Phytotoxicity of the Systemic Insecticide Imidacloprid on Tomato and Cucumber in the Greenhouse

Robert C. Ebel,¹
Byron Wallace,² and
Charles Elkins³

ADDITIONAL INDEX WORDS. **Marathon**

SUMMARY. Imidacloprid is a long-term systemic insecticide that is currently labeled under the trade name Marathon (imidacloprid, 1-[(6-chloro-3-pyridyl)methyl-4,5-dihydro-N-nitro-1-H-imidazol-2-amine, 1% granular on fritted clay, Bayer Corp., Kansas City, Mo.) for ornamental crops grown in greenhouses. The company that markets Marathon is seeking to expand its label to greenhouse-grown vegetable crops, although the rates they plan to label have not yet been divulged. Marathon was applied to cucumber (*Cucumis sativus* L. 'Turbo') and tomato (*Lycopersicon esculentum* Mill. 'Rutgers') at 0, 1/8, 1/4, 1/2, 3/4, and 1 tsp (0, 5, 10, 20, 30, and 40 mg a.i.) per 4.5-inch (550-mL) pot. Both species developed phytotoxicity symptoms of leaf chlorosis of the oldest leaves and distorted growth and marginal necrosis of newer leaves within 1 week after application. By the end of the experiment, even the lowest rate caused phytotoxicity symptoms. The symptoms were similar in appearance to Ca deficiency but cucumber foliar analysis revealed no difference in Ca, Zn, Fe, or Co across imidacloprid rates, however, Mg and B decreased whereas K and Mn increased linearly across imidacloprid rates. P, Cu, and

Mo varied quadratically with 1/2 tsp (20 mg a.i.) per pot having the lowest P and Mo, and Cu increasing at the higher rates. These data indicate that imidacloprid can alter plant nutrition. The rates of imidacloprid applied here are not recommended for use on greenhouse-grown cucumber and tomato under similar growing conditions as in this study.

Imidacloprid is a new, long-term, systemic insecticide that is highly effective against a wide range of sucking insects and some species in the Coleoptera, Diptera and Lepidoptera orders (Mullins, 1993). Marathon, the only formulation of imidacloprid that is labeled for greenhouse use, is currently registered for ornamental plants. We applied imidacloprid to tomato and cucumber at the rates labeled for ornamental crops of 1/4 tsp (10 mg) per 4.5-inch (550-mL) pot but found leaf chlorosis and marginal necrosis and suspected that imidacloprid was the cause.

Most research reports on imidacloprid have been on field-grown plants, including tomato and cucumber, and most have not reported phytotoxicity symptoms (Lutzinsky et al., 1996; Marciano and Gonzalez, 1993). Only two reports were found that indicated phytotoxicity by imidacloprid, a reduction in seed germination of sugar beets (Dewar et al., 1997) and marginal leaf necrosis of cauliflower (Natick et al., 1996). The following study was conducted to determine whether imidacloprid caused the damage to cucumber and tomato that we previously observed.

Materials and methods

PLANT CULTURE. The experiments were conducted in 1997 in an uncoated glasshouse in Auburn, Ala. Day/night temperatures averaged 82.4 °F/71.6 °F (28 °C/22 °C), respectively. Relative humidity never dropped below 40%. Plants were grown in sphagnum peat moss (75% to 85% by vol.) with the rest consisting of perlite, vermiculite, and dolomitic and calcitic limestone medium (Pro-Mix 'BX', Premier, Red Hill, Pa.).

TOMATO EXPERIMENT. On 1 July, 'Rutgers' tomato seeds were sown into a single, 72-count seedling tray that was misted every 2 h during the day to maintain high relative humidity. After germination, the seedlings were fertil-

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¹Assistant professor, Department of Horticulture, 101 Funchess Hall, Auburn University, Auburn, AL 36849.

²Assistant superintendent and ³superintendent, Plant Science Research Center, Auburn University, Auburn, AL 36849.

Fig. 1. Effect of soil-applied imidacloprid (1% granular on fritted clay) on chlorosis measured by a SPAD meter of the oldest leaf of tomato and cucumber. L, Q, and C represent significance of linear, quadratic, and cubic relationships within date across imidacloprid treatments. ns, **, * Nonsignificant or significant at $P = 0.05$, 0.01 , or 0.001 , respectively. Significant linear relationships indicate that plant response increased or decreased in a straight line across imidacloprid treatments. Significant quadratic relationships indicate that plant response increased to some maximum and then decreased. Treatments were 0, 5, 10, 20, 30, and 40 mg a.i. per 4.5-inch (550-mL) pot.**

ized once to drip with 0.021 oz/gal (11.4 mm) N as 15N-2.2P-12.5K (Cal-Mag Peters' Excel, Scotts-Sierra, Horticultural Products Co., Marysville, Ohio). Seedlings were selected for uniformity and transplanted into 48 4.5-inch standard square pots. Each pot received 15N-2.2P-12.5K using Cal-Mag Peters' Excel every 3 d for the duration of the experiment.

The experiment was conducted as a randomized complete block design with eight blocks, six imidacloprid treatments and single plant replications within each block. Marathon was broadcast on the potting media surface on 25 July 1997 at 0, 1/8, 1/4, 1/2, 3/4, and 1 tsp (0, 5, 10, 20, 30, and 40 mg a.i. per 4.5-inch pot.

CUCUMBER EXPERIMENT. 'Turbo'

cucumber seeds were sown on 14 Aug. 1997 with four seeds placed in each of 48 4.5-inch square pots. Plants were watered daily to drip. Four days after seeding, plants were thinned to two plants per pot and on 25 Aug. plants were selected for uniformity and thinned to one plant per pot by severing the other plant at the soil line so as not to disturb the root system of the remaining plant. Plants were fertilized to drip on 21 Aug., 26 Aug., and 1 Sept. with 0.022 oz/gal N (11.8 mm) as 15N-7.0P-14.1K (Peter's Peat-Lite fertilizer, Scotts-Sierra, Horticultural Products Co., Marysville, OH). The experimental design and Marathon application rates were the same as that in the tomato experiment. Marathon was applied on 26 Aug.

DATA COLLECTION. Chlorosis of the oldest leaves was estimated by light absorption at 650 nm and 940 nm and measured at 1- to 3-d intervals after treatment using a SPAD light meter (model 502, Minolta, Japan).

Tomato and cucumber plants were harvested 10 d after treatment on 25 July and 5 Sept., respectively, which corresponded to 10 d after treatment application. All leaves were removed from the stems and total leaf surface area was determined using a leaf area meter (model LI-3100; LI-COR, Lincoln, Neb.). Necrotic areas of leaves were excised using a surgical scissors and total leaf area of the undamaged portion of the leaves determined. Leaves and shoots were dried for 48 h at 167 to 185 °F (75 to 85 °C) and weighed. Leaves from the cucumber experiment were ground in a Wiley Mill and nutrient content determined by an inductively coupled argon plasma spectrometer (model ICAP 9000; Thermo-Jarrell-Ash, Franklin, Mass.) according to the procedure of Hue and Evans (1986).

STATISTICAL ANALYSIS. Data were analyzed as a randomized complete block design using the General Linear Models procedure of the Statistical Analysis System (SAS Institute, 1988). Significance of linear, quadratic and cubic polynomials were determined to ascertain the trend of plant responses across imidacloprid treatments.

Results and discussion

Phytotoxic symptoms developed on all imidacloprid treatments within 1 week after application. Leaf chlorosis decreased linearly across imidacloprid

treatments starting 5 and 4 d after treatment for tomato and cucumber, respectively, although there was also a significant quadratic relationship for cucumber 4 and 5 d after treatment because chlorosis of the low imidacloprid rates took longer to develop (Fig. 1). Chlorosis as measured

Fig. 2. Marginal leaf necrosis and reduction in whole plant growth measured by total leaf area and shoot dry weight in cucumber and tomato 10 d after imidacloprid application (1% granular on fritted clay) to soil. L, Q, and C represent significance of linear, quadratic, and cubic relationships, respectively.

ns, **, *** Nonsignificant or significant at $P = 0.05$, 0.01 , or 0.001 , respectively. Significant linear relationships indicate that plant response increased or decreased in a straight line across imidacloprid treatments. Although some quadratic and cubic relationships were significantly different, the strongest relationship for all responses was linear, so this relationship was chosen for representation. Treatments were 0, 5, 10, 20, 30, and 40 mg a.i. per 4.5-inch (550-mL) pot.

Table 1. Effect of soil-applied imidacloprid (1% granular on fritted clay) on nutrient content of cucumber leaves 10 d after treatment.

Imidacloprid (tsp/pot) ²	P	K	Ca	Mg	Mn	B	Zn	Fe	Co	Cu	Mo
	(%)					(mg·g ⁻¹ dry wt)					
0 ²	1.02	3.05	2.4	0.59	157	50	78	159	0.71	7.2	7.5
1/8	0.92	2.98	2.4	0.56	162	47	76	156	0.72	8.5	6.4
1/4	0.91	2.91	2.4	0.53	171	45	78	172	0.86	7.9	5.3
1/2	0.90	3.01	2.4	0.51	171	45	76	146	0.67	8.5	4.5
3/4	0.95	3.34	2.3	0.46	191	44	77	150	0.72	9.9	4.9
1	0.93	3.28	2.2	0.45	190	43	75	149	0.64	8.8	6.0
Significance											
L	NS	*	NS	***	***	**	NS	NS	NS	NS	*
Q	*	NS	NS	NS	NS	NS	NS	NS	NS	**	**

²0, 5, 10, 20, 30, and 40 mg a.i. per 4.5-inch (550-mL) pot.

³Linear relationships indicate that plant response increased or decreased in a straight line across imidacloprid treatments, significant quadratic relationships indicate that plant response increased to some maximum and then decreased again, or decreased to some minimum and then increased again. None of the cubic relationships were significant; 1 mg·g⁻¹ = 0.016 oz./lb.

NS, *, **, *** Nonsignificant or significant at $P = 0.05$, 0.01 , or 0.001 , respectively.

by the SPAD meter has been shown to be directly correlated with nitrogen and leaf chlorophyll content (Schepers et al., 1992; Wood et al., 1992) and photosynthetic rate (Ma et al., 1995). By the end of each experiment, there was a linear relationship in chlorosis across imidacloprid treatments.

Newly emerging leaves were distorted especially near the edges forming a cup-shape on cucumber but across the entire leaf on tomato within 5 d after treatment. Leaf cupping and marginal necrosis was most severe on the oldest leaves and diminished towards the shoot tip. Leaf necrosis was visible 7 d after treatment on both species and was most severe on oldest leaves. By the end of each experiment, the percent of total leaf area that exhibited marginal necrosis increased linearly across imidacloprid treatments, although the cubic relationship was also significant for cucumber (Fig. 2).

Whole plant growth was reduced by imidacloprid at the end of both experiments. Total leaf area and shoot dry weight decreased linearly across imidacloprid treatments. The quadratic relationship was significant for total leaf area of tomato with leaf area not strongly affected above 1/2 tsp (20 mg a.i.) per pot but decreased steeply below that rate. The root systems were observed to be smaller on imidacloprid treated plants, but they did not appear to be distorted compared to the controls.

The phytotoxic symptoms of leaf marginal necrosis, malformed leaves, and reduced shoot growth are similar to those of Ca deficiency in cucumber (Locascio, 1996), however, leaf foliar

Ca of treated plants were similar to the controls (Table 1). K and Mn increased whereas Mg and B decreased linearly across imidacloprid rates. P, Cu, and Mo varied quadratically with 1/2 tsp (20 mg a.i.) per pot having the lowest P and Mo, and Cu increasing at the higher rates. It is clear that the imidacloprid treatments altered plant nutrition, however, typical deficiency symptoms of those that differed are not similar to the damage observed in this study. Thus, differences in plant nutrition are likely a result and not a cause of the phytotoxicity symptoms.

Imidacloprid has been shown to have a half-life of <3 d when injected into stems of cucumbers (Ishii et al., 1994). This short half-life likely indicates that imidacloprid is directly catabolized by the plant, especially considering that the half-life in soil is considerably greater, up to 150 d (Mullins, 1993). It appears that excess imidacloprid in the plant disrupts metabolism sufficiently to cause senescence of older leaves and abnormal development of new leaves that culminates in marginal necrosis. The maximum amount of imidacloprid that plants can tolerate needs to be determined and probably varies by species and cultivar.

The phytotoxic symptoms reported here are similar to those reported by Natwick et al. (1996), and their procedure was somewhat similar to ours. They drenched roots of cauliflower seedlings in flats with as little as 2.57 oz imidocloprid/acre (180 g a.i./ha), transplanted the seedlings into the field 12 h later, and found that marginal leaf necrosis developed within

2 weeks after application. However, they found phytotoxicity at only one of two field locations so other factors in the growing environment apparently affect development of symptoms.

Olympic Horticultural Products (Bradenton, Fla.), the marketing company for Bayer Corp. (Kansas City, Mo.), is seeking to expand the label of Marathon for use on vegetable crops in the greenhouse, but they have not divulge publically the rates they plan to label. The rates of imidacloprid applied in this study are not recommended for use on greenhouse-grown cucumber and tomato under growing conditions similar to those in this study. Since growing conditions apparently affect sensitivity of plants to imidacloprid, we are conducting studies to determine what conditions result in phytotoxicity.

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