 3EC, Gowan Co., Yuma, AZ) at 1.1 kg AI/ha . The imidacloprid was side-dressed with water through narrow shanks at a depth of 15 cm and delivered at 140 liters$\cdot$ ha^{-1} total volume immediately preceding furrow irrigation on 21 Mar. Foliar applications of bifenthrin and endosulfan were initiated on 21 March and repeated for 6 weeks using a ground sprayer equipped with two overhead hollow-cone spray tips/bed (TX-18, Spraying Systems Co.,Wheaton, Il) at 22.1 kg$\cdot$$cm^{-2}$ CO_2 pressure resulting in ca. 560 liters$\cdot$ ha^{-1} spray volume.

Whitefly counts were taken weekly beginning 30 Mar. Nymphs and pupal cases were counted on four 1-cm^2 leaf disks taken from the 4th and 10th leaf proximal to the base of ten randomly selected plants per plot per sample date. Yield data were collected from four individual harvests over 9 days. Harvested melons were culled, sorted and assessed for size and quality based on USDA standards (Johnson and Mayberry 1982) that included measurements of total number of mature cantaloupe fruit per 10-m section of row, mean circumference (cm) of each harvested cantaloupe fruit, percentage soluble sugars (Atago® refractometer, Kew Gardens, NY), and the occurrance of sooty mold on fruit. The data were analyzed by subjecting mean whitefly densities and yields to analysis of variance using ANOVA procedure of SAS employing mean separation with a protected LSD (SAS Institute 1988).

Results and Discussion

Greenhouse studies. Greenhouse plants exposed to sweetpotato whiteflies for a 35-day infestation period developed very high densities of immatures when not treated with imidacloprid (Table 1). However, the addition of imidacloprid significantly reduced the mean numbers of eggs, nymphs and pupal cases per cm^2 per leaf. Because no nymphs were found on treated plants (Table 1), the study was repeated using sequentially lower insecticide rates (Table 2). Although a few nymphs were located on plants receiving 0.005 or 0.01 g AI/pot (Table 2), nymph densities were > 70-fold higher in the control plants. This density:rate response is inversely proportional to the insecticidal activity of imidacloprid on whiteflies (Oetting and Anderson 1990). Pupal cases existed only on the untreated plants indicating that whiteflies had completed immature development and adults had emerged during the experimental period. We could not quantify the feeding effects of adults on the plants because of the difficulty in accurately measuring their absolute density. However, because female whiteflies feed and oviposit concomitantly (van Lenteren and Noldus 1990), low levels of adult feeding likely occurred on imidacloprid treated plants based on the incidence of eggs (Table 1 and 2).

Plants treated with imidacloprid and exposed to whitefly feeding pressure grew significantly better than the untreated controls. In the first test, dry weights and leaf areas were reduced 45% and 20% in control plants, respectively; during the second trial, reductions were 52% and 25%. Dry weights and leaf area measurements for all rates of imidacloprid were similar in both tests. The significant quadratic responses of plant growth measured between the untreated control and imidacloprid-treated plants were inversely proportional to whitefly densities. This was evident from the reduction in relative growth rate and net assimilation rate (Table 1, Table 2), both of which can be adversely affected by the feeding of sucking insects (Barlow and Messmer 1982, Burd and Burton 1992). Although leaf photosynthetic rates were not measured, the direct effect of whitefly feeding on photosynthesis and leaf-gas exchange likely occurred as evidenced by whitefly-induced chlorosis on the control plants. Buntin et al. (1993) reported that feeding by sweetpotato whitefly nymphs reduced leaf chlorophyll content of tomato, *Lycopersicum esculentum* Mill., leaflets and adversely affected rates of leaf photosynthesis and CO_2 assimilation.

Imidicloprid induced no positive plant growth responses when insects were excluded from cantaloupe plants. Analysis of three separate cage studies showed no significant ($P > 0.05$) increase in plant growth relative to applied rates of imidacloprid (data not shown). Pooled analysis showed that mean plant dry weight (range 0.80 to 0.84 g) and mean total leaf area (200-230 cm^2) per plant were similar for each rate of imidacloprid and the control. Similarly, R (0.25 mg/mg per day for all) and E (0.76-0.79 mg/cm^2 per day) calculated for the duration of each study showed no positive response to rate of imidacloprid. Visible evidence of leaf chlorosis, irregular growth or necrosis was absent with the exclusion of whiteflies. These findings are similar to those in cotton where aldicarb applied to the potting soil did not increase plant weight or leaf area in the absence of insect feeding (Womack and Shuster 1986). Consequently, the failure to detect a positive growth response in our study suggests that no PGR effect was associated with soil uptake of imidacloprid.

We suggest that the reductions in plant growth during our study were caused by the effects of whitefly feeding. Because whiteflies feed primarily on carbohydrates and amino acids in the phloem tissue (Byrne and Miller 1990), the lower net assimilation rates (E) observed in the infested cantaloupes (Table 1, Table 2) can be attributed largely to the removal of assimilated carbohydrates and nutrients, which would be destined for new growth and metabolic sinks in the plant. Consequently, the production of new tissue was decreased by the disruption of photosynthetic function and loss of photosynthate to whiteflies.

Field Study. Seasonal average densities of whitefly nymphs and pupal cases were significantly higher on the untreated control plants than for those receiving imidacloprid or bifenthrin+endosulfan treatments (Table 3). At harvest, nymph densities on leaves were much higher (>8 fold) in the untreated plots. Nymph densities in the insecticide treated plots were significantly lower than in the controls throughout the season. Fruit yield, melon size and percentage of soluble sugars were all significantly lower for the untreated plants, whereas yields were similar for the two insecticide treated plots. Leaf chlorosis and necrosis were evident on older leaves of the control plants. The high percentage of cantaloupe fruit from the untreated control plots that were contaminated with honeydew and associated sooty mold indicates that large amounts of phloem sap were removed from the plant (Byrne and Miller 1990). We attribute the yield differences between the control and insecticide treatments directly to whitefly feeding damage.

Mean whitefly densities and fruit yields were similar for imidacloprid and the bifenthrin+endosulfan treatments, suggesting that neither treatment had an affect on plant productivity relative to each other. These insecticides differ in terms of chemical composition, mode of action, and their route of entry into the plant (Ware 1989). Neither bifenthrin nor endosulfan have been shown to enhance plant growth or yield. Trumble et al. (1988) showed that increased yields and fruit size in strawberrys, *Fragaria x ananassa* Duchesne, treated with bifenthrin was attributed to suppression of mites and aphids, and did not chemically alter photosynthetic function. Similarly, plant growth in sorghum, *Sorghum bicolor* (L.) Moench, was not affected by applications of endosulfan (Veeraswamy 1993). Our data suggest that the similarity in yield obtained from the use of bifenthrin+endosulfan and imidacloprid was due to whitefly control and damage prevention, rather than a physiological enhancement of plant growth. Overall, our results demonstrate that soil applications of imidacloprid to cantaloupes does not affect plant growth and fruit yield in the absence of whitefly infestation and increases in seedling growth and yield associated with application of imidacloprid are due directly to a reduction in insect pest damage.

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Table 1. Effect of imidacloprid on whitefly densities (mean•cm^{-2} • leaf^{-1}), leaf area, dry weight, relative growth rate (R) and net assimilation rate (E) of cantaloupe plants grown in the greenhouse, spring 1994.

Rate[a] (g)	Eggs	Nymphs	Pupal cases	Leaf area (cm^2)	Dry wt. (g)	R (mg mg^{-1} d^{-1})	E (mg cm^{-2} d^{-1})
0.00	45.5	95.4	65.6	391	1.71	0.212	0.765
0.02	8.8	0.0	0.0	456	3.02	0.229	1.161
0.04	2.0	0.0	0.0	446	3.09	0.230	1.213
0.08	1.4	0.0	0.0	487	3.01	0.228	1.071
Lin.	**	**	**	**	**	**	*
Quad	**	**	***	**	**	**	**

[a] Rate expressed as the amount of imidacloprid active ingredient applied to the soil of each pot.
*, **,*** indicates significance at $P < 0.05$, $P < 0.01$, or $P < 0.001$ respectively.

Table 2. Effect of imidacloprid on whitefly densities (mean•cm^{-2} • leaf^{-1}), leaf area, dry weight, relative growth rate (R) and net assimilation rate (E) of cantaloupe plants grown in the greenhouse, spring 1994.

Rate (g)	Eggs	Nymphs	Pupal cases	Leaf area (cm^2)	Dry wt. (g)	R (mg mg^{-1} d^{-1})	E (mg cm^{-2} d^{-1})
0.000	34.5	58.2	27.9	268	1.90	0.251	1.351
0.005	1.7	0.8	0.0	356	4.15	0.278	2.255
0.010	1.3	0.3	0.0	390	3.99	0.276	2.189
0.020	1.5	0.0	0.0	360	4.05	0.276	2.177
Lin.	**	*	*	**	**	**	**
Quad.	**	**	**	**	**	**	**

[a] Rate expressed as the amount of imidacloprid active ingredient applied to the soil of each pot.
*, **, indicates significance at $P < 0.05$, *or* $P < 0.01$, respectively.

Table 3. Effect of imidacloprid and bifenthrin+endosulfan applications on whitefly infestation, yield, soluble sugars, size, and sooty mold incidence of cantaloupes grown in small experimental plots at the Yuma Agricultural Center, 1994.

Treatment	Seasonal density		Density at harvest		Yield [z] (fruit/10m)	Soluble Sugar (%)	Size [y] (cm)	Sooty [x] mold (%)
	Nymphs	Pupal cases	Nymphs	Pupal cases				
Untreated control	14.9	2.9	26.5	5.2	30.8	10.2	29.4	87.5
Imidacloprid	1.9	1.0	2.5	1.0	50.3	11.5	32.4	5.0
Bifenthrin +Endosulfan	2.4	1.5	3.0	1.2	52.1	11.4	32.6	6.5
$LSD_{0.05}$	2.3	0.8	8.5	2.9	16.3	1.2	2.8	17.8

[z] Yield measured as the total number of mature cantaloupe fruit per 10-m section of row.

[y] Size measured as the mean circumference (cm) of each harvested cantaloupe fruit.

[x] Percentage of harvested fruit with greater than 20% of netting contaminated with sooty mold.