HORTSCIENCE 37(6):914–918. 2002.

Field Evaluations of Novel Chloronicotinyls and Insect Growth Regulators against the Greenhouse Whitefly on Strawberry

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Additional index words. Trialeurodes vaporariorum, imidacloprid, thiamethoxam, buprofezin, pyriproxyfen, *Fragaria ananassa*

***Abstract*. The efficacy of two novel chloronicotinyls and two novel insect growth regulators against the greenhouse whitefly [*Trialeurodes vaporariorum* (Westwood)] on summer-planted strawberries was evaluated in field experiments. Imidacloprid applied in soil 3 weeks after planting decreased whitefly adult numbers by 58% to 90%, first and second instars by 78% to 93% up to 56 days postapplication, and third and fourth instars by 42% to 86% up to 77 days postapplication, whereas thiamethoxam applied similarly reduced adults by 58% to 80%, first and second instars by 78% to 93% up to 6 weeks posttreatment, and third and fourth instars by 48% to 80% up to 10 weeks after initial application, compared to nontreated controls. Imidacloprid applied in soil immediately prior to planting further suppressed numbers of whiteflies by 71% to 83% (adults), 58% to 74% (first and second instars), and 52% to 74% (third and fourth instars), in comparison with the same compound applied through drip irrigation lines 4 weeks after planting. Buprofezin and pyriproxifen applied 6 weeks after planting reduced numbers of adult whiteflies by 25% to 81% and 40% to 73%, respectively; first and second instars by 61% to 92% and 51% to 100%, respectively; and third and fourth instars by 45% to 100% and 37% to 87%, respectively, on most sampling dates up to 7 weeks postapplication. The potential roles of these insecticides in integrated greenhouse whitefly management programs are discussed.**

The greenhouse whitefly is a worldwide pest of many horticultural crops. Large populations of this insect can ingest sufficient quantities of plant phloem sap to cause yield reduction (Johnson et al., 1992). In addition, this insect produces large amounts of honeydew and associated sooty mold, which can decrease the market value of crop products (Liu et al., 1993). Furthermore, this insect may transmit plant virus diseases (Muniyappa, 1980).

Strawberry [*Fragaria ananassa* (L.)] is an economically important horticultural crop in California, with annual values exceeding $200 million since 1980 (McGregor 1981). In recent years, this crop has been increasingly under attack by the greenhouse whitefly, especially in the coastal area of southern California. Prevention of economic losses requires development of an integrated greenhouse whitefly management program.

Insecticides are important components of integrated pest management systems designed to suppress whitefly populations on various crops (Liu et al., 1993; Toscano et al., 1998). Intensive research has been carried out in recent years for evaluating insecticides with novel modes of action against whiteflies. Imidacloprid and thiamethoxam are chloronicotinyl insecticides that act as nicotinic acetylcholine receptor agonists and are used to control homopteran pests (Elbert et al., 1998; Leicht, 1993). Buprofezin is an insect growth regulator that inhibits chitin synthesis in several homopteran pests, including whiteflies (De Cock et al., 1990). Pyriproxyfen is a juvenile hormone mimic affecting the hormonal balance in insects and resulting in strong suppression of embryogenesis and adult formation (Ishaaya and Horowitz, 1994). The separate modes of action of these compounds, together with their selectivity against targeted insect pests and relative safety to beneficial insects and other organisms, present an exciting opportunity for their effective integration into pest management strategies (Darvas and Polgar, 1998; Ishaaya and Horowitz, 1998). The availability of such chemical diversity enables the development of a management strategy that minimizes the threat of insecticide resistance (Denholm et al., 1998).

Agronomic factors influence insecticide efficacy against sucking insects. Slosser et al. (1997) showed that cotton plant maturity and application timing of dicrotophos affected control of the cotton aphid *Aphis gossypii* (Glover). Fuson et al. (1995) demonstrated that efficacy of chlorpyrifos and endosulfan against cotton aphid was better on late-planted than early-planted cotton. For commercial strawberry production in southern California, two planting seasons exist. Summer plantings are usually made in late July to mid-August and the crop is terminated in late December, whereas fall plantings are made in late September to late October and the crop is terminated the following summer (late June). We previously investigated efficacy of chloronicotinyls and insect growth regulators against greenhouse whiteflies on fall-planted strawberries when these chemicals were applied in midseason (April). We demonstrated that all these chemicals were effective in suppressing the whitefly populations except for foliar-applied thiamethoxam (Bi et al., 2001). The present study was initiated to test the efficacy of two chloronicotinoids and two insect growth regulators against greenhouse whitefly on summer-planted strawberry when applied in early season under field conditions.

Materials and Methods

Experimental plots and insecticides. The efficacies of imidacloprid, thiamethoxam, buprofezin, and pyriproxyfen were evaluated against the greenhouse whitefly in a commercial strawberry field in Oxnard, Calif. Strawberry plants of ‘E6’ were planted in late July 2000 on four-row beds. Each bed was 1.3 m wide × 70 m long. The test was arranged in a randomized complete-block design with four replicates. Plot size was 8 m long × 1.3 m wide with a 1-m buffering area between plots. There were ≈106 plants in each plot. The following insecticides were obtained from their respective manufacturers: imidacloprid (Admire 2F, from Bayer Crop Protection, Kansas City, Mo.), thiamethoxam (Platinum 2SC, from Syngenta, Inc., Greensboro, N.C.), buprofezin (Applaud 70 WP, from AgrEvo USA Co., Pikeville, N.C.), and pyriproxyfen (Knack 0.86 EC, from Valent USA Corp., Walnut Creek, Calif.).

Insecticide concentrations and applications. Insecticides applied at the label-recommended concentrations were as follows: imidacloprid at 0.5556 $kg\cdot ha^{-1}$ a.i., thiamethoxam at 0.1758 $kg\cdot ha^{-1}$ a.i., buprofezin at 0.3888 $kg\cdot ha^{-1}$ a.i., and pyriproxyfen at 0.06 $kg\cdot ha^{-1}$ a.i.

Imidacloprid and thiamethoxam were delivered into the soil through the drip irrigation lines on 24 Aug. The effect of application timing (preplanting vs. postplanting) on efficacy of imidacloprid was also investigated. For the preplanting applications, a 10-mL solution was applied on 28 July to each of the planting holes, immediately prior to planting. For postplanting applications, imidacloprid was injected into the drip irrigation lines 4 weeks after planting.

Buprofezin and pyriproxyfen were applied on 14 Sept. at a volume of 15323.9 L of water per hectare with an ECHO air-assisted sprayer. Control plots were left untreated.

Whitefly sampling methods. Sampling of whitefly adults and immatures was initiated just prior to application of all the insecticides, except for sampling of immatures from chloronicotinyl-treated plants, which was initiated 3 to 6 weeks after applications. The sampling was conducted on a weekly basis. The number of whitefly adults was deter-

Received for publication 13 Nov. 2001. Accepted for publication 27 Feb. 2002. We thank Frank Byrne and Steve Castle for critical review of an earlier version of the manuscript. This research was funded in part by the California Strawberry Commission.
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mined using a leaf turn method. Adults were counted on 20 of the youngest and fully expanded middle leaflets of trifoliates, each from randomly selected plants in each of the plots. Ten older leaflets from 10 randomly chosen plants in each plot were excised and transported to the laboratory to count nymphs and pupae within a 4.5-cm^2 disk area in the center of the leaflet using a stereo dissecting microscope.

Statistics. A least significant difference (LSD) test in one-way randomized complete-block design of analysis of variance (ANOVA) in SAS (SAS Institute Inc., 1989) was used in this study to analyze the data and separate the means. Before the ANOVA, numbers of whitefly adults and immatures were transformed using the formula log (y + 1) to normalize the data.

Results

Efficacy of chloronicotinyls. Applications of imidacloprid decreased adult numbers by 58% to 90% ($P < 0.05$) from 7 (31 Aug.) to 56 d (19 Oct.) posttreatment, compared to the control, followed by a 4-week period when the numbers in imidacloprid-treated and control plants were about the same; then control numbers increased, and those that were imidacloprid-treated had 40% to 66% fewer adults ($P < 0.05$) until end of the season (Fig. 1). Numbers of first and second instars were reduced by 78% to 93% ($P < 0.05$) up to 56 d (19 Oct.) posttreatment, after which the effect of reduction was diminished ($P > 0.05$) (except that on 30 Nov. sampling date, the number decreased 67%) (Fig. 2). Numbers of third and fourth instars were reduced by 42% to 86% ($P < 0.05$) up to 77 d posttreatment (Fig. 2).

Application of thiamethoxam suppressed adult numbers by 58% to 80% ($P < 0.5$) from 2 (7 Sept.) to 6 weeks (6 Oct.) and up to 48% ($P < 0.05$) in late season starting from 22 Nov. (Fig. 1). Numbers of first and second instars were decreased by 83% to 85% ($P < 0.05$) from 4 (21 Sept.) to 6 weeks (6 Oct.) and the effect was nonsignificant ($P > 0.05$) thereafter (Fig. 2). The application of thiamethoxam effectively decreased numbers of third and fourth instars by 48% to 80% ($P < 0.05$) up to 10 weeks (prior to 2 Nov.) (Fig. 2).

Efficacy of imidacloprid against whiteflies was affected by the timing of application. Compared to postplanting application, preplanting application further decreased numbers of adults from 71% to 83% ($P < 0.05$) from 24 Aug. to 6 Oct. sampling date and from 35% to 62% from 9 Nov. to 14 Dec. (Fig. 3). However, adult numbers between pre- and posttreatments were not significantly different from 12 Oct. to 2 Nov. (Fig. 3). The preplanting application suppressed numbers of first and second instars by 58% to 74% ($P < 0.05$) more than the postplanting application from 14 Sept. to 12 Oct., and the difference in numbers was nonsignificant thereafter ($P > 0.05$) (Fig. 4). The preplanting application decreased numbers of third and fourth instars by 52% to 74% ($P > 0.05$) from 27 Sept. to 2 Nov., in comparison with the postplanting

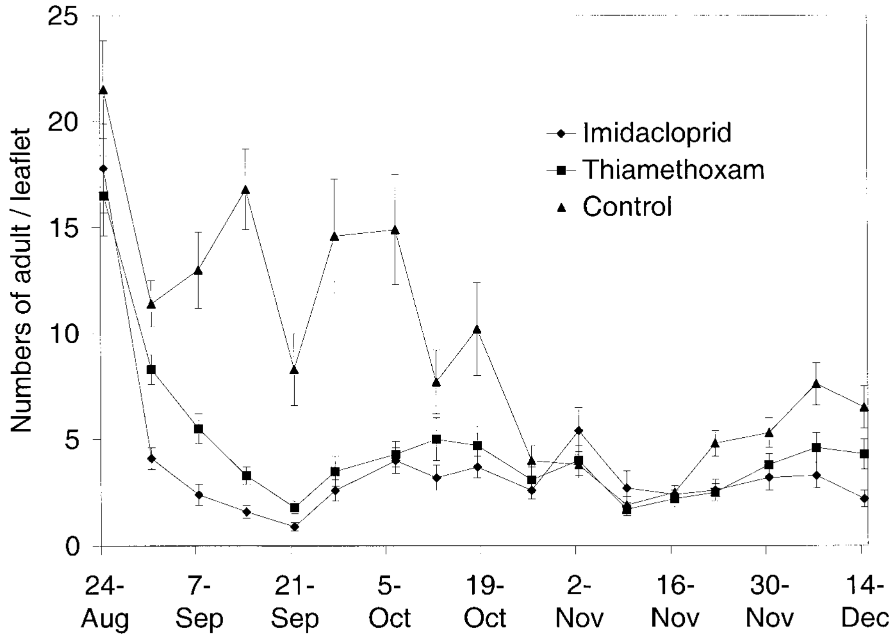

Fig. 1. Efficacy of chloronicotinyls on numbers of adult greenhouse whiteflies on summer-planted strawberries. Points with error bars represent means ± SE.

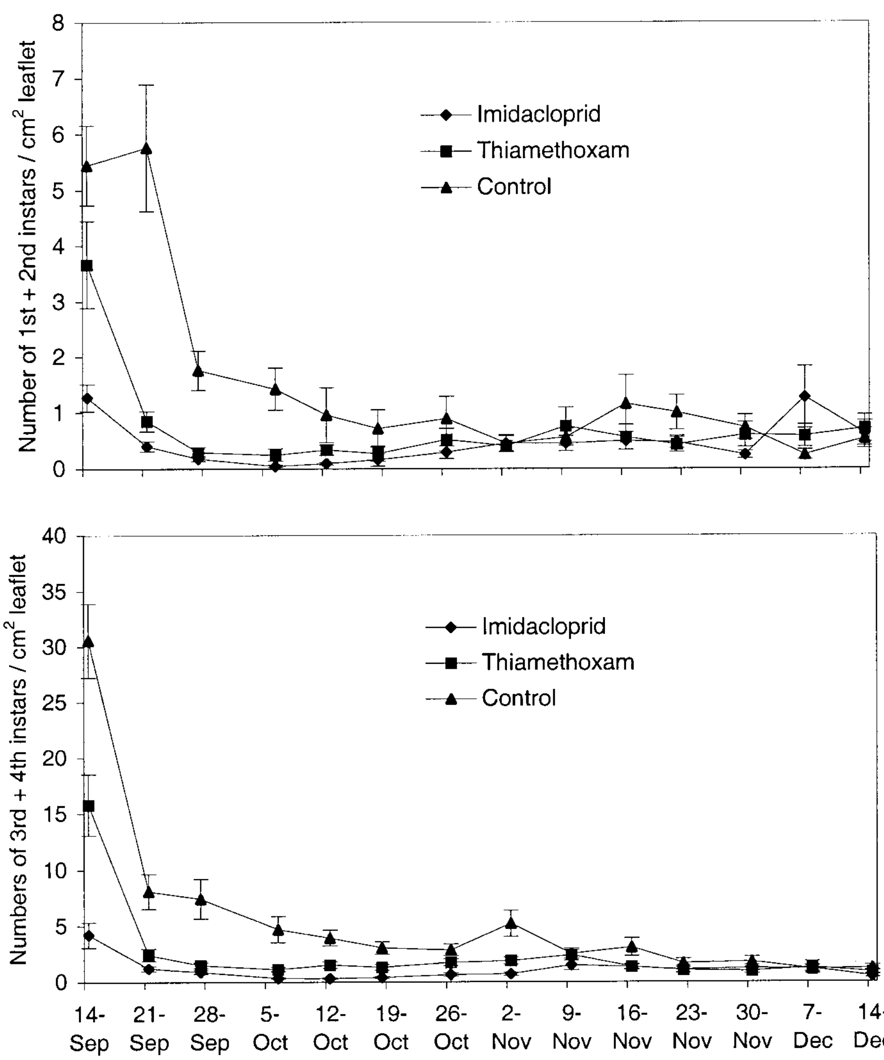

Fig. 2. Efficacy of chloronicotinyls on numbers of immature greenhouse whiteflies on summer-planted strawberries. Points with error bars represent means ± SE.

application, while the effect of preplanting application was not significantly different ($P > 0.05$) on other sampling dates. (Fig. 4).

Efficacy of insect growth regulators. Application of buprofezin suppressed numbers of adult whiteflies by 25% to 81% ($P < 0.05$), in comparison with the control, on all the sampling dates except those on 9 and 16 Nov. (Fig. 5). The application decreased numbers of first and second instars by 61% to 92% ($P < 0.05$) from 3 to 7 weeks postapplication (Fig. 6). The application suppressed numbers of third and fourth instars by 45% to 100% ($P < 0.05$) up to 9 weeks after initial application (Fig. 6).

Application of pyriproxyfen resulted in significant reduction in numbers of adults by 40% to 73% ($P < 0.05$) compared with the control on 10 of the 14 sampling dates, especially in the early (from 27 Sept. to 2 Nov.) and late season (from 23 Nov. to 14 Dec.) (Fig. 5). The application also caused a reduction in numbers of first and second instars by 51% to 100% ($P < 0.05$) from 21 Sept. to 18 Oct., only by 73% to 75% ($P < 0.05$) from 16 to 30 Nov. (Fig. 6). The application reduced numbers of third and fourth instars by 37% to 87% ($P < 0.05$) relative to the untreated control from 3 to 9 weeks after the initial treatment (Fig. 6).

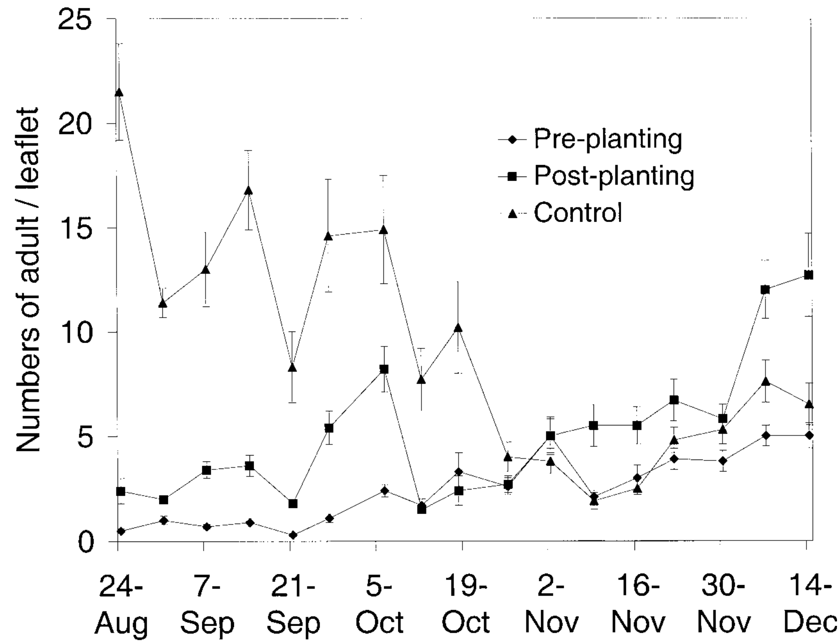

Fig. 3. Effect of imidacloprid application timings on numbers of adult greenhouse whiteflies on summer-planted strawberries. Points with error bars represent means ± SE.

Discussion

This study demonstrated that applications of the chloronicotinyl imidacloprid to summer-planted strawberries under field conditions strikingly suppressed the adult and nymphal whitefly populations (Figs. 1 and 2). The resulting efficacy is even greater than our previous findings on fall-planted strawberries (Bi et al., 2001). Imidacloprid controls whiteflies resistant to conventional insecticides and soil treatments have no adverse effects on beneficial organisms, so it fits well into resistance management strategies and can be considered as an important component of integrated whitefly management (Elbert et al., 1998).

Application timing affected efficacy of imidacloprid against the whiteflies on summer-planted strawberries (Figs. 3 and 4). Plant factors have been recognized by several researchers that affect insecticidal toxicity against sucking arthropods. Walsh et al. (1996) reported that the systemic mortality effects of avermectin against the twospotted spider mite [*Tetranychus urticae* (Koch)] on strawberry were greater on fruiting summer-type plants than on plants in winter semidormancy, concluding that translaminar movement of the acaricide was affected by the physiological status of strawberry plants. Wyss and Bolsinger (1997) demonstrated that efficacy of pymetrozine against the aphid *Myzus persicae* (Sulzer), following drench application, correlated with plant age and leaf developmental stage. The higher efficacy of preplanting application in this study may also be, at least partly, attributed to strawberry plant physiological status and leaf developmental stage. We found that the efficacy in younger plants was higher than in older ones (Bi and Toscano, unpublished data), probably

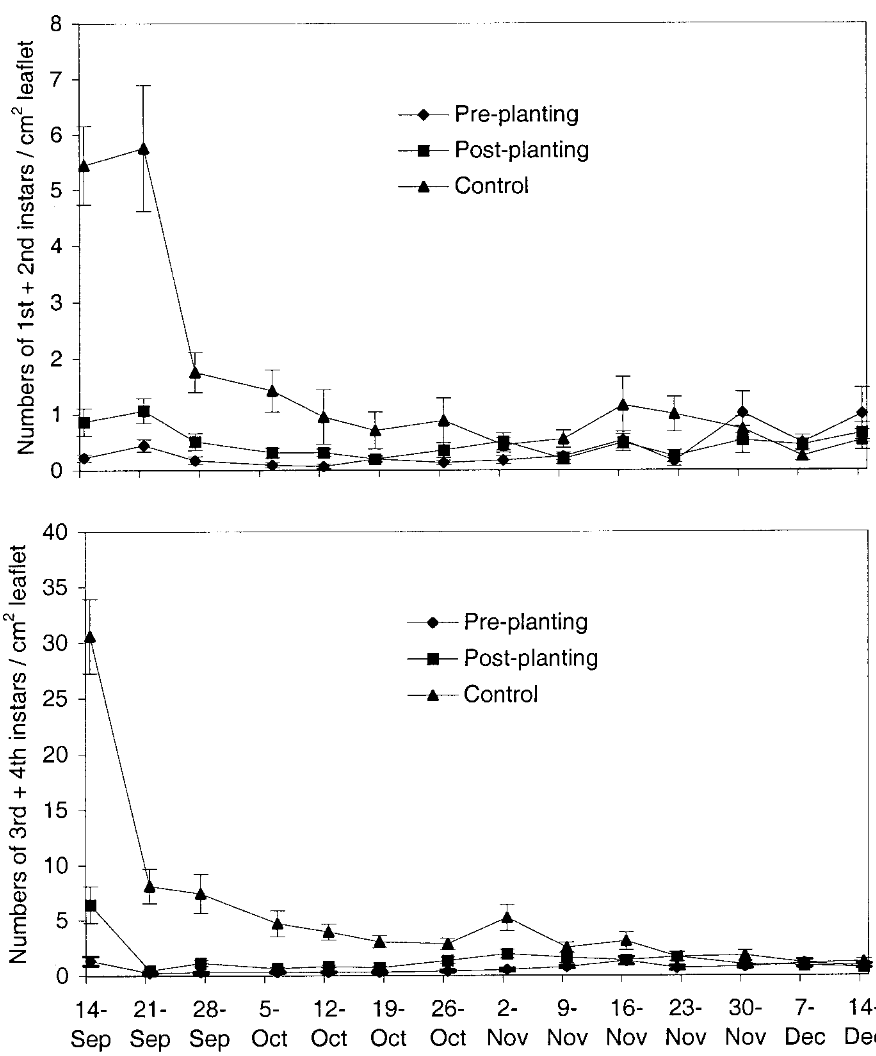

Fig. 4. Effect of imidacloprid application timings on numbers of immature greenhouse whiteflies on summer-planted strawberries. Points with error bars represent means ± SE.

due to imidacloprid being concentrated in the young leaves rather than the mature ones. The differential distribution of imidacloprid in strawberry plants at different developmental stages and physiological status, and the resulting efficacy, needs to be further investigated.

Although the chloronicotinyl thiamethoxam significantly suppressed numbers of the whitefly adults and immatures, the efficacy was not as great as that of imidacloprid (Figs. 1 and 2). The lower efficacy may be due, in large part, to the lower dosage (thiamethoxam was applied at 0.1758 kg·ha^{-1} a.i., whereas imidacloprid was applied at 0.5556 kg·ha^{-1} a.i.). We previously reported that thiamethoxam applied foliarly in midseason to fall-planted strawberries had no effect on both adult and immature greenhouse whitefly populations (Bi et al., 2001). The discrepancy in efficacy with this study may be attributed to the different insecticidal formulations, different strawberry plant physiological status, and/or different translocation mechanisms.

The insect growth regulators buprofezin and pyriproxifen significantly decreased the whitefly populations on summer-planted strawberries (Figs. 5 and 6), confirming similar results on fall-planted strawberries (Bi et al., 2001). Due to the excellence in controlling their target insects, low toxicity to mammals, and relative safety to most parasitoids, buprofezin and pyriproxifen can be considered as important components of integrated whitefly management (DeCock and Degheele, 1998; Ishaaya and Horowitz, 1998; Ishaaya et al., 1994).

Chemical control is still an important component of integrated pest management systems. As indicated in this study, imidacloprid, thiamethoxam, pyriproxyfen, and buprofezin can be powerful tools for managing the greenhouse whitefly on strawberry, especially considering that greenhouse whitefly has already developed resistance to some conventional insecticides such as acephate and dicrotophos in California (Omer, et al., 1992). Alternating these chemicals on strawberries in a defined way should reduce the potential risk of greenhouse whitefly resistance to these insecticides and alleviate the resistance problem for other insecticides. Because these insecticides are selective to targeted insect pests, including the greenhouse whitefly, and relatively safe to beneficial insects and other organisms (Darvas and Polgar, 1998; Ishaaya and Horowitz, 1998), they fit well into integrated greenhouse whitefly management programs.

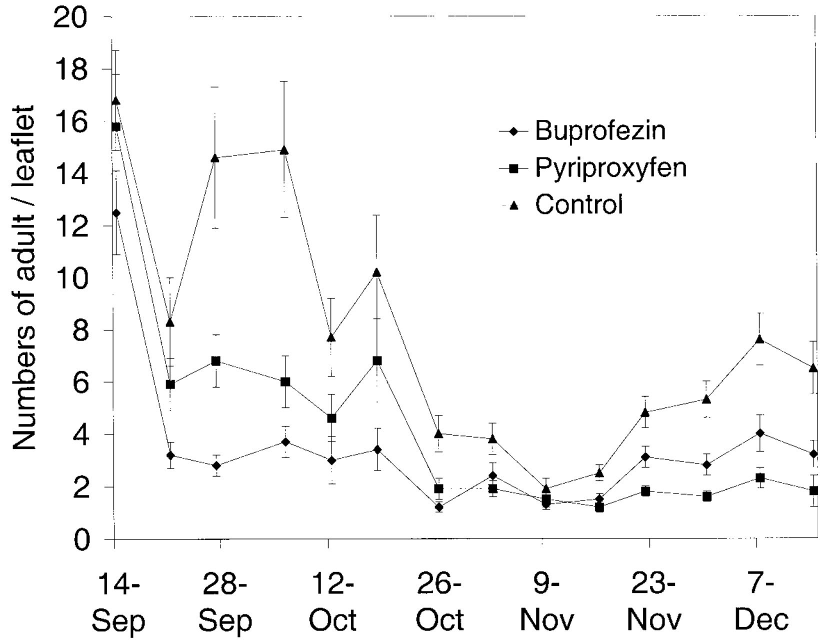

Fig. 5. Efficacy of insect growth regulators on numbers of adult greenhouse whiteflies on summer-planted strawberries. Points with error bars represent means ± SE.

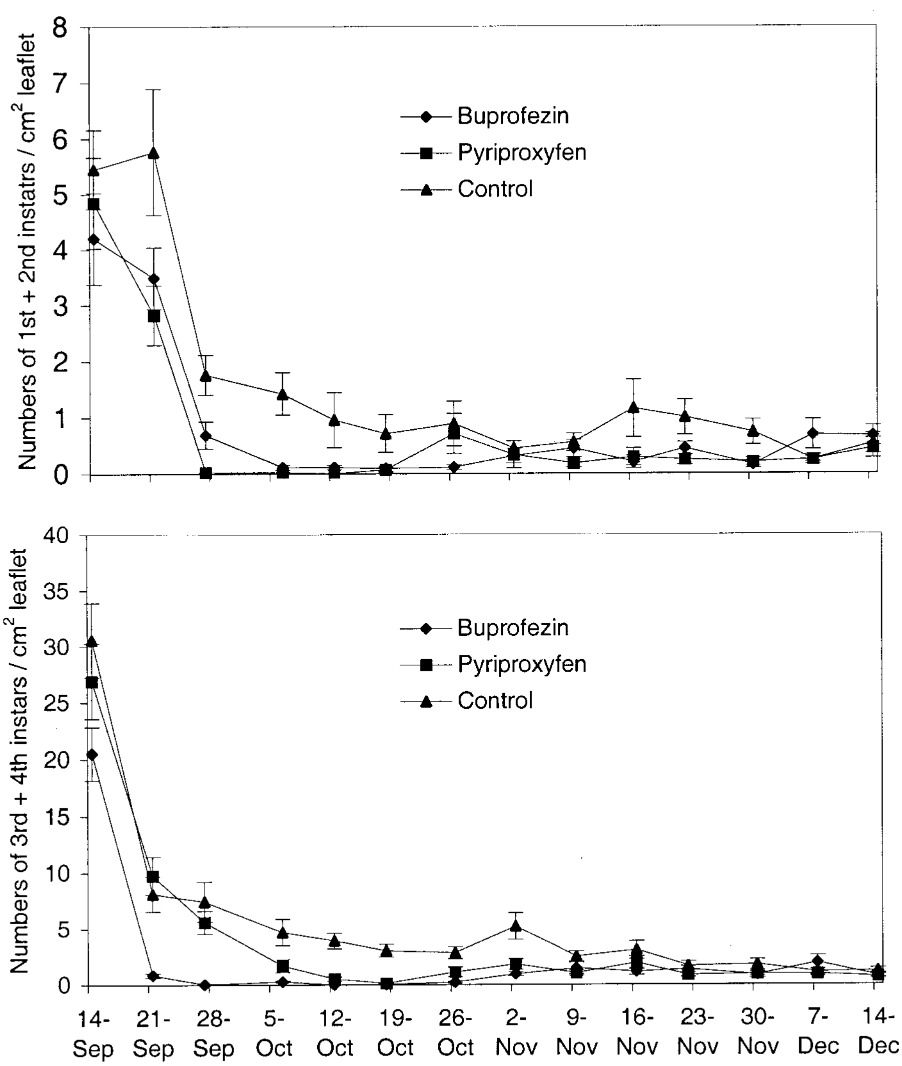

Fig. 6. Efficacy of insect growth regulators on numbers of immature greenhouse whiteflies on summer-planted strawberries. Points with error bars represent means ± SE.

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