

Fecundity in Twospotted Spider Mite (*Acari: Tetranychidae*) is Increased by Direct and Systemic Exposure to Imidacloprid

DAVID G. JAMES¹ AND TANYA S. PRICE

Department of Entomology, Washington State University, Irrigated Agriculture Research and Extension Center, 24106 North Bunn Road, Prosser, WA 99350

J. Econ. Entomol. 95(4): 729–732 (2002)

ABSTRACT The effect of imidacloprid on fecundity in twospotted spider mites, *Tetranychus urticae* Koch, was investigated in laboratory experiments using individual females on bean leaf discs. Mites were directly exposed to spray formulations of imidacloprid or fed on discs cut from a systemically treated bean plant. Imidacloprid-treated *T. urticae* produced 10–26% more eggs during the first 12 d of adult life and 19–23% more during adulthood compared with a water-only treatment. Increased egg production occurred immediately after exposure and lasted for about 15 d in sprayed mites. In mites exposed to imidacloprid by ingestion, increased egg production was not apparent until after 6 d and lasted until about day 18. Longevity was significantly greater in mites that ingested imidacloprid but not in sprayed mites. The significance and importance of imidacloprid-stimulation of fecundity in *T. urticae* to pest management in crop systems like hops, which routinely use this insecticide, is discussed.

KEY WORDS *Tetranychus urticae*, twospotted spider mite, imidacloprid, hormoligosis, fecundity

IMIDACLOPRID, THE FIRST chloronicotinyl insecticide, was introduced in the early 1990s, and is now widely used throughout the world for the management of a range of pests on a wide range of crops. It is a versatile, broad-spectrum, systemic compound with activity against sucking insects (e.g., aphids, whiteflies, leafhoppers) and several species of Coleoptera, Diptera and Lepidoptera (Elbert et al. 1990, 1991). At normal field rates imidacloprid is not toxic to phytophagous mites (Elbert et al. 1991).

Imidacloprid has a mixed reputation regarding its safety to natural enemies of pests. It has low toxicity to spiders, some predatory beetles (carabids, staphylinids) (Kunkel et al. 1999, James and Voegelé 2001), and some predatory bugs (anthocorids, lygaeids, pentatomids, reduviids) (Hough-Goldstein and Whalen 1993, Elzen 2001, James and Voegelé 2001). However, Mizell and Sconyers (1992), Delbecke et al. (1997), Stark et al. (1995), Sclar et al. (1998) and James and Voegelé (2001), showed that imidacloprid was highly toxic to other species from most of these families. Similarly, some predatory mite (Phytoseiidae) species were tolerant of imidacloprid (Mizell and Sconyers 1992, James, 1997, James and Voegelé 2001) while others were susceptible (James and Coyle 2001). Sublethal effects of imidacloprid on natural enemies reported to date, include reduction in prey consumption (Elzen 2001) and alteration in locomo-

tory behavior (Smith and Krischik 1999, Vincent et al. 2000). A beneficial sublethal effect of imidacloprid was reported by James (1997) who reported that the predatory mite, *Amblyseius* (= *Euseius*) *victoriensis* Womersley, increased egg production by up to 54% when exposed to the compound.

Reproductive stimulation of pests (or beneficials) by sublethal doses of insecticides is the basic hypothesis of hormoligosis (Luckey 1968). For example, residues of azinphosmethyl increased the fecundity of green peach aphids, *Myzus persicae* (Sulzer) (Lowery and Sears 1986). Citrus thrips, *Scirtothrips citri* (Moulton), produced more eggs on leaves containing residues of dicofol and malathion (Morse and Zareh 1991), and twospotted spider mite, *Tetranychus urticae* Koch, increased egg production when exposed to carbaryl or DDT (Dittrich et al. 1974).

Tetranychus urticae is the most important mite pest of horticultural and field crops worldwide and is exposed to imidacloprid in many crop systems, particularly those that have aphids and whiteflies as principal pests. One example is hop production in south-central Washington where hop aphid, *Phorodon humuli* Schrank, and *T. urticae* are the major pests. Imidacloprid is routinely used to control *P. humuli* in late spring and is harmful to most predators of *T. urticae* (James and Coyle 2001), contributing to mite outbreaks during summer (James et al. 2001). The usual severity of these outbreaks led us to consider the possibility that hormoligosis is an additional factor stimulating mite population development.

¹ E-mail: djames@tricity.wsu.edu.

Materials and Methods

The effect of imidacloprid on egg production in *T. urticae* was examined in the laboratory. The *T. urticae* strain used in these experiments was obtained in 1999 from a back yard (annual weed species) in Kennewick, Washington and is held in culture on dwarf bean plants at WSU-Prosser. In each experiment, a total of 60 females were transferred from the culture onto four detached bean leaves placed lower side up on saturated cotton wool in a plastic box. Females oviposited for 24 h at 28°C under constant illumination and were then removed. Eggs were allowed to develop to adulthood under the same conditions. At adulthood, single, mated females were transferred using a fine bristle, to individual bean leaf discs (39 mm diameter) and sprayed with formulations of imidacloprid or water using a Potter Precision Spray Tower (Burkard, Rickmansworth, UK) (Potter 1952). The tower spraying pressure was 50 kPa and 2 ml of liquid was used giving a deposit of 1.6–1.8 mg of liquid per cm². In the first experiment the hop yard rate (0.013% [AI]) of a flowable formulation of imidacloprid (Admire two Flowable, Bayer, Kansas City, MO) was compared with a water-only treatment. In the second experiment the hop yard rate (0.011% [AI]) of another flowable formulation of imidacloprid (Provado 1.6 Flowable, Bayer) was compared with the Admire two formulation and water-only treatment. A fourth treatment in the second experiment consisted of watering a young dwarf bean plant with 500 ml of a 0.013% solution of Admire 2. Each experiment was replicated three times. Single females were placed on discs cut from this plant 48 h after watering. These and sprayed discs were placed on saturated cotton wool in plastic boxes and stored at 28°C under constant illumination. Ten discs were used per treatment in each replicate of both experiments. Leaf discs were examined daily and the number of eggs present were recorded and removed. The first experiment was terminated after 12 d of adult life while the second experiment continued until all females died. Data were analyzed by Student's *t*-tests or analysis of variance (ANOVA) with means separated by Fisher least significant difference procedures ($P < 0.05$).

Results

The 12-d experiments showed that female *T. urticae* sprayed with the Admire two Flowable formulation of imidacloprid produced significantly greater numbers of eggs than females sprayed with water only (Table 1). Egg production was increased by 10–26% during the first 12 d of adult life.

Both spray formulations and the systemically applied imidacloprid (Admire 2) resulted in significantly greater lifetime egg production than the water-only treatment (Table 2). Combined data from the three replicates of experiment 2, showed imidacloprid increased egg production by 19–23%. Increased egg production occurred immediately after exposure and lasted for about 15 d in sprayed mites. In mites exposed

Table 1. Effect of imidacloprid (0.013% [AI], Admire 2 Flowable) sprays on egg production of *T. urticae* during the first 12 d of adulthood, compared with water-only spray (experiment 1)

Replicate and Treatment	Mean (\pm SE) egg production	
	Daily	12-d period
1		
Admire	*14.3 (0.8)	*172.6 (8.6)
Water	12.6 (0.4)	150.1 (7.7)
2		
Admire	*16.2 (1.0)	*194.6 (4.3)
Water	12.9 (0.7)	155.1 (5.2)
3		
Admire	*16.3 (0.7)	*195.6 (5.4)
Water	14.8 (0.5)	177.7 (5.3)
Overall (1–3)		
Admire	*15.6 (0.5)	*187.6 (6.1)
Water	13.4 (0.5)	160.9 (6.9)

* All means for Admire were significantly greater than for corresponding water treatments ($P < 0.05$, *t*-test).

to imidacloprid by ingestion, increased egg production did not become apparent until day 6 and lasted until about day 18 (Fig. 1).

Overall, mite longevity was not significantly different between spray and water treatments. However, mites exposed to imidacloprid by ingestion were significantly longer-lived (Table 2).

Discussion

This study indicates that spray and systemic applications of imidacloprid at rates used in Washington hop yards, significantly increase the fecundity of *T. urticae*. Female spider mites exposed to imidacloprid produced 30–70 more eggs during their lifetime (1–1.5 eggs/d), than those not exposed to the insecticide.

Table 2. Effect of spray and systemically applied imidacloprid (0.013% [AI] Admire 2 Flowable, 0.011% [AI] Provado 1.6 Flowable) on daily and lifetime egg production and longevity in *T. urticae*, compared with water only treatment (experiment 2)

Replicate and Treatment	Mean (\pm SE) egg production		Mean (\pm) longevity, d
	Daily	Lifetime	
1			
Admire (spray)	7.8 (0.2)a	237.2 (6.6)ab	30.4 (0.5)a
Admire (systemic)	8.0 (0.5)a	221.6 (10.6)b	28.2 (1.5)a
Provado (spray)	8.3 (0.3)a	257.4 (12.5)a	30.8 (0.7)a
Water	6.6 (0.2)b	198.2 (6.7)c	30.1 (0.9)a
2			
Admire (spray)	8.4 (0.7)a	208.0 (13.9)a	25.2 (1.2)a
Admire (systemic)	7.3 (0.2)a	197.8 (6.7)a	27.1 (0.7)a
Provado (spray)	8.1 (0.2)a	182.2 (6.9)a	22.5 (0.7)ab
Water	7.2 (0.5)a	153.0 (8.6)b	21.7 (1.1)b
3			
Admire (spray)	8.8 (0.6)a	181.8 (7.2)a	21.0 (1.0)a
Admire (systemic)	7.8 (0.3)a	200.5 (4.2)a	25.7 (0.4)a
Provado (spray)	9.3 (0.9)a	173.9 (9.5)a	19.3 (1.0)b
Water	7.7 (0.5)a	134.4 (7.6)b	18.4 (0.5)b
Overall			
Admire (spray)	8.4 (0.4)a	204.9 (7.7)a	24.9 (1.0)b
Admire (systemic)	7.6 (0.2)a	205.5 (5.1)a	26.9 (0.5)a
Provado (spray)	8.6 (0.4)a	198.1 (9.3)a	23.4 (1.1)b
Water	7.1 (0.2)b	167.5 (6.6)b	24.0 (1.1)b

Means (within experiments or overall) followed by different letters were significantly different ($P < 0.05$, LSD, ANOVA).

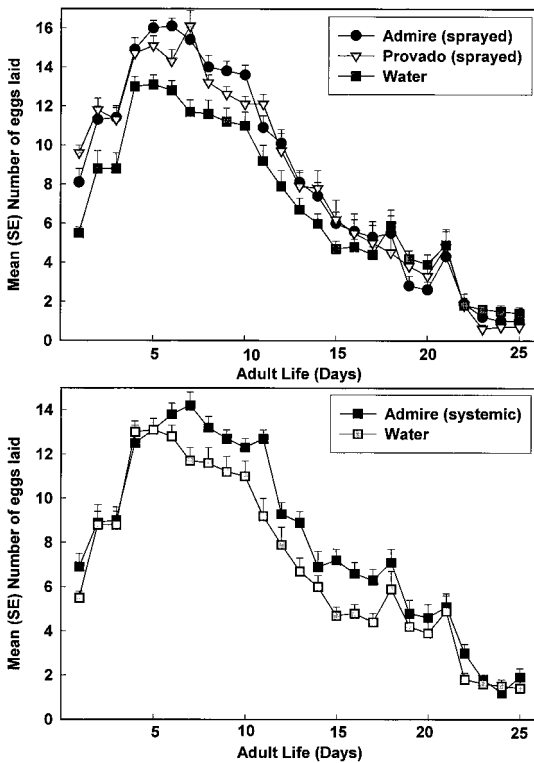


Fig. 1. Effect of sprayed and systemic applications of imidacloprid on daily egg production of *T. urticae* (experiment 2). Error bars represent standard error of the mean, 95% CL.

This represents an increase in fecundity of 20–50%, which clearly has the potential to dramatically increase the rate of population development in *T. urticae*. The massive outbreaks of *T. urticae* that are frequently seen on hops in Washington may be a consequence of imidacloprid stimulation of mite reproduction combined with suppression of natural enemies (James and Coyle 2001).

Sclar et al. (1998) concluded rather indirectly, that natural enemy suppression rather than hormoligosis was the cause of significant increases in *T. urticae* populations on imidacloprid-treated ornamentals. Field experiments (which did not involve natural enemy monitoring) showed *T. urticae* populations increased significantly on imidacloprid-treated marigolds and honeylocust trees. However, greenhouse experiments in the absence of predators showed no difference in numbers of *T. urticae* on imidacloprid-treated or untreated marigolds. Thus, the authors rejected the hormoligosis hypothesis, reinforced by their observations of increased mortality in one species of mite predator, *Orius tristicolor* (White), when confined with imidacloprid-treated plants. Egg production by individual mites was not examined.

Previously reported values for lifetime fecundity of *T. urticae* at temperatures 25–30°C range from 55.6 to 143.9 (Bengston 1969, Gutierrez 1976, Shih et al. 1976,

Carey and Bradley 1982, Wilson 1994), which are below the 167.5 reported here for mites not exposed to imidacloprid. Bounfour and Tanigoshi (2001) working with *T. urticae* from western Washington, recorded a lifetime fecundity of 121.1 and a daily oviposition rate of 7.1, the latter identical to that reported in this study for nontreated mites. The discrepancy between the lifetime fecundities in the two studies may be explained by greater longevity of our nontreated mites (24 versus 17.1 d). Thus, applications of imidacloprid to hops in south central Washington may be enhancing an already above average reproductive potential of *T. urticae* in this region.

The use of systemically applied imidacloprid to hops via drip irrigation systems is currently advocated in Washington because of presumed reduced risks to beneficial arthropods. However, the results from this study indicate that stimulation of mite fecundity is not lessened by this application method. In fact it may potentially have a greater impact because of imidacloprid's stability in the soil (Elbert et al. 1991), demonstrated multi-year carryover in hop plants (Wright and Cone 1999), and consequent season-long exposure to feeding mites. In contrast, residues from foliar applied imidacloprid degrade within a few days (Scholz and Fritz 1998). This study did not examine the effect of imidacloprid residues alone on female *T. urticae*, an issue which should be addressed in future work. We did look briefly at whether application of imidacloprid to eggs of *T. urticae* and allowing nymphs to develop on the treated leaves resulted in increased fecundity in resulting females. We saw no effect, supporting the idea that the residues of this insecticide are short-lived (unpublished data).

Other issues which should be addressed in future research include the effect of different rates of imidacloprid (is the fecundity response dose-dependent?) on *T. urticae*. Imidacloprid is only one representative from an expanding class of insecticides and whether other chloronicotinyls have the same fecundity-stimulating effect on *T. urticae*, should be determined. The impact of imidacloprid on all mite species (pest and beneficial) present in affected crop systems should also be considered. The imidacloprid-enhanced reproductive potential of *E. victoriensis* in Australian stone fruit orchards shown by James (1997) may be counter-balanced to some extent by increased reproduction of *T. urticae*, the target mite pest in that crop system. The major phytoseiid species (*Galendromus occidentalis* Nesbitt, *Neoseiulus fallacis* Garman) important in hop mite management in Washington are both eliminated by foliar applications of imidacloprid at the recommended rate (James and Coyle 2001). However, one-quarter of the rate is still effective against hop aphids and allows some survival of both predator species (D.G.J., unpublished data). We also have field evidence suggesting that this rate may be stimulatory to population development of *G. occidentalis* (James and Price, unpubl. data). If confirmed, this would open the possibility of using a reduced rate of imidacloprid to counter-balance the stimulatory effect on *T. urticae* by stimulating *G. occidentalis*.

Although there is no reason to suspect that the fecundity-stimulating effect of imidacloprid on *T. urticae* is confined to populations in Washington, the effect and its magnitude should be examined in mite populations in other parts of the United States and the world. The widespread stimulation of fecundity in *T. urticae* by imidacloprid and other chloronicotinyls, if confirmed, would have great significance and importance to many crop protection and integrated pest management (IPM) programs throughout the world. The development of IPM programs, in particular, should take into account the possibly complex interactions between imidacloprid and pest and beneficial mites.

Acknowledgments

We thank Jennifer Coyle for assistance with the early experiments. This research was partially funded by the Washington Hop Commission and Hop Research Council.

References Cited

- Bengston, M. 1969. Effect of various temperatures and relative humidities on the population growth potential of *Tetranychus urticae* (Koch). Qld. Dep. Primary Ind. Div. Plant Ind. Bull. 497. Brisbane, Queensland, Australia.
- Bounfour, M., and L. K. Tanigoshi. 2001. Effect of temperature on development and demographic parameters of *Tetranychus urticae* and *Eotetranychus carpini borealis* (Acari: Tetranychidae). Ann. Entomol. Soc. Am. 94: 400–404.
- Carey, J. R., and J. W. Bradley. 1982. Developmental rates, vital schedules, sex ratios and life tables for *Tetranychus urticae*, *T. turkestanii* and *T. pacificus* (Acarina: Tetranychidae) on cotton. Acarologia 23: 333–345.
- Delbeke, F., P. Vercruyssen, L. Tirry, P. De Clercq, and D. Degheele. 1997. Toxicity of diflubenzuron, pyriproxyfen, imidacloprid and diafenthiuron to the predatory bug, *Orius laevigatus* (Heteroptera: Anthracoridae). Entomophaga 42: 349–358.
- Dittrich, V., P. Streibert, and P. A. Bathe. 1974. An old case reopened: Mite stimulation by insecticide residues. Environ. Entomol. 3: 534–540.
- Elbert, A., H. Overbeck, K. Iwaya, and S. Tsuboi. 1990. Imidacloprid, a novel systemic nitromethylene analogue insecticide for crop protection. Proc. Brighton Crop Prot. Conf. Pests and Diseases 1: 21–28.
- Elbert, A., B. Becker, J. Hartwig, and C. Erdelen. 1991. Imidacloprid—a new systemic insecticide. Pflanzenschutz Nachr. Bayer 44: 113–116.
- Elzen G. W. 2001. Lethal and sublethal effects of insecticide residues on *Orius insidiosus* (Hemiptera: Anthracoridae) and *Geocoris punctipes* (Hemiptera: Lygaeidae). J. Econ. Entomol. 94: 55–59.
- Gutierrez, J. 1976. Etude biologique et ecologique de *Tetranychus neocaledonicus* Andre (Acariens: Tetranychidae). Travaux et Documents de L'Orstom 57: Orstom, Paris.
- Hough-Goldstein, J., and J. Whalen. 1993. Inundative release of predatory stink bugs for control of Colorado potato beetle. Biol. Control 3: 343–347.
- James, D. G. 1997. Imidacloprid increases egg production in *Amblyseius victoriensis* (Acari: Phytoseiidae). Exp. Appl. Acarol. 21: 75–82.
- James, D. G., and B. Voegelé. 2001. The effect of imidacloprid on survival of some beneficial arthropods. Plant Prot. Quart. 16: 58–62.
- James, D. G., and J. Coyle. 2001. Which pesticides are safe to beneficial insects and mites? Agric. Environ. News 178: 12–14. (<http://www2.tricity.edu/aenews>).
- James, D. G., T. Price, L. C. Wright, J. Coyle, and J. Perez. 2001. Mite abundance and phenology on commercial and escaped hops in Washington State, USA. Int. J. Acarol. 27: 151–156.
- Kunkel, B. A., D. W. Held, and D. A. Potter. 1999. Impact of halofenozide, imidacloprid and bendiocarb on beneficial invertebrates and predatory activity in turfgrass. J. Econ. Entomol. 92: 922–930.
- Lowery, D. T., and M. K. Sears. 1986. Stimulation of reproduction of the green peach aphid (Homoptera: Aphididae) by azinphosmethyl applied to potatoes. J. Econ. Entomol. 79: 1530–1533.
- Luckey, T. D. 1968. Insecticide hormoligosis. J. Econ. Entomol. 61: 7–12.
- Mizell, R. F., and M. C. Sconyers. 1992. Toxicity of imidacloprid to selected arthropod predators in the laboratory. Fla. Entomol. 75: 277–280.
- Morse, J. G., and N. Zareh. 1991. Pesticide-induced hormoligosis of citrus thrips (Thysanoptera: Thripidae) fecundity. J. Econ. Entomol. 84: 1169–1174.
- Potter, C. 1952. Apparatus for applying direct sprays. Ann. Appl. Biol. 39: 2–20.
- Scholz, K., and K. Fritz. 1998. Photolysis of imidacloprid (NTN 33893) on leaf surfaces of tomato plants. 9th International Congress on Pesticide Chemistry, London, UK (abstr.).
- Scelar, D. C., D. Gerace, and W. S. Cranshaw. 1998. Observations of population increases and injury by spider mites (Acari: Tetranychidae) on ornamental plants treated with imidacloprid. J. Econ. Entomol. 91: 250–255.
- Shih, C. T., S. L. Poe, and H. L. Cromroy. 1976. Biology, life table and intrinsic rate of increase of *Tetranychus urticae*. Ann. Entomol. Soc. Am. 69: 362–364.
- Smith, S. F., and V. A. Krischik. 1999. Effects of systemic imidacloprid on *Coleomegilla maculata* (Coleoptera: Coccinellidae). Environ. Entomol. 28: 1092–1100.
- Stark, J. D., P. C. Jeppson, and D. F. Mayer. 1995. Limitations to use of topical toxicity data for prediction of pesticide side-effects in the field. J. Econ. Entomol. 88: 1081–1088.
- Vincent, C., A. Ferran, L. Guige, J. Gambier, and J. Brun. 2000. Effects of imidacloprid on *Harmonia axyridis* (Coleoptera: Coccinellidae) larval biology and locomotory behavior. Eur. J. Entomol. 97: 501–506.
- Wilson, L. J. 1994. Plant quality effect on life history parameters of the twospotted spider mite (Acari: Tetranychidae) on cotton. J. Econ. Entomol. 87: 1665–1673.
- Wright, L. C., and W. W. Cone. 1999. Carryover of imidacloprid and disulfoton in subsurface drip-irrigated hop. J. Agric. Urban Entomol. 16: 59–64.

Received for publication 8 November 2001; accepted 12 March 2002.