Professional and Consumer Insecticides for Management of Adult Japanese Beetle on Hybrid Tea Rose

GARIMA GUPTA AND VERA A. KRISCHIK[1]

Department of Entomology, University of Minnesota, 219 Hodson Hall, 1980 Folwell Avenue, St. Paul, MN 55108

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ABSTRACT In many states, Japanese beetle, *Popillia japonica* Newman (Coleoptera: Scarabeidae), is no longer quarantined, and management is left to professional applicators and consumers. Adult management in hybrid tea rose, *Rosa* L., was compared among biorational insecticides, novel imidacloprid applications (tablet, gel, and root dip), and conventional insecticides. Efficacy of biorational insecticides used by consumers varied widely and may not offer predictable management: mortality was 3.0% with Garlic Barrier, 5.0% with Monterey Neem Oil, 15.1% with Pygenic (1.4% pyrethrins), and 27.3% with Orange Guard (D–limonene). Only JB Killer (0.02% pyrethrins plus 0.2% piperonyl butoxide) had mortality of 90.9%, probably due to piperonyl butoxide. Professional biorationals did not show significant mortality: 7.7% with Azatin XL (azadirachtin) and 3.7% Conserve (spinosad). In contrast, conventional insecticides demonstrated significant mortality; 88.4% with Decathlon 20 WP (cyfluthrin) and 83.3% with Discus SC (imidacloprid plus cyfluthrin). New imidacloprid applications (tablet, gel, and root dip) worked as well as standard drench and granular methods, but they showed 9.1–42.7% mortality. However, beetles were incapacitated as demonstrated by inability to walk (82–106-s flip time) compared with controls (30-s flip time). No phytotoxicity was observed in any treatments. However, some imidacloprid treatments produced growth enhancement: higher leaf chlorophyll (1X, 3X granular, and one tablet), and larger leaf area and higher nitrogen (3X granular, drench). The highest (active ingredient) imidacloprid was in 3X granular treatment, which in an unplanned infestation, showed highest numbers of twospotted spider mite, *Tetranychus urticae* Koch (Acari: Tetranychidae). Effects of imidacloprid on leaf quality and mite outbreaks deserves research.

KEY WORDS *Popillia japonica*, hybrid tea rose, imidacloprid, biorational insecticides

Japanese beetle, *Popillia japonica* Newman (Coleoptera: Scarabeidae), is an important pest of turf and landscape plants. Adults feed on >300 species of plants, but they prefer linden, grape, and rose (Fleming 1972, Ladd 1987). Introduced from Japan in 1916, beetles were first detected in New Jersey and have spread throughout the East Coast to Minnesota and south to the Gulf Coast (Fleming 1968; USDA 2006, 2001). Females are attracted to fertilized and irrigated turf where they lay eggs (Potter and Held 2002). Adults disperse to uninfested areas when they emerge from turf and fly to landscapes to feed on preferred hosts. Management in the landscape is accomplished by consumers and professionals.

USDA–APHIS no longer regulates the movement of nursery stock for Japanese beetle. The interstate movement of nursery material is regulated by state agencies in a protocol developed by the National Plant Board called the U.S. Domestic Japanese Beetle Harmonization Plan (Johnson et al. 2004). The agreement details ways to grow plants, use insecticides to prevent grubs from moving with nursery stock to uninfested areas, and use trapping programs to detect adults. Under the agreement, category 1 states are uninfested with quarantine status (Arizona, California, Hawaii, Idaho, Montana, Nevada, Oregon, Utah, and Washington) and require state issued Phytosanitary Certificates for shipping that declare plants were grown in nurseries that were Japanese beetle free based on negative detection. Nursery stock can be grown in Japanese beetle-free production areas or grown outside the adult flight period to prevent oviposition in containers. Acceptable treatments include root ball dips with chlorpyrifos, soil surface application of imidacloprid, and media incorporation of imidacloprid (Marathon 1% G), bifenthrin (Talstar Nursery Granular) or tefluthrin (Fireban 1.5G), and methyl bromide fumigation. Category 2 states (partially infested: Arkansas, Iowa, Kansas, Minnesota, Michigan, Nebraska, Oklahoma, Tennessee, Texas; noninfested: Alabama, Alaska, Colorado, Louisiana, Mississippi, New Mexico, North Dakota, South Dakota) require a state issued Nursery Certificate declaring that the plants were grown in nurseries that were free of Japanese

[1] Corresponding author, e-mail: krisc001@tc.umn.edu.

Table 1. Professional and consumer insecticides with trade name, common name, labeled rate, and active ingredient (AI) in ppm recommended for control of adult Japanese beetles

Insecticide trade name (common name)	(%AI) insecticide	Manufacturer's name and address	Labeled product rate	(AI) in labeled rate	(AI)/plant (ppm)
Professional insecticides					
KLN Dyna-Gro, soil (rooting concentrate, indole butyric acid and 1-naphthaleneacetic acid)	Amounts not on product	Dyna-Gro Nutrition Solutions, San Pablo, CA	1.3 ml/liter	Amounts not on product	Amounts not on product
Azatin XL, foliar (azadirachtin)	3	OHP, Inc., Mainland, PA	1.3 ml/liter	0.04 ml/liter	5
Conserve SC, foliar (spinosad)	11.6	Dow AgroSciences LLC, Indianapolis, IN	0.5 ml/liter	0.06 ml/liter	5
Decathlon 20WP, foliar (cyfluthrin)	20	OHP, Inc.	0.13 g/liter	0.03 g/liter	2.8
Discus SC, foliar (imidacloprid and cyfluthrin)	2.94 + 0.7	OHP, Inc.	1.9 ml/liter	0.06 + 0.01 ml/liter	5 + 1
Merit 2.5G, soil 1X, label rate (imidacloprid granular)	2.5	Bayer Environmental Science, Research Triangle Park, NC	20 g/plant	0.5 g/plant	125
Merit 2.5G, soil 3X, 3 times label rate (imidacloprid granular)	2.5	Bayer Environmental Science	60 g/plant	1.5 g/plant	375
Merit 2F, soil drench (imidacloprid liquid)	21.4	Bayer Environmental Science	2.08 ml/liter	0.45 ml/liter	42.5
Merit 2F, root dip (imidacloprid liquid)	21.4	Bayer Environmental Science	3.1 ml/liter	0.7 ml/liter	62.5
Merit tablet, soil, 1 tablet (imidacloprid granular)	20	Bayer Environmental Science	2.5 g/plant	0.5 g/plant	125
Merit tablet, soil, 2 tablet (imidacloprid granular)	20	Bayer Environmental Science	5 g/plant	1.0 g/plant	250
Imidacloprid gel, soil	5	Bayer Environmental Science	10 g/plant	0.5 g/plant	125
Imidacloprid + fipronil gel, soil	1 + 5	Bayer Environmental Science	10 g/plant	0.1 + 0.5.g/plant	25 + 125
Consumer insecticide					
Garlic Barrier, foliar (garlic water)	99.3	Garlic Research Labs, Glendale, CA	20 ml/liter	19.8 ml/liter	1875
JB Killer, foliar (pyrethrins+piperonyl butoxide)	0.02 + 0.2	Bonide Products., Oriskany, NY	Ready to use	0.20 + 2.0 ml/liter	19 + 190
Monterey Neem Oil 70%, foliar (clarified hydrophobic extract of neem oil)	70	Lawn and Garden Products Inc., Fresno, CA	7.9 ml/liter	5.5 ml/liter	525
Orange Guard, foliar (D-limonene)	5.8	Orange Guard, Carmel Valley, CA	200 ml/liter	11.6 ml/liter	1105
Pygenic, foliar (pyrethrins)	1.4	McLaughlin Gormley King Company, Minneapolis, MN	2.5 ml/liter	0.035 ml/liter	2.5
Insecticides not used in study but included for comparison					
Monterey Garden Insect Spray (spinosad)	0.5	Lawn and Garden Products Inc.	14.8 ml/liter	0.074 ml/liter	5
Rose and Flower Insect Killer, soil (imidacloprid + cyfluthrin)	0.36 + 0.18	Bayer Advanced, Research Triangle Park, NC	Ready to use	0.036 + 0.018 ml/liter	2.5 + 1.75
Tree and Shrub Insect Control, soil (imidacloprid)	1.47	Bayer Advanced	177.4 ml/plant	2.6 ml/plant	650

beetle. All category 1 treatments will satisfy category 2 requirements. Many of the category 2 states are partially infested.

The Harmonization Plan outlines the use of pyrethroids and imidacloprid, which is also suggested for professional applicators (Zenger and Gibb 2001, Isaacs et al. 2004). Imidacloprid is a neonicotinyl insecticide (Mullins 1993) that is common in professional (Merit, Marathon) and consumer products (Bayer Advanced Rose and Flower Care and Bayer Advanced 12-mo Tree and Shrub Insect Control). Because of its systemic properties, it has a lower risk to people (Sclar and Cranshaw 1996, Bayer Crop Sciences 1998, Gill et al. 1999, Krauter et al. 2001). Imidacloprid is recommended for use in blueberry against Japanese beetle adults (Anonymous 2006). Many new consumer products are biorationals that contain novel chemicals and advertise efficacy against adult Japanese beetles; however, there is very little efficacy data available. In the landscape, relying on the public to help reduce the movement of Japanese beetle adults may not work, and the insect will move into uninfested areas, despite state efforts at regulating the interstate movement of nursery stock.

The objective of this study was to evaluate biorational and conventional insecticides to manage adult Japanese beetle on hybrid tea rose. Insecticides that were evaluated include: biorational insecticides available to consumers (Garlic Barrier, JB Killer, Monterey 70% Neem Oil, Orange Guard, and Pygenic), conventional insecticides available to professionals that are also used in the Harmonization Plan (Merit, Decathlon 20 WP, and Discus), some new professional formulations of imidacloprid and fipronil (tablet, gel, and root dip) that offer improved worker safety, and biorational insecticides available to professionals (Conserve SC and Azatin XL) (Table 1).

Materials and Methods

Experimental Organisms. Adults were field collected from five sites in Minnesota (Theodore Worth Golf Course, Minnekhada Golf Course, and Lyndale Park Rose Garden, Hennepin Co; Stillwater Golf Course and Oak Glen Golf Course, Washington Co.) from 3 July 2006 to 10 August 2006 with Japanese beetle traps (Trécé Trap, T9004, Gempler, Madison, WI) and double lures (Trécé, Adair, OK). The lure contained kairomones (phenyl ethyl propionate and eugenol) and a floral attractant (geraniol) (Trécé, MSDS) (Ladd et al. 1976, Klein and Edwards 1989). Beetles were kept in plastic containers (30 by 15 by 10 cm) and fed fresh linden leaves placed in water tubes (25 ml, Syndicate Sales, Kokoma, IN). Because Japanese beetle adults are especially destructive to cultivated roses, *Rosa* spp. (Rosaceae), and feed on both flowers and leaves (Hawley and Metzger 1940, Fleming 1972, Potter 1998), a common tea rose, 'Mr. Lincoln', was used as the host. Mr. Lincoln was purchased in bare root bundles from Jackson and Perkins (Hebron, OH) and planted in 11.4-liter containers filled with Sunshine Professional Growing Mix (Sungro Horticulture Canada, Seba Beach, Canada). Soil at planting was fortified with ≈21 g of 14–14-14 N–P–K granular fertilizer and 35 g of slow release Osmocote (Scotts-Sierra Horticultural Products Company, Marysville, OH). Roses were grown outside on a gravel pad and supplied with water through a drip irrigation line for 10 min twice daily (St. Paul Campus, MN).

Experiment 1: Conventional and Biorational Insecticide Bioassay. Three replicated experiments were conducted simultaneously. In each replicate, there were 15 treatments with seven roses per treatment. Foliar sprays and soil applications were applied at labeled rates. Soil treatments were done 1 mo after planting on 13 June 2006 for all three replicates. Foliar sprays were applied on 19 July 2006 by using 8-liter lawn and garden sprayers (H. D. Hudson Manufacturing Company, Hastings, MN). Plants were allowed to dry for 24 h, and then leaves were excised and bioassayed. Information on insecticides and amount of active ingredient used per plant is presented in Table 1. Professional insecticide treatments were 1X (label rate) and 3X (three times label rate) granular Merit 2.5 G (imidacloprid), Merit 2 F drench (imidacloprid), Merit 2 F root dip (imidacloprid), one tablet and two tablet Merit (imidacloprid), imidacloprid gel, imidacloprid gel plus fipronil, Discus SC (imidacloprid plus cyfluthrin), and Decathlon 20 WP (cyfluthrin). Professional biorational insecticides were Azatin XL (azadirachtin), Conserve SC (spinosad) and KLN Dyna-Gro (plant hormone containing indole butyric acid and 1-naphthaleneacetic acid) reported by growers to provide pest control. Consumer biorational insecticide treatments were Monterey 70% Neem Oil, Orange Guard (D-limonene), JB Killer (pyrethrins plus piperonyl butoxide), and Pygenic (pyrethrins).

From each of seven roses per treatment, two sets of compound leaves were collected and placed on moist filter paper (12.5 cm in diameter, medium porosity filter paper, Fisher, Fair Lawn, NJ) in petri dishes (100 by 15 mm, Fisher) containing four adult beetles. Leaves were replaced as needed. After 4 d, data on daily mortality and cumulative percentage of leaf damage were recorded. In addition, because beetles did not die in all treatments, but remained upside down and trembled, a relative measurement of beetle's ability to perform normal activities such as walking was developed (as flip time). Flip time was determined by placing beetles dorsal side down on a piece of paper and recording the time required to flip onto their legs; a maximum time of 120 s was allowed (Smith and Krischik 1999). Beetles that died during the first 4 d of the bioassay were not included in the analysis of flip time.

Replicates were combined and data were analyzed by PROC GLM for treatment, replicate and treatment by replicate interactions. Data were analyzed for homogeneity using Levene's test and arcsine transformed when necessary. Means were compared using Tukey–Kramer honestly significant difference (HSD) test (SAS Institute 2003). When replicates were analyzed separately by analysis of variance (ANOVA), data were analyzed for homogeneity using Levene's

Table 2. Mean ± SEM of mortality, flip time, and leaf damage of adult Japanese beetles at 96 h postfeeding on tea rose leaves treated with consumer and professional insecticides

Insecticide trade name, (AI) ppm/plant	Mortality (%)	Flip time (s)	Leaf damage (%)
Control	2.6 ± 0.4h	30.4 ± 2.2h	100.0 ± 0.0a
		Consumer insecticides	
Garlic Barrier, 1,875 ppm	3.0 ± 1.1gh	22.2 ± 4.1h	100 ± 0.0a
JB Killer, 1,900 ppm	90.9 ± 2.9a	120.0 ± 0.0a	4.8 ± 1.7ef
Monterey 70% Neem Oil, 525 ppm	5.0 ± 1.4fgh	40.3 ± 6.0gh	27.4 ± 2.9d
Orange Guard, 1,105 ppm	27.3 ± 4.7cde	64.2 ± 6.3ef	13.4 ± 2.6e
Pygenic, 2.5 ppm	15.1 ± 2.6efg	62.1 ± 3.2f	50.8 ± 2.7b
		Professional insecticides	
KLN Dyna-Gro	5.9 ± 2.1gh	47.9 ± 4.5fg	100.0 ± 0.0a
Azatin XL, 5 ppm	7.7 ± 1.8gh	34.6 ± 2.7gh	37.5 ± 3.3c
Conserve SC, 5 ppm	3.7 ± 1.1gh	52.5 ± 3.5fg	100.0 ± 0.0a
Decathlon 20WP, 2.8 ppm	88.4 ± 1.9a	120.0 ± 0.0a	0.3 ± 0.2f
Discus SC, 5 + 1 ppm	83.3 ± 2.4a	120.0 ± 0.0a	0.2 ± 0.1f
Merit 2.5G, granular, 1X, 125 ppm	35.9 ± 4.4bc	101.9 ± 3.6abc	3.4 ± 0.3f
Merit 2.5G, granular, 3X, 375 ppm	42.7 ± 4.8b	106.0 ± 3.8ab	2.7 ± 0.3f
Merit 2F, drench, 42.5 ppm	30.1 ± 3.6bcd	98.6 ± 3.7bcd	2.1 ± 0.3f
Merit 2F, root dip, 62.5 ppm	21.3 ± 3.2def	95.9 ± 3.5bcd	2.3 ± 0.3f
Merit tablet 1, 125 ppm	9.1 ± 2.2fgh	82.0 ± 3.8de	11.8 ± 2.7e
Merit tablet 2, 250 ppm	10.6 ± 2.1fgh	95.5 ± 3.4bcd	7.1 ± 1.4ef
Imidacloprid gel, 125 ppm	16.8 ± 3.4defg	106.1 ± 2.6ab	8.2 ± 2.4ef
Imidacloprid + fipronil gel, 130 ppm	16.4 ± 3.1efg	86.2 ± 5.9cd	12.1 ± 3.6e
F (df), *P* treatment	138.5 (18, 392), <0.0001	96.9 (18, 392), <0.0001	752.5 (18, 392), <0.0001
F (df), *P* treatment (Welch)	193.2 (18, 129), <0.0001	644.4 (18, 133), <0.0001	969.8 (18, 132), <0.0001
F (df), *P* block	7.7 (2, 392), 0.0005	3.4 (2, 392), 0.0341	1.2 (2, 392), 0.3042
F (df), *P* treatment × block	2.8 (36, 392), <0.0001	2.1 (36, 392), 0.0006	2.3 (36, 392), <0.0001

Means in the same column followed by different letters are significantly different; PROC GLM, Welch test, and Tukey–Kramer HSD comparison of means, $\alpha = 0.05$.

test. If arcsine transformation could not meet the assumptions of homogeneity, then the Welch's test was recorded. Means were compared using Tukey–Kramer HSD test (JMP 2005).

Experiment 2: Growth Enhancement of Imidacloprid on Roses. Three replicated experiments were conducted simultaneously. In each replicate, there were 15 treatments with seven roses per treatment. To determine whether imidacloprid enhanced growth in roses, we obtained data on chlorophyll content, leaf area, shoot length, and percentage of total nitrogen. For chlorophyll content, leaves on the third shoot from the top were evaluated using a Field Scout CM 1000 (Spectrum Technologies, Plainfield, IL) on two dates, leaf area by using a LI-COR leaf area meter (LI-COR, Lincoln, NE), and shoot length with a ruler. Total nitrogen was determined by the Dumas Dry Combustion method at the University of Minnesota Soil Testing Laboratory (St. Paul campus). This technique uses a LECO FP-528 Nitrogen Analyzer to determine total nitrogen (N) in plant materials. A 150–200-mg sample is weighed into a gel capsule and dropped into an 850°C furnace purged with O_2 gas. The combustion products of CO_2, H_2O, and nitrate-nitrite (NO_x) are filtered, cooled by a thermoelectric cooler to condense most of the water, and collected in large ballast. A 3-cc aliquot of the ballast combustion products is integrated into a He carrier stream and passed through a hot copper column where the O_2 is removed and the NO_x gases are converted to N_2 and a reagent tube that scrubs the CO_2 and remaining H_2O from the stream. The N_2 content is then measured by a thermal conductivity cell against a He background, and the result is displayed as weight percentage of nitrogen.

Data were analyzed as described previously under experiment 1. The natural infestation of twospotted spider mites, *Tetranychus urticae* Koch (Acari: Tetranychidae) in the granular and drench treatments was analyzed by chi-square test because the variance was large (JMP 2005).

Experiment 3: Treated and Untreated Choice Test. Three replicated experiments were conducted simultaneously. In each replicate, there were 15 treatments with six roses per treatment. Insecticides that had least mortality to Japanese beetle were selected for choice tests. Beetles were given a choice between treated and untreated shoots (two shoots, 25 cm in length in water tubes) placed at opposite ends of a plastic container (30 by 15 by 10 cm). Containers were covered with mesh cloth and 15–20 beetles were released at equal distances from both shoots. Numbers of beetles on each shoot and percentage of leaf damage were recorded after 24 h. Data were analyzed as described in experiment 1.

Results

Experiment 1: Conventional and Biorational Insecticide Bioassay. Among professional products, Japanese beetle mortality was high with Decathlon 20 WP (88%), Discus SC (83%), and most imidacloprid formulations (9.1–42.7%). Beetles on these treatments died quickly and could not flip over (120-s maximum

Table 3. Mean ± SEM of chlorophyll index, leaf area, shoot length, total nitrogen, and number of mites on leaves of imidaclopird-treated hybrid tea rose

Insecticide trade name, (AI) ppm/plant	Chlorophyll index		Leaf area (cm^2)	Leaf area (cm^2)[a]	Shoot length (cm)	Total N (%)[b]	No. mites[b]
	Brightness 1–2	Brightness 3–6					
Control	326.2 ± 9.6cd	298.8 ± 10.9c	41.7 ± 2.2a	41.7 ± 2.2b	89.6 ± 4.1a	2.19 ± 0.02b	76.6 ± 27.5ab
Merit 2.5G, granular, 1X, 125 ppm	394.3 ± 12.8a	399.2 ± 27.3ab	46.1 ± 2.1a	46.1 ± 2.1ab	103.9 ± 5.3a	2.23 ± 0.03b	79.3 ± 23.4ab
Merit 2.5G, granular, 3X, 375 ppm	411.4 ± 13.1a	474.1 ± 26.9a	50.7 ± 1.9a	50.7 ± 1.9a	98.5 ± 6.1a	2.48 ± 0.03a	139.0 ± 28.5a
Merit 2F, drench, 42.5 ppm	388.4 ± 10.2ab	361.2 ± 23.5bc	50.8 ± 2.1a	50.8 ± 2.1a	90.9 ± 4.1a	2.44 ± 0.03a	24.3 ± 10.7b
Merit tablet 1, 125 ppm	392.4 ± 11.9a	390.1 ± 19.4b	45.4 ± 2.2a	45.4 ± 2.2ab	93.2 ± 4.6a		
Merit tablet 2, 250 ppm	371.2 ± 9.6abc	378.1 ± 12.9bc	41.9 ± 2.3a	41.9 ± 2.3b	96.0 ± 3.8a		
Merit 2F, root dip, 62.5 ppm	320.3 ± 10.2d	295.9 ± 11.5c	47.0 ± 1.8a		85.3 ± 4.3a		
Imidacloprid gel, 125 ppm	341.6 ± 10.1bcd	356.3 ± 11.1bc	47.3 ± 2.8a		84.1 ± 3.6a		
F (df), *P* treatment	10.4 (7, 120), <0.0001	2.6 (7, 120), 0.0168	2.6 (7, 120), 0.0168	3.6 (5, 90), 0.0049	2.1 (7, 120), 0.0459	23.9 (3, 60), <0.0001	3.9 (3, 57), 0.0121
F (df), *P* treatment (Welch)	9.3 (7, 58.2), <0.0001	10.2 (7, 57.8), <0.0001	2.5 (7, 58.2), 0.0262	3.5 (5, 47.5), 0.0089	1.9 (7, 58.2), 0.0719	24.2 (3, 37.5), <0.0001	5.8 (3, 33.9), 0.0027
F (df), *P* block	0.6 (2, 120), 0.5494	0.4 (2, 120), 0.6766	0.4 (2, 20), 0.6766	0.9 (2, 90), 0.4310	2.5 (2, 120), 0.0833	0.9 (2, 60), 0.4014	0.04 (2, 57), 0.9639
F (df), *P* treatment × block	1.7 (14, 120), 0.0553	1.3 (14, 120), 0.1981	1.3 (14, 120), 0.1981	1.1 (8, 90), 0.3868	0.75 (14, 120), 0.7231	1.0 (6, 60), 0.4114	2.7 (6, 57), 0.0212

Means in the same column followed by different letters are significantly different; PROC GLM, Welch test, and Tukey–Kramer HSD comparison of means, $\alpha = 0.05$.
[a] Excluding novel gel and root dip.
[b] Excluding tablet, novel gel, and root dip.

flip time allowed). Imidacloprid treatments killed beetles more slowly than cyfluthrin or pyrethrins, but these beetles had statistically longer flip times and could not remain upright or walk, rendering them incapable of feeding as measured by significant reduction in leaf damage. Two of the consumer product treatments, Monterey 70% Neem Oil and Garlic Barrier, did not show statistically significant mortality of Japanese beetle or reduce leaf damage. Japanese beetle mortality was low (15%) on Pygenic-treated leaves, but leaf damage (51%) was reduced. In contrast, Japanese beetle mortality on JB Killer was high (91%), but leaf damage (5%) was low (Table 2). No phytotoxicity was observed in any treatments.

Experiment 2: Growth Enhancement of Imidacloprid on Roses. Higher levels of chlorophyll for 1X and 3X granular and one tablet imidacloprid treatments were observed (two dates with different brightness due to ambient light levels) (Table 3). Leaf area and shoot length were measured for all imidacloprid treatments. Imidacloprid tablet, imidacloprid gel, and imidacloprid root dip are novel application methods and may affect the plant in a physiologically different way. Therefore, we excluded these treatments from analysis. We analyzed leaf area and nitrogen among standard drench and granular treatments. The 3X granular and drench imidacloprid treatments had a significantly higher leaf area and nitrogen than controls (Table 3). A natural infestation of mites occurred on the roses and the 3X granular imidacloprid treatments showed significantly higher mite numbers than controls (nonparametric chi-square test = 16.9189, df = 3, $P = 0.0007$).

Experiment 3: Treated and Untreated Choice Test. Azatin XL (azadirachtin), Monterey 70% Neem oil, Orange Guard (D-limonene) and 1X granular Merit (imidacloprid) treatments had significantly lower numbers of beetles than Garlic Barrier (garlic water), Pygenic (pyrethrins), and Conserve SC (spinosad) treatments (Table 4). It is concluded these treatments demonstrated some feeding deterrence to beetles.

Discussion

Managing Japanese beetle adults requires the use of effective insecticides. Many consumers prefer biorational products that are considered "green" and environmentally safe. Among consumer products, JB Killer had similar mortality to the two professional products containing pyrethroids (Decathlon and Discus) that are outlined in the Harmonization Plan. Therefore, JB Killer is an effective consumer product. Consumer products Pygenic and Orange Guard resulted in intermediate mortality compared with pyrethroid treatments. Although JB Killer (0.02% pyrethrins plus 0.2% piperonyl butoxide) and Pygenic (1.4% pyrethrins) both contained pyrethrins, JB Killer had greater mortality, probably due to the presence of piperonyl butoxide. On blueberries, the addition of piperonyl butoxide to pyrethrums had higher mortality of adult Japanese beetles (Issacs et al. 2004). Monterey 70% Neem Oil and Garlic Barrier did not result in signif-

Table 4. Mean ± SEM percentage Japanese beetles and leaf damage on shoots of hybrid tea rose in treated and untreated choice test

Insecticide trade name (AI) ppm/plant	Beetles (%)[a]	Leaf damage (%)
Azatin XL, 5 ppm	15.8 ± 2.4b	3.5 ± 0.7cd
Monterey 70% Neem Oil, 525 ppm	14.8 ± 2.3b	2.6 ± 0.7cd
Garlic Barrier, 1,875 ppm	46.3 ± 2.9a	15.8 ± 1.7a
Orange Guard, 1,185 ppm	24.1 ± 2.3b	2.2 ± 0.4cd
Merit 2.5G 1X (imidacloprid), 125 ppm	22.6 ± 4.1b	0.7 ± 0.2d
Pygenic (pyrethrins), 2.5 ppm	42.2 ± 3.1a	6.6 ± 1.5bc
Conserve SC (spinosad), 5 ppm	43.3 ± 4.3a	10.1 ± 1.3b
F (df), *P* treatment	18.4 (6, 119), <0.0001	25.1 (6, 119), <0.0001
F (df), *P* treatment (Welch)	20.7 (6, 52.6), <0.0001	1.5 (6, 52.8), 0.1912
F (df), *P* block	0.4 (2, 119), 0.6660	0.7 (2, 119), 0.5163
F (df), *P* treatment × block	1.1 (12, 238), 0.4020	1.5 (12, 238), 0.1405

Means in the same column followed by different letters are significantly different; PROC GLM, Welch test, and Tukey–Kramer HSD comparison of means, $\alpha = 0.05$.
[a] Percentage of total live beetle found on treated shoot at 24 h after introduction.

icant mortality to adults, and they are consequently poor choices for managing adult Japanese beetle. A consumer product is available that contains 0.5% spinosad Monterey Garden Insect Spray (Table 1), which is similar in active ingredients to the professional product Conserve SC, which was not effective.

Among professional products, biorational insecticides KLN Dyna-Gro, Azatin XL, and Conserve SC did not show significant mortality. In contrast, professional products containing pyrethroids resulted in significant mortality to Japanese beetles. All imidacloprid treatments effectively incapacitated beetles as demonstrated by loss of motor function and the inability to walk or flip (82–106-s flip time) compared with controls (30-s flip time), although mortality was not as high (9.1–42.7%) as in pyrethroid treatments (83.3–88.4%). New formulations of imidacloprid, such as tablet, gel, and gel with fipronil, are easier to apply and reduce the need to measure or dissolve imidacloprid in water. The gel was applied with a standard caulking gun, and tablets were placed under the soil surface. Fipronil is formulated with imidacloprid as it is systemic, binds to the soil, has little potential for groundwater contamination, and kills beetles. Fipronil and imidacloprid used as a soil application in soybean, *Glycine max* (L.) Merr., controlled *Decetes texanus texanus* (Coleoptera: Cerambycidae), which did not reduce yield (Bushman et al. 2005). Also, it is used for control of European corn borer, *Ostrinia nubilalis* (Hübner) (Lepidoptera: Crambidae); *Sternechus subsignatus* Boheman (Coleoptera: Curculionidae); *Lissorhoptrus oryzophilus* Kuschel (Coleoptera: Curculionidae); and several species of thrips. Fipronil is used as a soil or seed treatment and moves systemically through the xylem. Systemic activity seems to be more pronounced in monocots than dicots (Anonymous 2005).

Imidacloprid is available to consumers for Japanese beetle control in Bayer Advanced Rose and Flower Insect Killer and Bayer Advanced 12-mo Tree and Shrub Insect Control. These consumer products contain similar amounts of active ingredients (imidacloprid or cyfluthrin) compared with professional products, which were lethal in our experiments (Table 1). The Bayer Advanced 12-mo Tree and Shrub Insect Control product also is recommended for consumer control of emerald ash borer, *Agrilus planipennis* Fairmaire (Rebek and Smitley 2006), which is more difficult to control than leaf feeders.

Neem products (Azatin XL, Monterey 70% Neem Oil) and Orange Guard (D–limonene) deterred feeding as demonstrated by lower numbers of beetles on treated shoots. Garlic Barrier, Pygenic, and Conserve SC did not demonstrate deterrence. Reduction of feeding in Japanese beetles also was observed on soybean leaves when sprayed with 1% neem seed kernel extract (Ladd et al. 1978, Ladd 1981) and on linden leaves treated with neem-based feeding deterrents (Harper and Potter 1994, Held et al. 2001, Potter and Held 2002). D-limonene has deterrency to several other beetles (Paruch et al. 2001, Tripathi et al. 2003). Garlic Barrier was not effective for control of adult Japanese beetles in another study (Held et al. 2003). Studies on the role of phytochemistry in beetle host plant choice concluded that deterrence was more important than phytochemical stimulants, because Japanese beetle feeds on >300 species (Potter and Held 2002).

Although not related to Japanese beetle management, rose leaves had increased leaf chlorophyll content, larger leaf size, and higher nitrogen levels in some imidacloprid treatments. The highest rate of granular imidacloprid treatment (3X) also had the most spider mites. Growth of imidacloprid-treated plants may be altered as evidenced by increased yield in cotton (Oosterhuis and Brown 2003, Gonias et al. 2006), increased relative growth in poplar (Tenczar and Krischik 2006a), and increased leaf size and shoot length in cottonwood (Tenczar and Krischik, unpublished data). Imidacloprid increased available nitrogen in soil by 26% in ground nut (Singh and Singh 2005). Higher nitrogen levels in foliage may be related to outbreaks of leaf feeders. This observation needs to be confirmed with a planned experiment where treatments are exposed to a known amount of mites and their numbers measured over time. Increased suitability for mites in imidacloprid-treated plants also was reported in hops (James and Price 2002), hemlock (Raupp et al. 2004), and marigolds (Sclar et al. 1998, Cranshaw and Sclar 2006). When imidacloprid was used in Central Park, New York City, NY, to control defoliators, mite outbreaks occurred on treated trees (Raupp 2003). Research on elm and boxwood landscape trees treated with imidacloprid found that numbers of natural enemies were higher on treated trees, possibly as a numerical response to greater numbers of prey mites. Imidacloprid-induced changes in host plant suitability were apparently responsible for mite outbreaks, not a reduction in predator numbers (Szczepaniec and Raupp 2006). Researchers advocate control of mites after using soil applications of imidacloprid (Raupp 2003). Increased leaf size and suitability to mites may be related to increased leaf nitrogen and other changes in leaf chemistry induced by imidacloprid and deserve further research.

In summary, among consumer products, only JB Killer controlled adult Japanese beetle. Biorational products available to consumers varied greatly in efficacy. Neem products (Azatin XL, Monterey 70% Neem Oil) and Orange Guard deterred feeding, but they did not kill beetles. Consumers with backyard roses may be able to use these biorationals, but nurseries may experience high levels of leaf damage by beetles as they sample foliage before they are deterred. This may necessitate the use of conventional insecticides by growers. In contrast, conventional insecticides containing pyrethroids kill beetles and imidacloprid-containing insecticides incapacitate beetles so they no longer feed. Unless insecticides are used properly, Japanese beetle adults will disperse and more areas will become infested.

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