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Effect of Simulated Rainfall on the Control of Colorado Potato Beetle (Coleoptera: Chrysomelidae) and Potato Leafhopper (Homoptera: Cicadellidae) with At-Plant Applications of Imidacloprid, Thiamethoxam or Dinotefuran on Potatoes in Laboratory and Field Trials

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Additional information is available at the end of the chapter

1. Introduction

The Colorado potato beetle, *Leptinotarsa decemlineata* (Say) [Order Coleoptera] (CPB), is considered the most important pest of potatoes throughout the northeastern and mid-Atlantic regions of the United States [1]. Both larval and adult CPB feed on potato foliage, stems, and flowers, which can severely defoliate plants, significantly reducing yields [2]. Growers rely on insecticidices to control CPB in the field but it has developed resistance to 52 different compounds used against it, which includes all major insecticide classes [3].

Another economically important insect pest of potatoes is the potato leafhopper, *Empoasca fabae* (Harris) [Order Homoptera] (PLH), a sap-feeding insect that causes damage known as "hopper burn" [4]. Feeding results in curling, stunting, yellowing and eventual browning of the potato foliage, and even low numbers of leafhoppers can cause significant yield losses [4, 5]. The potato leafhopper overwinters in the southern US and migrates northward on wind currents [6,7], typically arriving in the northeast United States in mid- to late May or early June each year.

Currently throughout the potato-producing regions of the United States, the neonicotinoid class of insecticides, which includes dinotefuran, imidacloprid and thiamethoxam, is widely

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used for control of several insect pests of white potatoes [8,9], including early to mid-season infestations of both CPB and PLH. These insecticides are toxic to both of these pests [10], have excellent systemic uptake and translocation in plants, are used at low application rates, and present reduced environmental hazards [11,12]. Although most neonicotinoids can be applied as either a seed treatment, a soil treatment or as a post-planting foliar treatment, many commercial growers prefer a soil application at planting time. Applied to the soil, these materials are absorbed by the roots and translocated acropetally (xylem movement) within the whole plant [12,13]. However, the effectiveness of soil-applied insecticides are influenced by soil and climatic conditions, including soil moisture, clay and organic content, rainfall, soil temperature, plant size, sorption, adsorption, and physical properties of the insecticide, such as stability to chemical and microbial degradation [14,15,16]. Thus, when used as a soil-applied insecticide, the length of effective protection can vary and additional foliar insecticide sprays may be needed to control midsummer populations of both the CPB and PLH.

The solubility of an insecticide and its activity in soil and uptake by the roots is known to be important, but this relationship has not been well documented [17]. In general, increased solubility is positively related to increased uptake of a systemic chemical. A compound's relative affinity between soil and water phases is measured by log Koc (organic carbon referenced sorption coefficients). With sufficient soil moisture, materials with higher log Koc bind more tightly to soil colloids and release at a slower rate, affecting the availability for root uptake; materials with a higher solubility enter the plant roots more quickly and thus move through a plant faster than materials with a lower solubility. The uptake of dinotefuran, which is 80 times more soluble than imidacloprid, in both yellow sage and poinsettia plants was more rapid and resulted in quicker and higher percentage mortality of whitefly nymphs compared with imidacloprid [18]. However, materials with a lower log Koc are also more easily leached out of the root zone, which can reduce effectiveness. For example, thiamethoxam has a strong potential to leach under heavy rainfall conditions [19], and imidacloprid has a potential to leach to ground water [20]. Leaching of the insecticide would impact insect pest control because less insecticide would be available for uptake by the plant, resulting in reduced efficacy or in reduced longevity of efficacy. Although much research has been conducted on the bioefficacy of the neonicotinoids against CPB and PLH as soil-applied insecticides, little published information is available on the effect of rainfall on these materials after application to the soil.

Therefore, laboratory and field studies were conducted to examine the effect of two levels of simulated rainfall on three neonicotinoids with different solubilities for control of CPB and PLH on white potato.

2. Methods and materials

Laboratory Trials. Two "Superior" cv. potato seed pieces were each planted into 22.9 cm (9") diam pots half-filled with soil in the field on 23 Apr. The pots were then aligned in the field in a straight row, each pot touching the next, to approximate a grower-practiced seed

spacing of 22.9 cm (9"). Treatments consisted of three neonicotinoid insecticides, at full labeled rates, and an untreated: imidacloprid (Admire PRO, 635.9 ml/ha [8.7 fl oz/acre], BayerCropScience, Research Triangle Park, NC), thiamethoxam (Platinum 2SC, 584.2 ml/ha [8.0 fl oz/acre], Syngenta, Greensboro, NC), dinotefuran (Venom 70SG, 525.5 g/ha [7.5 oz/acre], Valent BioSciences, Libertyville, IL), and an untreated water spray. The solubility of the three neonicotinoids, from least to most soluble, are imidacloprid (solubility of 0.51 g/liter at 20^0 C, [20], thiamethoxam (solubility of 4.1 g/liter at 20^0 C, [12], and dinotefuran (solubility of 40.0 g/liter at 20^0 C, [21]. To simulate a field application, treatments of insecticides were applied over the top of the pot as a 10.2 cm (4") band open-furrow application on 23 Apr using a 3785 ml (1 gal) Agway (Southern States Cooperative, Richmond, VA) water sprinkler calibrated to deliver 189.3 liter/0.405 ha (50 gpa). The seed pieces were then covered by filling the pots with clean field soil. Because soil texture, clay content and organic matter influence mobility, the same soil (Sassafrass sandy loam, 65% sand, 23% silt, 12% clay, 1% organic matter) was used for all the laboratory pots and for the field trials. A total of 32 pots were prepared (8 pots per treatment with the 4 treatments described above) and were immediately moved to an environmentally-controlled plexiglass greenhouse. Pots were evenly divided into 2 groups, with 4 pots (4 replications) of each treatment in the low rainfall group and 4 pots of each treatment in the high rainfall group. Thus main plots were amount of rainfall, and sub-plots were insecticide treatment. All 16 pots in either the low rainfall group or high rainfall group were placed on an 1.8 m (6 ft) diameter round table. A mechanical rainfall simulator [see 22] consisting of a rotating boom with a single TeeJet 8010 nozzle, operated by a 0.254 metric hp (¼ hp) electrical motor, delivered a 20.3 cm (8") band of water over the pots to simulate rainfall. Two rain gauges were placed opposite each other on the table between the pots: once every Monday the low rainfall group received 1.3 cm water (0.5") as measured in the rainfall gauge, and every Monday and Thursday the high rainfall group received 3.8 cm (1.5") each time, for a total of 7.62 cm (3") per week. Simulated rainfall commenced on 26 Apr, 3 days after planting, and continued every week until 11 Jun (a period of 8 weeks for a total of 4" low rainfall regimen, and 24" high rainfall regimen). Two leaves from the middle 1/3 foliage from each plant in each pot were picked and placed in sterile 12.7 cm diameter (5") Petri dishes on 30 May, 3, 15, 25 Jun and 2 Jul. Just after leaves were placed in the Petri dishes, CPB larvae were collected from untreated nursery potato plots ("Superior" cv) in the field and five same-instar larvae were placed in each Petri dish with the leaves and placed in the laboratory (2nd and 3rd instar larvae were tested May through early Jun, 3rd and 4th instar larvae were tested mid- to late Jun, and adults were tested early Jul because no larvae were available). After 72 hr, the total percentage leaf-feeding, based on visual assessment of percentage leaf tissue consumed by the CPB, and the number of live CPB in each Petri dish was recorded (3, 8, 21, 28 Jun and 5 Jul).

Field Trials. "Superior" cv. white potatoes were planted on 10 Apr into a prepared (disked, limed and fertilized) Sassafras sandy loam field. This soil was the same as used in the laboratory trials previously described. Plots consisted of 3 rows of potatoes, each row 7.62 m long (25 ft) and 0.9 m wide (3 ft), replicated 4 times in a split-plot design: whole plots were

amount of rainfall (a rainfall regimen of either 1.3 cm/week [½"] or 7.62 cm/week [3"), and sub-plots were insecticide treatment (imidacloprid, thiamethoxam, dinotefuran, or untreated). Insecticide treatments were the same as in the laboratory trials previously described and were applied at the same rates to the furrow at planting using a hand-held 7.6 liter (2-gal) Agway sprinkler can calibrated to deliver 189.3 liter/0.405 ha (50 gpa) in a 10.2 cm (4-in) band, after which the furrows were immediately closed; one treatment consisted of no insecticide. Whole plots were irrigated with an overhead irrigation system consisting of a 5.1 cm (2") main water pipe connected to a Rainbird J-20 revolving irrigation head delivering 0.5 cm water per 0.405 ha (0.2" per acre) per hour. Each whole plot had two rain gauges at plant height, one located near the irrigation head and one at the furthest wet point away from the irrigation head. Plots received overhead irrigation every Wednesday starting 23 Apr and continued each week through 27 Jun (either 1.3 cm [1/2"]or 7.62 cm [3"]) over a total of 10 weeks. Plots that received a natural rainfall less then the treatment amount during the week received additional irrigation only to bring the total to 1.3 cm or 7.62 cm, and plots that received more natural rainfall than the treatment amount received no irrigation.

The total number of Colorado potato beetle larvae (small and large larvae) per 3 hills, and percentage plant defoliation caused by CPB feeding were recorded on 1, 11, 17, and defoliation ratings only on 25 Jun. Potato leafhopper damage ratings (0 = no damage, 5 = severe damage) were recorded on 25 Jun and 3 Jul.

All data were recorded from the center row of each 3-row plot. Data were averaged to obtain a plot mean for all recorded observation. Data for both the laboratory and field trial were subjected to a split-plot analyses of variance (ANOVA) [23]. Means were separated using Tukey's HSD Studentized range test [23] and were plotted on graphs with Microsoft Excel (www.microsoft.com/en-US/excel365/). .

3. Results

3.1. Laboratory results

The results of the ANOVA to test the main effects (amount of simulated rainfall and insecticide) and rainfall by insecticide interaction on CPB in laboratory trials are summarized in Table 1. ANOVA demonstrated significant ($P<0.05$) insecticide effects for both CPB mortality and percentage leaf feeding on all dates recorded. However, the main effect of the amount of simulated rainfall was significant only on the first date for percentage leaf tissue eaten by CPB larvae, and only on the first two dates for CPB larval mortality (Table 1). Similarly, the rainfall by insecticide interaction for CPB mortality was significant ($P<0.01$) only on the first observation date (Table 1, and significant ($P<0.01$) only on the first two observation dates for percentage leaf tissue eaten..

When CPB larvae were placed on leaves treated with imidacloprid or thiamethoxam, mortality was significantly ($P<0.01$) higher compared with larvae placed on leaves treated with dinotefuran or the untreated for the low rainfall regimen until 17 Jun (Fig. 1), when mortality of CPB on leaves treated with imidacloprid decreased; thiamethoxam remained

	No. dead CPB/20 after 72 hr					% leaf tissue eaten by CPB after 72 hr				
	6/3	6/8	6/21	6/28	7/5	6/3	6/8	6/21	6/28	7/5
MP										
SP	*	*	ns	ns	ns	*	ns	ns	ns	ns
MPxS	**	**	**	*	**	**	**	**	**	**
P	**	ns	ns	ns	ns	**	**	ns	ns	ns

MP= main effect of simulated rainfall; SP= main effect of insecticides; MPxSP= interaction
[1]Summary of results of analysis of variance. ns= nonsignificant; *, P<0.05%, **, P<0.01%

Table 1. Summary of effects of simulated rainfall and insecticides on efficacy of 3 soil-applied
neonicotinoids against Colorado potato beetle (CPB) on white potatoes in laboratory trials[1], Bridgeton,
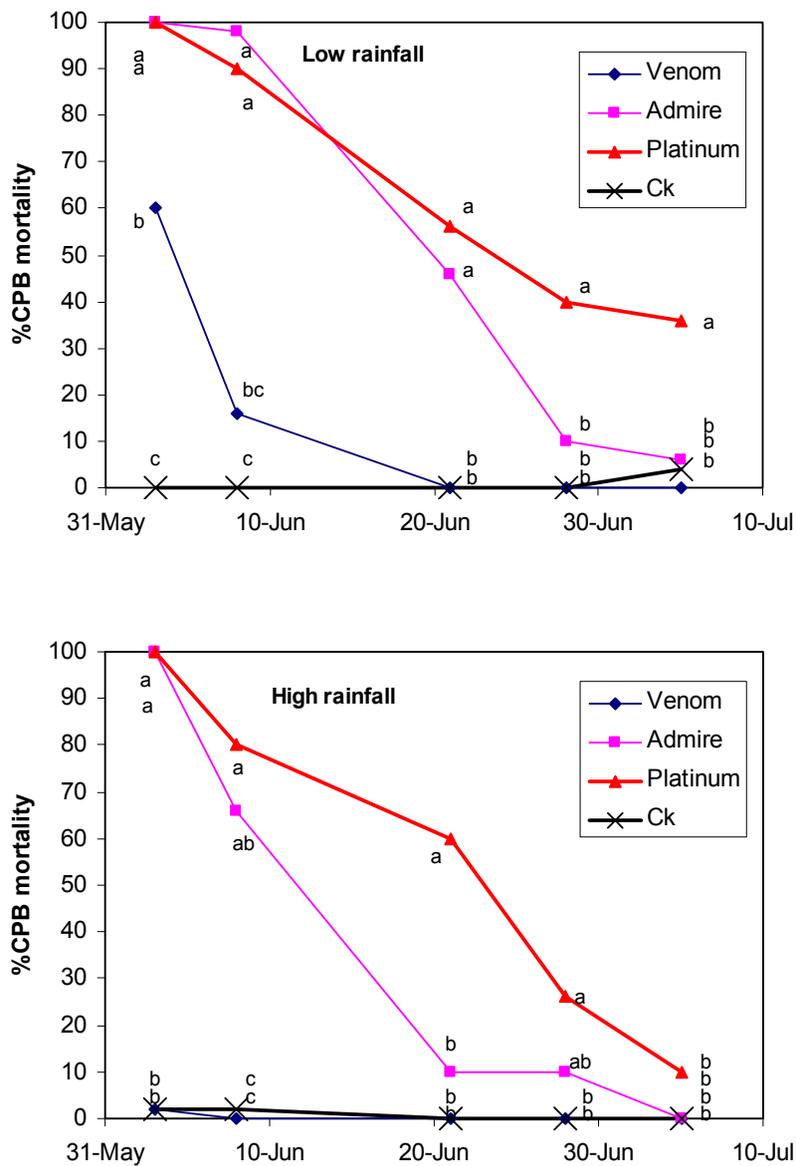NJ 2007

Figure 1. Effect of two levels of simulated rainfall on mortality of Colorado potato beetle larvae on
potato foliage treated with neonicotinoids in a laboratory bioassay. Bridgeton, NJ. 2007.

significantly (P<0.01) more toxic to CPB larvae than all other treatments through 7 Jul. Under the high rainfall regimen, larvae placed on leaves treated with imidacloprid or thiamethoxam had a significantly (P<0.01) higher mortality on 28 May and 7 Jun than did larvae placed on leaves treated with dinotefuran or leaves from plants that received no insecticide; mortality of CPB on leaves treated with thiamethoxam was still significantly higher than that of CPB larvae on leaves treated with dinotefuran or the leaves that received no insecticide through the end of Jun (Fig. 1).

CPB larvae placed on leaves from potato plants treated with imidacloprid or thiamethoxam ate significantly (P<0.01) less leaf tissue than did larvae on potato leaves from plants treated with dinotefuran or on leaves with no insecticide on each day recorded for both the low and high rainfall regimen (Fig. 2). Leaves from potato plants treated with dinotefuran under the low rainfall regimen had significantly (P<0.01) less CPB feeding damage as compared with
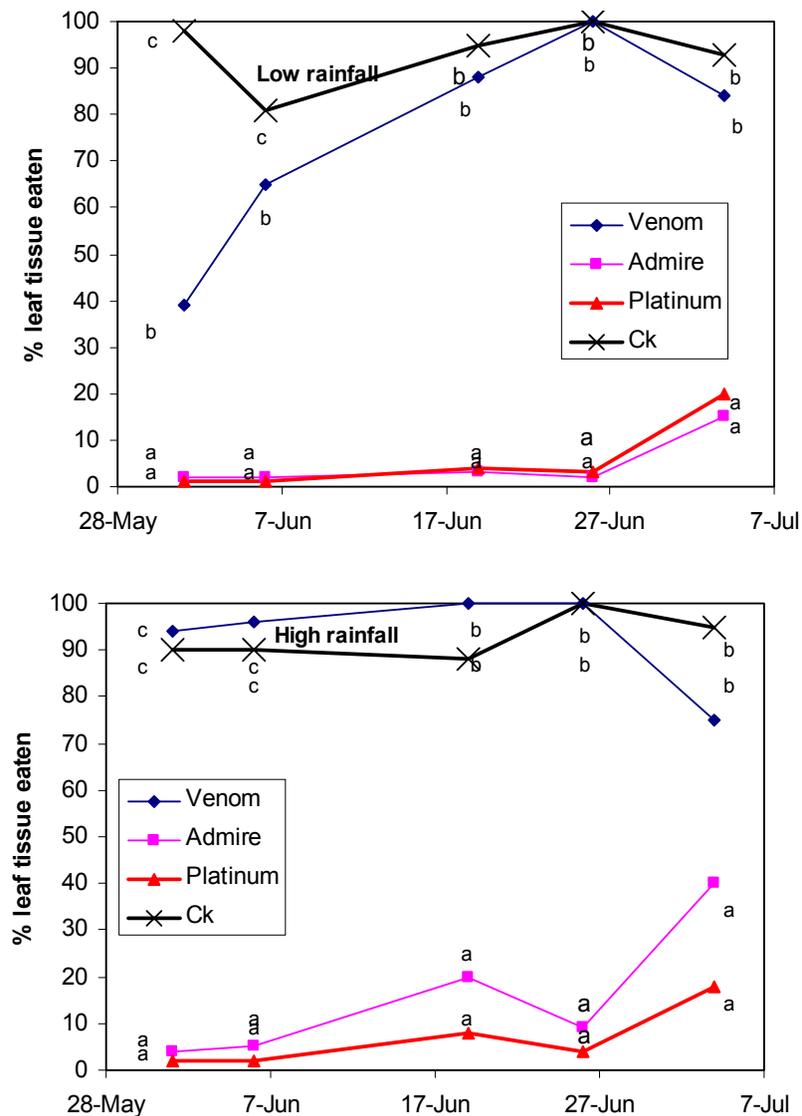

Figure 2. Effect of two levels of simulated rainfall on percentage leaf tissue eaten by Colorado potato beetle larvae on potato treated with neonicotinoids in a laboratory bioassay. Bridgeton, NJ 2007.

leaves with no insecticide only on 28 May and 7 Jun, but not on 17, 17 Jun or 7 Jul. Leaves from dinotefuran-treated potato plants under the high rainfall regimen showed no significant differences for damage as compared with the leaves with no insecticide on all dates of the bioassay (Fig. 2).

3.2. Field results

The results of the ANOVA to test the main effects (amount of simulated rainfall and insecticide) and rainfall by insecticide interaction on CPB and PLH in field trials are summarized in Table 2. ANOVA demonstrated significant (P<0.01) insecticide (sub-plots) effects for all data (total CPB, CPB defoliation and PLH damage rating). The main effect of the amount of simulated rainfall was significant (P<0.05) only for PLH damage. A significant (P<0.05) interaction of the amount of simulated rainfall by insecticide was observed for both the percentage defoliation caused by CPB and for PLH damage.

	No. CPB/3 hills			% CPB defoliation				PLH damage rating (0-5 scale)	
	6/1	6/11	6/17	6/1	6/11	6/17	6/25	6/25	7/3
MP	ns	ns	ns	ns	ns	ns	ns	**	**
SP	**	**	**	**	**	**	**	**	**
MPxSP	ns	ns	ns	*	*	*	ns	*	*

MP= main effect of simulated rainfall; SP= main effect of insecticides; MPxSP= interaction
[1]Summary of results of analysis of variance. ns= nonsignificant; *, P<0.05%, **, P<0.01%

Table 2. Summary of effects of simulated rainfall and insecticides on control of Colorado potato beetle (CPB) and potato leafhopper (PLH) on potatoes in field trials[1], Bridgeton, NJ 2007

Plots treated with either imidacloprid or thiamethoxam had fewer CPB larvae on all dates recorded as compared with plots that received no insecticide in both the high and low rainfall regimens; the number of CPB larvae/3 hills recorded in plots treated with imidacloprid or thiamethoxam remained low throughout the season (Fig. 3). The plots treated with dinotefuran had significantly (P<0.05) more CPB larvae then did either of the plots treated with either imidacloprid or thiamethoxam on 17 Jun. There were no significant (P<0.05) differences between plots treated with dinotefuran and plots that received no insecticide for number of CPB larvae/3 hills in either the low or high rainfall regimen on each day observed throughout the season. Both imidacloprid and thiamethoxam were effective in reducing the numbers of CPB larvae throughout the season (from planting through late Jun). Under the low rainfall regimen, dinotefuran was effective in reducing CPB larvae only through early Jun, and under the high rainfall regimen the number of CPB larvae/3 hills for potato plants treated with dinotefuran was not significantly (P<0.05) different than plants that received no insecticide on any date observed.

The percentage defoliation caused by CPB feeding was significantly ($P<0.05$) less in plots treated with imidacloprid or thiamethoxam as compared with dinotefuran or plots that received no insecticide after 12 Jun in both the low and high rainfall regimens (Fig. 4). The percentage defoliation in plots treated with dinotefuran was less than in plots that received no insecticide but greater than either imidacloprid or thiamethoxam in the low rainfall regimen, but was similar to the plots that received no insecticide in the high rainfall regimen, although these differences were not significant ($P<0.05$).
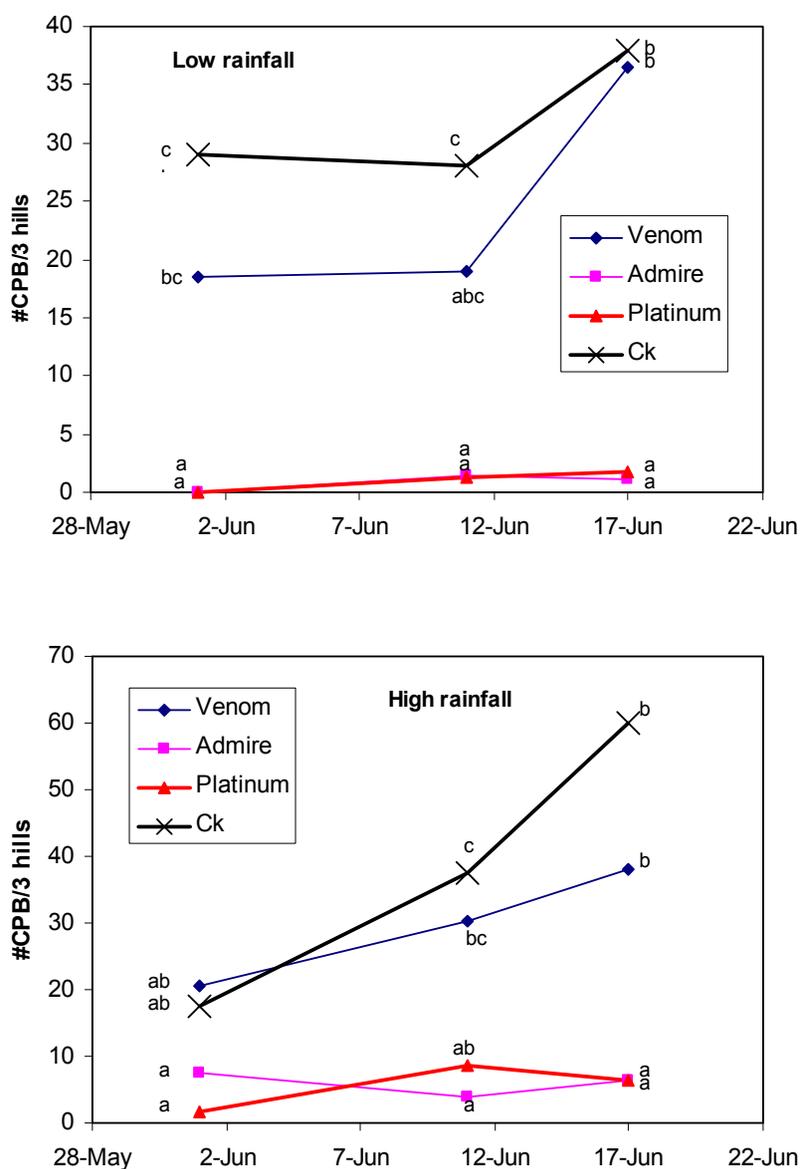

Figure 3. Effect of two levels of simulated rainfall on populations of Colorado potato beetle larvae on potatoes treated with neonicotinoid insecticides at planting, Bridgeton, NJ. 2007.

All insecticide-treated plots had significantly less (P<0.05) PLH damage on each day recorded for both the low and high rainfall regimens, as compared with plots that received no insecticide (Fig. 5). In the insecticide-treated plots that received low rainfall, no significant differences among the three treatments were recorded. Under the high rainfall regimen, however, the dinotefuran-treated plots had significantly higher PLH damage on 25 Jun than did plots treated with either imidacloprid or thiamethoxam, and by 7 Jul, plots treated with thiamethoxam had significantly (P<0.05) less PLH damage than all other treatments.
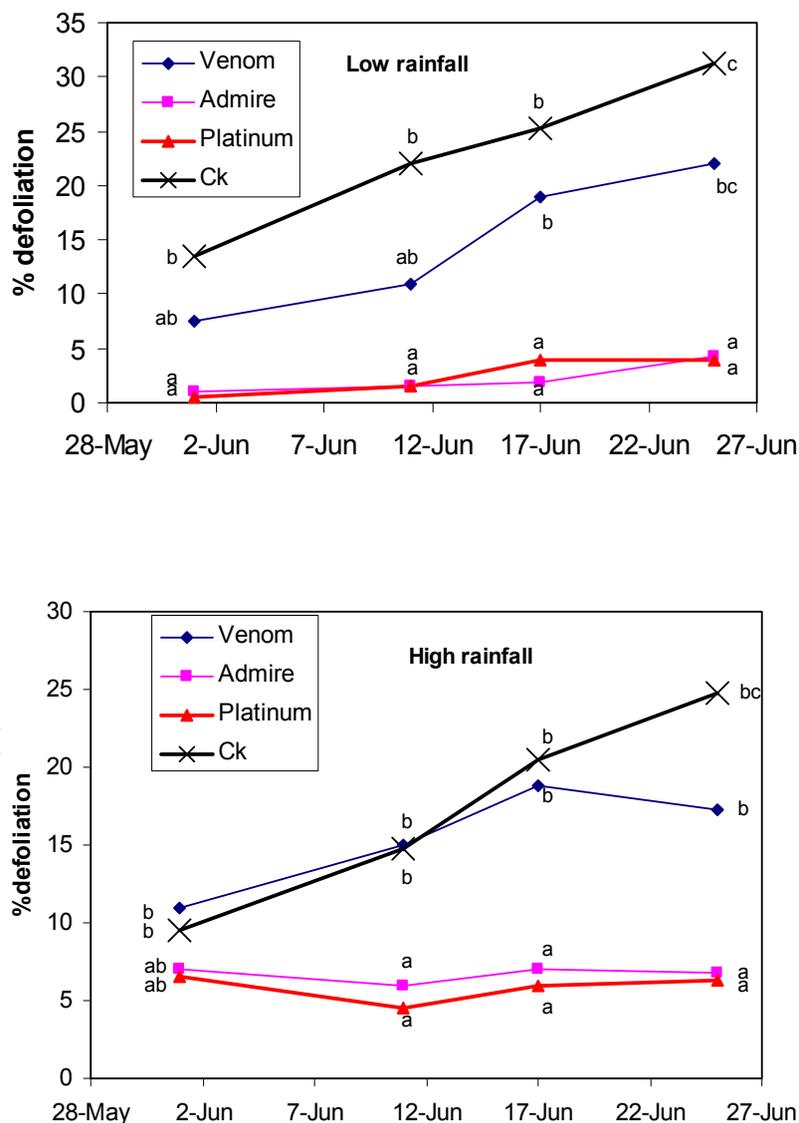

Figure 4. Effect of two levels of simulated rainfall on percentage plant defoliation caused by Colorado potato beetles on potatoes treated with neonicotinoids at planting, Bridgeton, NJ. 2007.
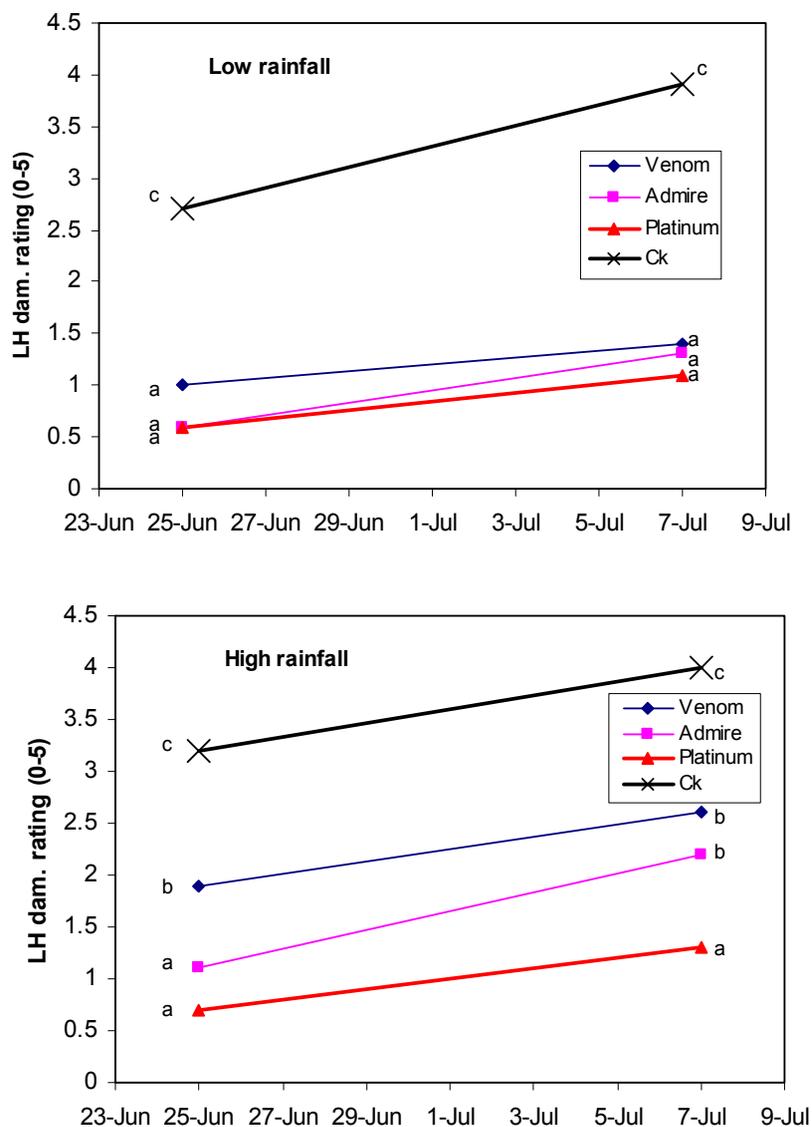
Figure 5. Effect of two levels of simulated rainfall on damage caused by potato leafhopper on potatoes treated with neonicotinoids at planting, Bridgeton, NJ. 2007.

4. Discussion

The CPB mortality bioassay showed that imidacloprid and thiamethoxam were more toxic to CPB larvae than dinotefuran during May and early June, but mortality of CPB larvae for all treatments declined over time (Fig. 1). It is likely that the continual simulated rainfall was partially responsible for this decrease in efficacy since dinotefuran, the most soluble material, was effective against CPB larvae early with the low amount of simulated rainfall, but was not effective at any time with the high amount of rainfall, suggesting that the material was leached from the soil before the potato plants had enough root matter to absorb the insecticide. Mortality would also decline over time because the material is no

longer available in the foliage when the CPB were placed on the leaves in the petri dish, as the bioassay was conducted from 37 to 70 days after the in-furrow treatment applications. It is also possible that CPB mortality within all treatments declined over time because the laboratory test larvae were field-harvested from an untreated potato nursery, and only large larvae (3rd and 4th instars) were available in late June whereas only small larvae (1st and 2nd instars) were available in late May and early June, and only adults were available in July. Large CPB larvae and adults are generally more difficult to intoxicate than small larvae [24,25,26]. Further, mortality of CPB on leaves from plants treated with thiamethoxam was significantly (P=0.05) higher than that of all other treatments, including imidacloprid, under the low rainfall regimen on 28 Jun and 5 Jul, the last two test dates, suggesting that thiamethoxam remains more active in the plant over a longer period of time. Plants from soybean seeds that had been treated with with thiamethoxam resulted in significantly fewer aphid numbers than did imidacloprid-treated plants after 3 weeks, likely due to faster imidacloprid metabolism in the plant, which would result in reduced insecticide activity over a shorter time [27]. However, the difference between imidacloprid and thiamethoxam observed in the laboratory trials was not observed in the field trial, possibly because the final CPB larval field count was conducted on 25 June. Also, the effect of high amounts of simulated rainfall may be more pronounced in the greenhouse pots than under actual field production.

Similarly, the percentage leaf tissue consumed by larvae was significantly (P<0.05) higher with dinotefuran and the untreated than with imidacloprid or thiamethoxam on all dates recorded. However, dinotefuran resulted in significantly less leaf tissue consumption than was observed with plants that received no insecticide in late May and early June (Fig. 2) only under the low rainfall regimen; there were no significant differences between dinotefuran and plants that received no insecticide under the high rainfall regimen, again indicating that rainfall level impacted the effectivess of dinotefuran more so than that of imidacloprid or thiamethoxam.

Data from the mortality and leaf-feeding laboratory bioassays showed significant (P<0.05) insecticide effects in that both imidacloprid and thiamethoxam, applied at planting with the seed piece, were significantly (P<0.05) more effective in reducing foliage consumption by CPB larvae from planting (23 Apr) through 7 Jul under both the low and high rainfall regimens compared with plants that were treated with dinotefuran or plants that received no insecticide. The interaction showed that plants treated with dinotefuran, under the low rainfall regimen, were significantly more effective in reducing leaf-feeding damage than plants that received no insecticide only from planting through 7 Jun; dinotefuran was ineffective in reducing foliage consumption under the high rainfall regimen for all dates observed as compared with plants that received no insecticide. Similarly, leaves from plants treated with either imidacloprid or thiamethoxam at planting resulted in significantly higher CPB mortality from May through mid-July under the low rainfall regimen and through mid-June under the high rainfall regimen as compared with CPB mortality on plants treated with dinotefuran or on plants that received no insecticide. As observed with the leaf-feeding bioassay, CPB mortality was significantly higher on plants treated with

dinotefuran under the low rainfall regimen only through early June, as compared with plants that received no insecticide; CPB mortality on plants treated with dinotefuran under the high rainfall regimen were not significantly different than the untreated on all dates observed. A highly water-soluble systemic insecticide may not provide long-term control or regulation compared with a less water-soluble systemic insecticide [28]. Mortality of CPB gradually on foliage treated with imidacloprid or thiamethoxam declined over time from May through July for both rainfall regimens, and mortality declined more quickly with dinotefuran for the low rainfall regimen as compared with imidacloprid or thiamethoxam.

Data from the field trials for CPB mortality are similar to the CPB mortality trials in the laboratory bioassay, with significant insecticide effects in that plots treated with either Admire or Platinum at planting resulting in significantly fewer CPB/3 hills through late June under both the low and high rainfall regimens. Plots treated with dinotefuran had significantly fewer CPB/3 hills than did plots that received no insecticide only on 2 Jun and only under the low rainfall regimen; there were no significant differences for CPB/3 hills between plots treated with dinotefuran and the no-insecticide plots on all dates observed under the high rainfall regimen. As was recorded with the CPB larval counts in the field and the laboratory trials, dinotefuran was less effective than either imidacloprid or thiamethoxam under the low rainfall regimen, and dinotefuran was ineffective under the high rainfall regimen. Further, both imidacloprid and thiamethoxam remained effective for a greater time period after planting than did dinotefuran, possibly due to the lower solubility of imidacloprid and thiamethoxam. Field data for the percentage defoliation caused by CPB feeding were similar to that observed for CPB mortality. Significant insecticide effects were observed as defoliation increased over time. Defoliation in plots treated with either imidacloprid or thiamethoxam remained low through all observation dates, but defoliation in plots treated with dinotefuran was not significantly different than plots that received no insecticide on any observation date. These data agree with [29], who reported that potatoes treated with dinotefuran had significantly greater percentage defoliation than either imidacloprid or thiamethoxam in white potatoes with in-furrow treatments.

The PLH data show significant insecticide and significant rainfall effects. Under the low rainfall regimen, all insecticides resulted in significantly less PLH damage through the season (mid- June through mid-July) as compared with the plots that received no insecticide; no significant effects among the three insecticides were observed for either observation date. However, under the high rainfall regimen, plots treated with either imidacloprid or thiamethoxam resulted in significantly less ($P<0.05$) PLH damage early in the season (25 Jun) than did all other treatments, but only plots treated with thiamethoxam had significantly ($P<0.05$) less PLH damage than all other treatments on 7 July. Our data agrees with that of [30], who reported that thiamethoxam provided longer and more consistent protection of snap beans from PLH than did imidacloprid when applied as a seed treatment. They concluded that thiamethoxam had greater physiological activity against PLH than did imidacloprid.

Overall, the effectiveness of dinotefuran against CPB and PLH was influenced by the amount of rainfall significantly more than either imidacloprid or thiamethoxam. Under a high rainfall regimen, plots that received a treatment of dinotefuran were not significantly different from plots that received no insecticide for either CPB mortality or for CPB leaf consumption, and under a low rainfall regimen the effectiveness of dinotefuran against CPB was significantly shorter over time than either imidacloprid or thiamethoxam. It has to be mentioned that our findings reflect the worst-case scenarios for rainfall (maximum rainfall total of 60.96 cm [24"] laboratory and 50.8 cm [20"] field) and that under practical conditions lower amounts of rainfall would likely naturally occur. These high rainfall amounts likely caused exaggerated leaching of all of the neonicotinoids, especially the highly soluble dinotefuran, resulting in reduced control of the CPB and PLH.

Results of the present study show that rainfall has an impact on effectiveness of soil-applied imidacloprid, dinotefuran and thiamethoxam for both CPB and PLH control in white potatoes. However, growers should not rotate imidacloprid or dinotefuran with thiamethoxam as part of their resistance management program. Alyokhin et al. (31) showed that the correlation for LC_{50} values for imidacloprid and thiamethoxam was highly significant using diet incorporation bioassays, and that there was substantial cross-resistance among three neonicotinoid insecticides. Further, Mota-Sanchez et al. (32) reported that cross-resistance was observed with all 10 different neonicotinoids in a bioassay using topical applications. They concluded that the rotation of imidacloprid with other neonicotinoids may not be an effective long-term resistance management strategy. For effective insecticide resistance management, control of CPB should not depend exclusively on the neonicotinoid class of insecticides. It is important to use all available effective pest management tools, including crop rotation, border treatments, and non-neonicotinoid (different class) insecticides.

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