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ARTHROPOD MANAGEMENT & APPLIED ECOLOGY

Residual Effects of Novaluron and Efficacy of Subsequent Applications to Control Mid-South Tarnished Plant Bug (Hemiptera: Miridae) Populations

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ABSTRACT

Novaluron is often used in the early-square development period of cotton in the midsouthern U.S. to manage immature *Lygus* populations. Preventing field populations of tarnished plant bug from reaching economically damaging levels is vital when protecting cotton yield. Field experiments were conducted in 2019 and 2020 to better understand impacts of initial novaluron applications, efficacy of subsequent insecticides, and residual activity of novaluron. Tarnished plant bug populations had less impact on cotton yield when an insecticide with adult activity was applied with novaluron at the third week of squaring.

There are multiple yield-limiting insect pests of cotton; however, the tarnished plant bug, *Lygus lineolaris* (Palisot de Beauvois), is the most economically important pest throughout the midsouthern region of the U.S. Insecticides are the primary means used for tarnished plant bug management, and multiple applications are often required (Cook, 2019; Williams, 2017; Wood et al., 2016). Resistance to several insecticide classes including pyrethroids, organophosphates, carbamates, and neonicotinoids now persist among Mid-South *Lygus* populations, indicating a need for alternative modes of action to manage infestations (Snodgrass, 1996a, b; Snodgrass et al., 2008). Jutsum et al. (1998) stated that resistance management should begin with introduction of novel chemistries. As insecticide chemistries have progressed over recent years, biorational insecticides have emerged to deliver valuable new modes of action. Chitin synthesis inhibitors, such as novaluron, represent a unique group of insect growth regulators (IGRs) available to cotton producers as an alternative to manage tarnished plant bug infestations.

Novaluron was first registered in the U.S. in 2001 for use in cotton, ornamentals, and other food crops (US EPA, 2001). Novaluron is a benzoylphenyl urea that acts as an IGR by disrupting the molting process of immature pests and is known to target immature arthropods among Coleoptera, Diptera, Hemiptera, and Lepidoptera (Ishaaya et al., 1996). The chitin synthesis inhibiting formulation interrupts transportation of proteins that form polymeric chitin, altering the integrity of the endocuticle layer causing molt inhibition and eventual death (Cutler and Scott-Dupree, 2007; Hajjar and Casida, 1978).

Novaluron was originally thought to effect only immature stages of susceptible insects. However, results from various studies have demonstrated impacts on adult insects. Novaluron ingestion negatively affects both male and female hatch rates as well as female tarnished plant bug oviposition (Catchot et al., 2021). Although uptake of the insecticide is primarily by ingestion, effects via topical contact have been observed (Ishaaya et al., 2003). Data from Catchot et al. (2021) indicated that ingestion of novaluron by tarnished plant bug adults was more effective than contact exposure; however, contact with treated foliage up to one day after application often led to the same result: decreased nymph populations. When adult females of any age were exposed to novaluron, reduced egg viability was observed in addition to ovarian malformation in newly reproducing adults (Catchot et al., 2020). Laboratory studies conducted by Owen et al. (2011) showed that novaluron is more active against first instar nymphs as compared to second and fifth instars. Other field trials have shown significant cotton yield increases when tank-mixing novaluron with other insecticides targeting tarnished plant bugs (Graham, 2020).

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Tarnished plant bug typically damages small- to medium-sized flower buds (squares), but other fruiting structures such as terminals and small bolls can be damaged (Tugwell et al., 1976). Feeding damage to smaller fruiting structures generally results in abscission, whereas older squares are normally retained. For larger-sized fruiting structures that do not abscise, boll set can be impacted if damage to flower anthers is severe (Layton, 2000).

To minimize yield losses attributed to tarnished plant bug populations, extensive research has been conducted to understand the pest and its impact in cotton. Studies have shown that applying novaluron at the third week of squaring improved tarnished plant bug control and cotton yields (Dobbins et al., 2014; Gore et al., 2010; Owen et al., 2011). Because novaluron has no lethal impact on adult populations, a tank mixture incorporating an insecticide with adult activity is typically used (Catchot et al., 2014). Properly timed novaluron applications in conjunction with other integrated pest management practices can help minimize insecticide applications (Graham, 2020). This research seeks to better understand residual activity of novaluron and evaluate both early season and subsequent insecticide efficacy to manage tarnished plant bug across Mid-South cotton production areas. Our primary objective in this research was to determine the long-term effects of novaluron in an overall tarnished plant bug management plan.

MATERIALS AND METHODS

Field experiments were conducted to determine management effects on tarnished plant bug populations treated with novaluron and efficacy of subsequent insecticide treatments across various locations in Mississippi, Arkansas, and Tennessee in 2019 and 2020. Experimental sites in 2019 were at Lonoke, AR; Jackson, TN; and two planting dates at Stoneville, Sidon, and Glendora, MS. Sites in 2020 were located at Sidon, Glendora, and Stoneville, MS. Experiments followed a randomized complete block design with a split-plot arrangement with four replications. Sites across both years were planted at a rate of 135,899 seed ha^{-1} on raised, conventional tilled beds in Mississippi and Arkansas, and in conservational tillage in Tennessee. Planting dates occurred between 20 May and 13 June in 2019 and between 7 May and 11 May in 2020. At each location a high-yielding two- or three-gene Bt cotton cultivar (Bollgard II®, Monsanto Co., St. Louis, MO; Bollgard 3®, Monsanto Co., St. Louis, MO; or Widestrike™, Corteva Agriscience, Indianapolis, IN) was selected to minimize damage from lepidopteran pests.

The two levels of whole-plot factors included treatment with novaluron at 0.096 kg ai ha^{-1} (Diamond® 0.83EC, ADAMA USA, Raleigh, NC) or acephate at 0.840 kg ai ha^{-1} (Orthene 97, AMVAC Chemical Corporation, Los Angeles, CA) at the third week of squaring. In 2019, there was not a true control treatment for the whole-plot effect, but we believe it is important to show those results because they demonstrate, in the 2020 data, the importance of an insecticide with adult activity during the early season. Therefore in 2020, acephate was applied to the entire test area at the third week of squaring as would be done in a typical tarnished plant bug management program. Novaluron was applied to half of the whole plots at 0.096 kg ai ha^{-1} to determine the additional impact of novaluron in an overall management program. Although there was not a true untreated control for the whole-plot factor, the acephate alone application served as the control for the whole-plot factor in 2020 in an overall management program. Although the study was not replicated over multiple years with the same whole-plot factors, the study was replicated over multiple locations and growing conditions within each year.

The split plots consisted of four rows of cotton measuring 12.20 to 15.25 m in length separated by an unplanted 3.05-m alley. Lonoke, AR; Jackson, TN; and all Stoneville, MS locations were planted on 101.6-cm rows, whereas the Glendora and Sidon, MS sites were planted on 96.52-cm rows for each site year. Split-plot treatments each year included six different insecticides applied 7 to 10 d following whole-plot insecticide application to measure the efficacy on tarnished plant bug populations. Split-split-plot treatments consisted of an untreated control, dicrotophos (Bidrin 8E, Amvac Chemical Company, Walnut Creek, CA), sulfoxaflor (Transform WG™, Dow AgroSciences, Indianapolis, IN), bifenthrin (Brigade® 2EC, FMC Corporation, Princeton, NJ), thiamethoxam (Centric®, Syngenta Crop Protection, Inc., Greensboro, NC), and oxamyl (Vydate® C-LV, DuPont Crop Protection, Wilmington, DE) to represent a variety of insecticide classes and were applied at labeled rates (Table 1). All treatments were applied with a MudMaster™ (Bowman Manufacturing, Newport, AR) high-clearance sprayer calibrated to deliver 93.5 L ha^{-1} with TX-6 hollow cone nozzles at 276 kPa. Standard production practices were followed according to the corresponding university extension recommendations. Management of other arthropods was achieved by using insecticides known to have no or minimal activity on tarnished plant bug. Established tarnished plant bug populations were naturally occurring across all locations for 2019 and 2020. Plots were sampled for tarnished plant bug nymphs at 3, 7, 10, and 14 d after split-plot applications with a black 0.76-m drop cloth, taking two samples per plot at each respective sampling interval. Cotton yield was determined by harvesting the center two rows at physiological maturity with a John Deere 9900 two-row modified spindle-type picker equipped for small plot research. Seed cotton yield was recorded and adjusted to kg lint ha^{-1} using 40% turnout.

Table 1. Sequential foliar insecticide trade name, active ingredient, IRAC class and rate that were applied at third week of cotton square for management of tarnished plant bug

Insecticide	Active Ingredient	Class[z]	kg ai ha^{-1}
Bidrin 8 EC	dicrotophos	1B	0.450
Transform 50 WG	sulfoxaflor	4C	0.053
Brigade 2 EC	bifenthrin	3A	0.110
Centric 40 WG	thiamethoxam	4A	0.056
Vydate 3.77 EC	oxamyl	1A	0.360

[z] Class refers to insecticide mode of action classification

Data for tarnished plant bug nymphs and yield were analyzed with a general linear mixed model analysis of variance (PROC GLIMMIX, SAS 9.4, SAS Institute, Cary, NC). Insecticide treatments were considered fixed effects. Replication and replication-nested-in-year were considered random effects. Means were separated using Fisher's Protected LSD procedure at the 0.05 level of significance.

RESULTS AND DISCUSSION

In 2019, there was no significant interaction between whole-plot and split-plot treatment for any tarnished plant bug sample date (p = 0.29; Df = 5, 253; F = 0.43) or for tarnished plant bug nymph seasonal means (Fig. 1) (p = 0.35; Df = 5, 875.9; F = 1.11). When evaluating the whole-plot treatment at each sample date (p = 0.13; Df = 1, 253; F = 0.45) and across the seasonal means (p = 0.15; Df = 1, 875.9; F= 0.69) for tarnished plant bug nymphs, there were no significant difference between acephate and novaluron. Although there was no yield difference across all whole-plot and split-plot treatments (Fig. 2, p = 0.86; Df = 5, 252; F = 0.37), there was a significant yield increase attributed to whole plots treated with acephate compared to novaluron (Fig. 3, p < 0.01; Df = 1, 252; F = 20.50). This shows the importance of controlling migrating adults. When evaluating tarnished plant bug means by whole-plot treatment at each sample period there was no influence on nymphs in 2019 (Table 2).

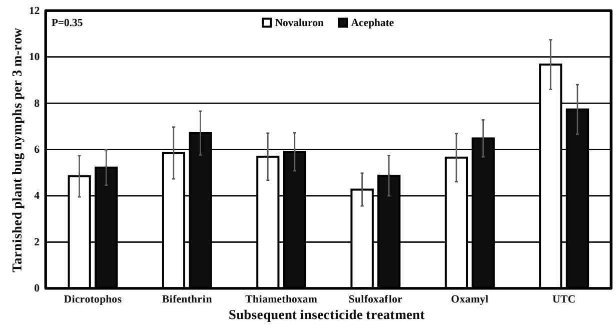

Figure 1. Mean ± SEM number of tarnished plant bug nymphs by split-plot treatment in 2019. Means separated by a common letter are not significantly different according to Fisher's Protected LSD (α = 0.05).

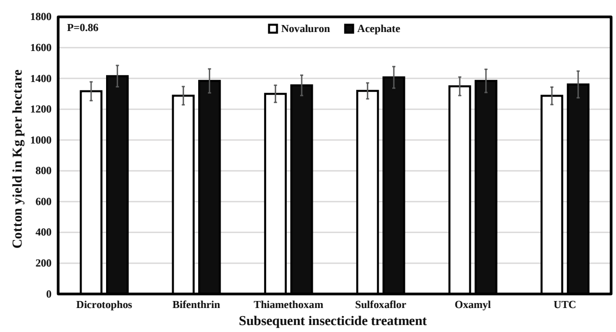

Figure 2. Mean ± SEM lint yield (kg ha^{-1}) by split-plot tarnished plant bug insecticide treatment in 2019. Means separated by a common letter are not significantly different according to Fisher's Protected LSD (α = 0.05).

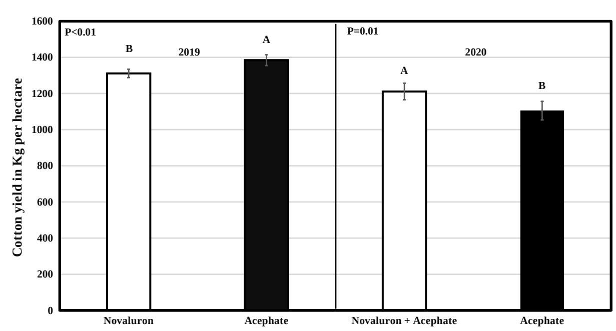

Figure 3. Mean ± SEM lint yield (kg ha^{-1}) by whole plot tarnished plant bug insecticide treatment in 2019 and 2020. Means separated by a common letter are not significantly different according to Fisher's Protected LSD (α = 0.05).

Table 2. Mean ± SEM counts of tarnished plant bug nymphs observed at each sampling period

Sampling Period[z]	Year	Initial Application[y]	TPB Nymphs[x]	F	DF	P-Value
3 DAT	2019	Novaluron	4.0 (0.5)	1.53	1,252	0.22
		Acephate	3.4 (0.4)			
	2020	Novaluron + Acephate	5.1 (0.6) b[w]	9.03	1,121	<0.01
		Acephate	7.5 (0.8) a			
7 DAT	2019	Novaluron	5.1 (0.5)	2.30	1,253	0.13
		Acephate	5.9 (0.7)			
	2020	Novaluron + Acephate	4.3 (0.7) b	17.26	1,121	<0.01
		Acephate	7.2 (0.6) a			
10 DAT	2019	Novaluron	8.9 (0.9)	0.44	1,253	0.50
		Acephate	9.4 (0.9)			
	2020	Novaluron + Acephate	5.8 (0.5) b	20.39	1,121	<0.01
		Acephate	10.1 (0.9) a			
14 DAT	2019	Novaluron	3.9 (0.9)	1.95	1,33	0.17
		Acephate	2.7 (0.8)			
	2020	Novaluron + Acephate	7.2 (0.7) b	21.37	1,77	<0.01
		Acephate	12.5 (1.1) a			

[z] Sampling period- the time at which insecticide evaluation were conducted

[y] Initial application is the first insecticide application put out at the third week of cotton squaring

[x] TPB – Tarnished plant bug

[w] Means separated by a common letter are not significantly different according to Fisher's Protected LSD

In 2020, insecticide treatments following either novaluron plus acephate or acephate alone made a significant difference on tarnished plant bug nymph abundance (Fig. 4, $p = 0.01$; Df = 5, 506.8; F = 2.95). Cotton treated with dicrotophos, thiamethoxam, and oxamyl all averaged lower tarnished plant bug nymph numbers when following a novaluron plus acephate application than when following acephate alone. Untreated plots that only received novaluron plus acephate had fewer plant bug nymphs than plots that only received acephate during the third week of squaring and were not followed with an additional insecticide application. Overall, plots that initially received novaluron plus acephate had fewer tarnished plant bug nymphs than plots that received only acephate regardless of application (Fig. 4). At every sample interval in 2020, plots treated during the third week of squaring with novaluron plus acephate had fewer tarnished plant bug nymphs than plots that were treated with acephate alone (Table 2). In 2020, there were no significant differences in yield across all whole-plot and split-plot treatments (Fig. 5, $p = 0.34$; Df = 5, 120; F = 1.14). However, overall plots treated with novaluron plus acephate during the third week of squaring yielded higher than plots that were treated with only acephate during the same period (Fig. 3, $p = 0.01$; Df = 1, 120; F = 12.28).

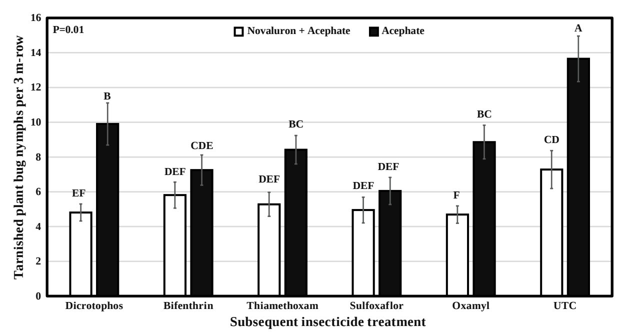

Figure 4. Mean ± SEM season long means of tarnished plant bug nymphs by split-plot treatment in 2020. Means separated by a common letter are not significantly different according to Fisher's Protected LSD (α = 0.05).

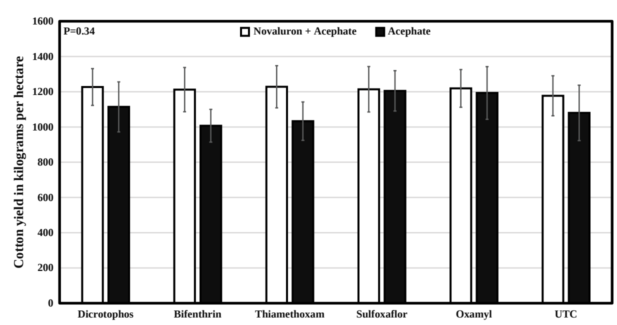

Figure 5. Mean ± SEM lint yield (kg ha^{-1}) by split-plot tarnished plant bug insecticide treatments in 2020. Means separated by a common letter are not significantly different according to Fisher's Protected LSD (α = 0.05).

These data clearly show the benefits of using an IGR, such as novaluron, for residual properties in the early-squaring period when peak adult migration is occurring. Additionally, tank-mixing an insecticide with adult activity improved efficacy, efficacy of subsequent products, and yield. The results demonstrate the importance of a residual when nymphs are expected to be hatching. These data are consistent with Owen et al. (2011) demonstrating that the early use of novaluron can provide increased efficacy of tarnished plant bug control and protect cotton yield. However, these data also indicate that to benefit fully from the residual properties of an IGR such as novaluron, novaluron must be tank-mixed with an insecticide with adult activity as demonstrated by Graham (2020). The success of this approach is likely due to migrating adults being controlled before economic damage from feeding and extensive egg lay occurs. Control of local nymph populations hatching while there was residual novaluron and the potential reduced fecundity of remaining tarnished plant bug adults by the IGR proved beneficial (Catchot et al. 2020). This strategy could prove useful in breaking the initial early season buildup of tarnished plant bugs moving into flowering cotton fields, which are most susceptible to yield loss (Wood et al., 2016).

Although it is unclear whether the use of novaluron plus acephate compared to acephate alone early in the season is increasing the efficacy of subsequent insecticide applications or simply helping those applications maintain the increased control of the initial application due to low numbers of nymphs, it clearly has a positive effect on long-term control of tarnished plant bug populations. The additive effect on long-term nymphal control and the importance of early season management of tarnished plant bug is demonstrated by comparing data in 2019 to 2020 when an insecticide with adult activity was incorporated. Furthermore, data from this study also indicated that if tarnished plant bug populations are controlled early and adequately, a broad array of insecticides can be used to further manage tarnished plant bug field populations. This can allow a diverse range of insecticide mode of actions to be effective, allowing for rotation of insecticide classes as well as providing growers with an option to use a more cost-effective late season management approach.

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