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Research

Impact of Insecticide Seed Treatments and Foliar Insecticides on Aphid Infestations in Wheat, Incidence of Barley Yellow Dwarf, and Yield in West Tennessee

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Abstract

Several species of aphids (Hemiptera: Aphididae) infesting wheat may reduce yield by the transmission of barley yellow dwarf (BYD). Neonicotinoid seed treatments and foliar application of insecticides are two common methods to control aphid infestations and reduce BYD. An analysis was carried out across 33 insecticide efficacy tests performed in west Tennessee during the last 11 yr to determine how insecticide seed treatments and/or a late-winter foliar insecticide application affected aphid populations, incidence of BYD, and yield. A significant decrease in springtime aphid populations and incidence of BYD was observed when using a seed treatment, a foliar insecticide application, or both. Average wheat yields were increased by 280–381 kg/ha (5.3–7.2%) if an insecticide seed treatment was used or when a foliar insecticide application was made. Compared with insecticide seed treatments, average springtime aphid populations and the incidence of BYD were lower when a foliar insecticide was applied. A foliar insecticide application made in addition to insecticide seed treatments increased yield by an average of 196 kg/ha (3.4%). The yield increases over the nontreated control suggest that wheat growers in west Tennessee can use insecticides to manage aphids and prevent transmission of BYD. Consideration of environmental conditions, whether or not insecticide seed treatments were used, and scouting can be used to help make decisions on when or if to apply foliar insecticides.

Key words: soft red winter wheat, *Triticum aestivium* L., aphid, barley yellow dwarf virus, insecticide control

World wheat (*Triticum* spp.) production is estimated at over 221 million ha, which makes it the most widely cultivated crop (USDA 2016). In Tennessee, wheat production varies considerably, but typically ranges from 100,000 to 200,000 ha of soft red winter wheat (*Triticum aestivium* L.), which is typically planted in the fall (September–November) and harvested in June. The majority of Tennessee's wheat is grown in west and middle Tennessee. Producers in the midsouthern and southeastern United States typically grow wheat in a double-crop system where wheat harvest is followed with planting of soybeans (*Glycine max* L.) or another summer crop. In 2017, the average wheat yield in Tennessee was 4,764 kg/ha (70 bu/acre; USDA-NASS 2016), and over the last 10 yr, average yield has ranged from 4,967 to 3,403 kg/ha (50–73 bu/acre).

Aphids (Hemiptera: Aphididae) are a threat to wheat production not only by feeding on the plant and causing yield loss, but also by transmitting barley yellow dwarf (BYD) virus (Family Luteoviridae). BYD virus within the host plant is phloem limited and cannot be transmitted without the assistance of aphids (Gildow 1987, Jensen and D'Arcy 1995). Several aphid species may infest wheat and have been shown to transmit BYD, including the bird cherry-oat aphid, *Rhopalosiphum padi* (L.) (Hemiptera: Aphididae); greenbug, *Schizaphis graminum* (Rondani) (Hemiptera: Aphididae); English grain aphid, *Sitobion avenae* (F.) (Hemiptera: Aphididae); and corn leaf aphid, *Rhopalosiphum maidis* (Fitch) (Hemiptera: Aphididae) (McPherson and Brann 1983, Johnson and Hershman 1996).

BYD is the most common and widespread disease of wheat and cereal crops worldwide (Edwards et al. 2000). BYD is a worldwide economic problem not only for wheat but also for other cereal grains, causing loss in yield and grain quality by stunting shoot and root growth (Plumb 1983). The magnitude of crop damage by aphids depends on the extent of infestation (Kieckhefer et al. 1995), timing of infestation (Kieckhefer and Gellner 1988), plant growth stage at time of infestation (Pike and Schaffner 1985), and whether or not BYD is successfully transmitted to the host (McPherson et al. 1986). In North America, the most serious BYD outbreaks have primarily been associated with fall transmission by the bird cherry-oat aphid (Halbert and Pike 1985, Clement et al. 1986, Araya et al. 1987, Halbert et al. 1992). Observations in Tennessee suggest that overwintering aphids and their offspring also transmit BYD during the late winter months, which also results in yield loss (S.D.S., personal communication).

Symptomology of BYD infection includes orange, red, or purple leaf discoloration, especially at the leaf tips (McKirdy and Jones 1996). A consistent indicator of BYD in Tennessee is an observable pink to reddish discoloration of leaf tips, especially during the spring. Reported yield loss associated with BYD in wheat has been variable. Kieckhefer and Kantack (1988) reported that high aphid populations can directly reduce yield up to 50%. Patterson et al. (1990) reported typical yield losses from BYD range from 2 to 10% in the United States. However, another study demonstrated that BYD could reduce wheat yield by 46%, and yield loss was 58% when infested with bird cherry-oat aphids (Riedell et al. 1961). A different study demonstrated that wheat yield could be decreased by 34% when infected with BYD virus (Herbert et al. 1999).

Aphids and BYD are managed most effectively by implementing an integrated pest management approach including region appropriate planting dates and use of tolerant varieties to BYD. Insecticides are commonly used to control aphid populations in wheat (Hays et al. 1999). Neonicotinoid seed treatments such as Gaucho (imidacloprid, Bayer CropScience, Raleigh, NC), Cruiser (thiamethoxam, Syngenta Crop Protection, Greensboro, NC), Poncho (clothianidin, Bayer CropScience), and NipsIt Inside (clothianidin, Valent, Walnut Creek, CA) are a recommended control method for the management of aphids and BYD (Stewart and McClure 2017). If insecticide seed treatments are not used, a foliar chemical application 30 d after planting and/or in late winter may reduce aphid populations and the incidence of BYD (Buntin 2007).

Materials and Methods

Design

An analysis was performed across 33 experiments in west Tennessee from 2006 to 2017 to evaluate the impact of insecticide seed treatments and foliar insecticide applications on aphid infestations, incidence of BYD, and yield (Table 1). Not all experiments contained both treatment factors, and neither did they all have complete,

Table 1. Summary of 33 tests analyzed over an 11-yr period in west Tennessee

Test ID	Treatment factors			Data collected[d]	Plot size	Planting date	Variety
	IST[a]	Foliar[b]	IST + foliar[c]				
1	I, T	LC	T + LC	A	S	28 Sep. 2005	Coker 9663
2	I, T	LC		A	S	2 Oct. 2006	Pioneer 26R22
3	T	LC		A, B, Y	S	15 Oct. 2008	Pioneer 26R22
4	T	LC		A, B, Y	L	22 Oct. 2008	Pioneer 26R22
5	T	LC		A, B, Y	S	15 Oct. 2008	Pioneer 26R22
6	T	LC		Y	S	15 Oct. 2008	Pioneer 26R22
7	T	LC		Y	S	15 Oct. 2008	Pioneer 26R22
8	I, I + C			A, Y	S	6 Nov. 2009	Pioneer 25R68
9		LC		A, Y	L	Oct. 2007	Unknown
10	I, T	LC		B, Y	L	Oct. 2007	Unknown
11		LC		A, Y BBB	L	22 Oct. 2010	Progeny P185
12		LC		A, Y	L	15 Oct. 2010	Pioneer 25R78
13	I	LC	I + LC	A, Y	L	22 Oct. 2010	Progeny P185
14	I, C, I + C			A, Y	S	28 Oct. 2010	Dixie
15	I, T			A, B, Y	S	10 Oct. 2010	Oaks
16		LC		A, B	L	17 Oct. 2011	Pioneer 26R15
17		LC		A, B, Y	L	24 Oct. 2012	Unknown
18		LC		A, B, Y	L	24 Oct. 2012	Pioneer 25R32
19	I	BC	I + BC	A, B, Y	S	21 Oct. 2013	Unknown
20	C	LC	C + LC	A, B, Y	L	21 Oct. 2013	Pioneer 26R10
21		LC		A, B, Y	L	21 Oct. 2013	Pioneer 26R10
22		LC		A	S	21 Oct. 2014	Pioneer 26R10
23		LC		A, B, Y	L	21 Oct. 2014	Pioneer 26R10
24	I			A, B, Y	S	22 Oct. 2014	Pioneer 26R10
25	T	LC	T + LC	A, B, Y	L	22 Oct. 2014	Pioneer 26R10
26		LC		A, Y	L	15 Oct. 2010	Pioneer 25R78
27	I	LC	I + LC	A	S	16 Oct. 2015	Pioneer 26R10
28	I	LC	I + LC	A, B, Y	L	16 Oct. 2015	Pioneer 26R10
29		LC		A, B, Y	L	16 Oct. 2015	Pioneer 26R10
30	I, T	BC	I + BC	A, B, Y	S	16 Oct. 2015	Pioneer 26R10
31	T	BC	T + BC	B, Y	L	12 Oct. 2011	USG 3251
32	I	LC	I + LC	A, B, Y	L	18 Oct. 2016	Pioneer 26R10
33		LC		A, B, Y	L	18 Oct. 2016	Pioneer 26R10

Treatment factors included IST, foliar insecticide applications, insecticide seed treatment plus a foliar insecticide application. Plot size (small or large), data collected, planting date, and wheat variety are also shown. IST (insecticide seed treatment).

[a]Insecticide seed treatments included in tests with I = imidacloprid, T = thiamethoxam, and C = clothianidin.

[b]Foliar insecticide applications where LC = lambda-cyhalothrin and BC = beta-cyfluthrin.

[c]Indicates base insecticide seed treatment (I, T, or C) used for test of insecticide seed treatments in combination of foliar insecticide applications (LC or BC).

[d]A = aphid density (spring rating), B = BYD (spring rating), and Y = yield.

balanced data of treatment effects on aphid populations, incidence of BYD, or yield. All experiments except one were performed at the West Tennessee Research and Education Center in Jackson. Tests were both small plot and large plot, and all were arranged in a randomized complete block design. Individual plots in small-plot tests were 1.5 m wide by 9 m long. Plots in large-plot tests were 7.7 m wide and ranged between 30.5 and 300 m long. Planting dates ranged from late September until late November, with the median planting date of approximately 17 October. All tests were planted at a target seeding rate of 2.5–3.0 million seeds/ha and a row spacing of 19 cm. Average planting depth was 2.5–3.8 cm. Although several varieties were used during the 11-yr period, P26R10 or P26R22 (Pioneer Hi-Bred International, Inc., Johnston, IA) was used in the majority of these experiments. These varieties are commonly planted in the region and are midrange in their sensitivity to BYD based on evaluations made in Tennessee (Allen et al. 2012, 2013). Wheat was fertilized and managed for weeds based on standard recommendations made by the University of Tennessee (Main et al. 2008).

Treatment Factors

Among these experiments, treatments included 1) plots not treated with insecticide, 2) one to four neonicotinoid seed treatment entries, 3) a foliar-applied insecticide treatment, and 4) a foliar insecticide application made on wheat having a base insecticide seed treatment. In each test, a single variety was planted (Table 1). Only seed treatments tested at rates labeled for aphid control were included in the analyses. If an experiment contained a foliar insecticide application, a single treatment was applied between 31 January and 25 February. Karate Z at a rate of 27.3 g ai/ha (lambda-cyhalothrin, Syngenta Crop Protection) was normally used, but Baythroid XL at a rate of 13.2 g ai/ha (beta-cyfluthrin, Bayer CropScience) was used in some tests.

Data Collection

Aphid counts were taken as numbers per 0.91–1.52 m of row (3–5 row ft). Counts were often taken at various times throughout the fall and spring, but assessments were consistently made in March approximately 30 d after any springtime foliar insecticide application and these data were used in these analyses. Ratings on the incidence of BYD were subsequently made between Feekes stage 8 (just before boot) to 10.5 (flowering) by counting the number of flag leaves showing distinct symptoms of BYD, primarily characterized by reddish or pink coloration on the leaf tips, in the entire plot (small plot) or in an area ranging from 9.3 to 13.9 m^2 (large plots; Wise et al. 2011). Timing of this rating was based on the optimum occurrence of symptomology as judged by the researcher. For small-plot experiments, whole-plot yield data were collected using a research-grade plot combine. A yield monitor was used in large-plot tests, but only the center 4.6 m of each plot was harvested.

Data Analysis

Matching aphid counts, BYD ratings, and yield were not collected on all tests (Table 1). Thus, we only made comparisons among tests that were balanced in respect to data on aphid numbers, incidence of BYD, or yield when evaluating treatment effects. Response variables reported include spring aphid densities (numbers/row m), frequency of leaves showing BYD symptomology (numbers/10 m^2), and yield (kg/ha). We did not attempt to compare the efficacy of different insecticide seed treatments, in part because rates varied both within and between tests. Data were analyzed using Proc GLIMMIX (SAS Institute, Cary, NC) using a protected LSMEANS for detection of main effects ($\alpha = 0.05$). Similar to the approach of North (2016), treatment factors were fixed effects within the model with test, replicate, and replicates nested with test considered random effects, thus helping to make inferences across a wide range of environments (Carmer et al. 1989, Blouin et al. 2011). Log transformations were performed on aphid and BYD numbers prior to analyses to satisfy the assumptions for analysis of variance. We also present data on the frequency that significant ($\alpha = 0.05$) treatment responses were observed in individual tests based on standard analysis of variance methods (Proc GLIMMIX, LSMEANS). The cost of neonicotinoid seed treatments varies between \$24.70 and \$37.10/ha assuming a seedling rate of 134 kg/ha (2 bu/acre), whereas the costs of a foliar insecticide application varies from \$11.10 to \$18.60/ha with the range depending mostly on application costs (Smith et al. 2017 and personal communication with local retailers). These values were used in calculating the approximate economic benefits of treatment.

Results

Effects of Insecticides on Number of Aphids

Aphid densities during the fall were not routinely collected and not consistently collected at a specific time point after planting. However, when analyzed across eight trials, fall aphid density was 78% lower when an insecticide seed treatment was used ($F = 37.21$; df = 1, 75; $P < 0.001$). Spring aphid densities were significantly reduced by the use of insecticide seed treatments, a foliar insecticide application, or a combination of both. Although we did not consistently distinguish between the type of aphids present when making ratings, bird cherry-oat aphids and English grain aphids were the predominate aphids observed, with bird cherry-oat aphid being most common in the fall and a comparable mix of these species in the spring. Compared with plots not treated with insecticide, insecticide seed treatments reduced aphid populations by an average of 86% (Table 2). A late-winter foliar insecticide application caused a similar reduction (90%) in aphid populations. For springtime counts, insecticide seed treatments significantly reduced aphid numbers in 10 of 12 individual tests (Table 2). A foliar insecticide application significantly reduced aphid numbers in 15 of 22 tests. Finally, a foliar insecticide application significantly reduced aphid numbers in four of six tests where a base insecticide seed treatment was also used.

Effects of Insecticides on the Incidence of BYD Virus

Similar to aphid populations, symptomology of BYD was reduced by the use of insecticides. When used alone, insecticide seed treatments reduced the visual incidence of BYD by an average of 60% (Table 2) compared with seed not treated with insecticide, whereas a foliar insecticide reduced the incidence of BYD by over 84%. Very low incidence of BYD was observed when a foliar insecticide application was made in addition to an insecticide seed treatment. The incidence of BYD was significantly reduced in individual tests by insecticide seed treatments (6 of 10) or a foliar insecticide application (13 of 17). In four of seven tests, applying a foliar insecticide on top of a base insecticide seed treatments also significantly reduced BYD.

Yield Protection Provided by Insecticides

Relative to a nontreated wheat, insecticide seed treatments alone resulted in a yield increase of 280 kg/ha (5.3%, 4.2 bu/acre), but a statistically significant yield increase was not observed in any of 11 individual tests (Table 2, Fig. 1). Similarly, yield was increased by an average of 381 kg/ha (7.2%, 5.7 bu/acre) when a foliar

Table 2. Average number of aphids during the spring, incidence of BYD, and yield for wheat treated or not treated with insecticide seed treatment (IST), treated or not treated with a foliar insecticide application, or treated with insecticide seed treatments but with or without a foliar insecticide application

Aphids (number/meter row)	Treated	Not treated	*F* value	df	*P* value	Frequency of response[a]
Insecticide						
IST	10.1	74.6	214.1	1, 121	<0.0001	10/12
Foliar	7.5	71.7	175.9	1, 77	<0.0001	15/22
IST ± foliar	4.0	20.0	48.69	1, 23	<0.0001	4/6
BYD (number of flag leaves per 10 m^2)[b]						
IST	14.2	35.3	76.89	1, 107	<0.0001	6/10
Foliar	6.1	39.0	63.30	1, 60	<0.0001	13/17
IST ± foliar	1.6	8.4	29.02	1, 60	<0.0001	4/7
Yield (kg/ha)						
IST	5,262	4,982	21.40	1, 164	<0.0001	0/11
Foliar	5,262	4,881	83.38	1, 83	<0.0001	2/18
IST ± foliar	5,807	5,611	6.20	1, 62	0.0154	3/7

Data were collected across 33 tests over an 11-yr period in west Tennessee.

[a]Number of individual tests with a significant insecticide response where aphid numbers or BYD was reduced by treatment or yield was increased ($P < 0.05$).

[b]Symptomatic flag leaves.

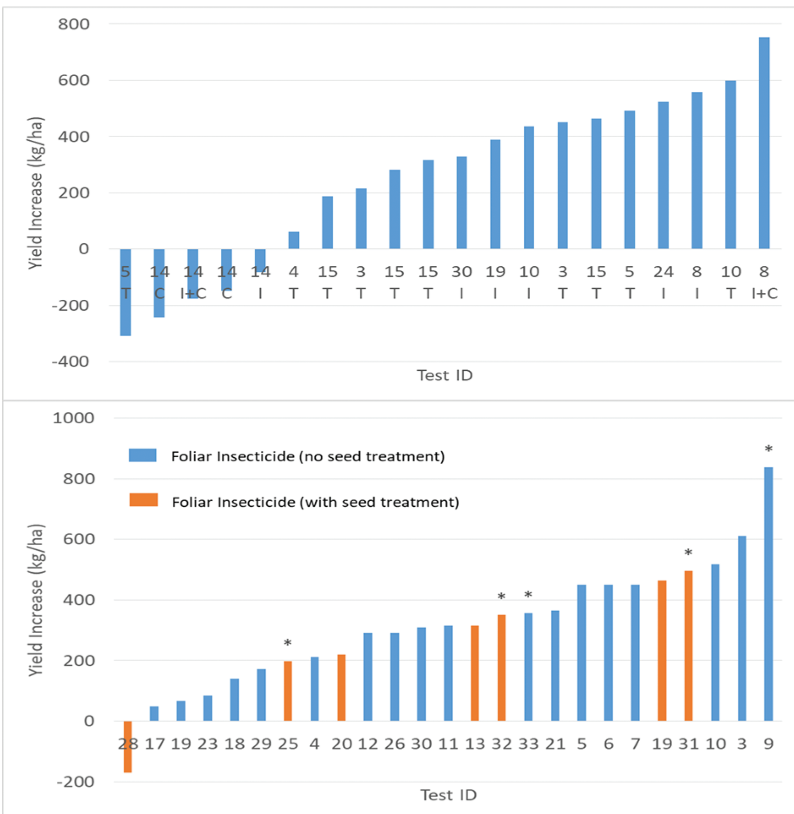

Fig. 1. Mean yield response (kilogram per hectare), by test ID as shown in Table 1, for wheat treated with an insecticide seed treatment (top; nontreated mean [SEM] = 794.1 [175.9 kg/ha]) or when a foliar insecticide application was made during late winter (bottom; nontreated mean [SEM] = 833.0 [238.2 kg/ha]). C, I, and T on the x-axis indicate clothianidin, imidacloprid, and thiamethoxam seed treatment, respectively. *Significant increases within individual tests ($P < 0.05$).

insecticide application was used instead of insecticide seed treatments, with a significant increase observed in only 2 of 18 individual tests. A negative yield response (not significant) of a foliar insecticide application was only observed in one test (Fig. 1) and that was when an insecticide seed treatment was also used. When a foliar insecticide application was made to wheat that had a base insecticide seed treatment, yield was increased by an average of 196 kg/ha (3.4%, 2.9 bu/acre). This was significant across seven tests ($P = 0.015$, Table 2), and a significant increase was observed in three individual tests (Fig. 1).

Comparison of Insecticide Seed Treatments Versus Foliar Insecticide Usage

For tests where there was a direct comparison of insecticide seed treatments versus a late-winter foliar insecticide application, average springtime aphid numbers were 75% lower where a foliar insecticide was applied (Table 3). Similarly, visual symptomology of BYD was 39% lower when a foliar insecticide was applied compared with an insecticide seed treatment. This difference was not significant in any individual tests (n = 17). Wheat that was treated with a foliar insecticide application yielded 170 kg/ha (2.5 bu/acre) more than wheat treated with insecticide seed treatments, as this difference was significant (P = 0.030) when analyzed across tests; however, significant differences were not observed in any individual test.

Discussion

Collectively, these data indicated that insecticide seed treatments or a late-winter foliar insecticide application (or both) increased yield and reduced aphid density and the transmission of BYD virus relative to nontreated wheat. Because aphid counts were taken in the spring, relatively soon after the foliar insecticide application, it is not surprising that aphid counts were relatively low compared with insecticide seed treatments. However, there was opportunity for aphid transmission of BYD before the foliar insecticide application. Thus, aphid densities may not fully reflect the benefits of insecticide seed treatments in protecting wheat yields. Counts of aphids were only occasionally made during the fall because infestations are generally low, averaging about 4.2 aphids/m in plots not treated with insecticides across tests, thus making it difficult to separate treatment differences. However, the use of an insecticide seed treatment reduced aphid densities in the spring by an average of 86%, similar to the 78% reduction of aphid numbers observed in the more limited number of fall samples. This suggests that colonization of aphids during the fall and/or early winter months is parental source of springtime aphid infestations in Tennessee, as it is unlikely that insecticide seed treatments provide residual control past the winter months.

This summary of experiments in Tennessee demonstrates that the management of aphid infestations in wheat increased yields by about 5–10% depending on the insecticide treatment regime. On average, where direct comparisons were made, a late-winter foliar application reduced aphid numbers and the incidence of BYD more than insecticide seed treatments alone. The average yields of wheat treated with a foliar insecticide were 170 kg/ha higher than where only a seed treatment was used. Applying a late-winter foliar insecticide application in addition to insecticide seed treatments provided a similar yield increase (averaging 196 kg/ha) compared with only using a foliar application alone, and there were several individual tests where this increase was statistically significant.

Presumably yields were protected because insecticides reduced the incidence of BYD rather than the direct benefits of aphid control or other pests that may have been present. Aphid populations generally did not reach economically damaging levels apart from BYD infection in these tests. It is possible that seed treatments and foliar insecticides were controlling other pests and therefore affecting yield results. Neonicotinoid seed treatments are labeled for control of Hessian fly, *Mayetiola destructor* (Diptera: Cecidomyiidae), although at rates higher than those typically used in our tests, and foliar pyrethroid insecticide may also affect this pest (Flanders et al. 2013). The most common variety used in our tests, P26R10, has shown good resistance to Hessian fly. However, another variety we commonly used, P26R22, has low resistance to Hessian flies (Noland et al. 2017). Application of insecticides could also potentially affect other pests such as cereal leaf beetles, *Oulema melanopus* (Coleoptera: Chrysomelidae), or armyworm, *Mythimna unipuncta* (Lepidoptera: Noctuidae). Cereal leaf beetles and armyworms are rarely observed in Tennessee wheat fields until March or later, but the impact of our treatments on these pests was not assessed. However, economically damaging infestations of these other pests were not apparent.

Climate ultimately influences the occurrence of aphids, and thus BYD, in wheat. Perry et al. (2000) reported that environmental factors and the strain of BYD influence yield reductions of small grains. Bockus et al. (2015) found the greatest economic losses occurred when plants are infested with viruliferous cereal aphids at early leaf development stages. Our data indicates that some aphids survive the winter in Tennessee, serving as the parents of springtime aphid populations. Unlike more northern geographies, aphid survival during the winter probably increases the risk of BYD transmission during warm winter days when wheat is essentially dormant. Thus, results in Tennessee are almost certainly not applicable to all geographies and are only directly relevant to those growing winter wheat.

The range of planting dates in our experiments reflects local production practices. If growers plant before the recommended planting window (October 15, Stewart and McClure 2017), they would probably increase the risk of infection with BYD, and early planted wheat may benefit more from the use of an insecticide seed treatment. The University of Tennessee's current recommendations for the management of aphids and BYD state that if a seed treatment is not used, a foliar insecticide application during the fall (approximately 30 d after planting) and/or late winter (prior to March) may also reduce BYD (Stewart and McClure 2017). These recommendations also suggest that insecticide applications should be made before aphid populations exceed 6–8/row ft; otherwise, any BYD transmission may have already occurred.

Our data would generally support these recommendations. In practice, pest managers are coached to scout for aphid infestations in the fall and treat if aphids are found in sufficient numbers (>3/row ft, S.D.S., personal communication). If aphid infestation remains low, as often occurs during years with cool falls or when wheat is late planted, growers are encouraged to delay any applications until late winter, typically January or February. Other areas in the South also promote fall and/or late-winter applications of insecticide to control aphids and BYD. For example, The University of Kentucky recommends a foliar insecticide application 30 d post-emergence when numbers exceed 9.8 aphids per row meter (3/row ft) and from 30 to 60 d post-emergence when counts exceed 19.7 aphid per row meter (6/row ft; Johnson and Townsend 1999). Similarly, the

Table 3. Direct comparison between wheat treated with an insecticide seed treatment (IST) and a late-winter applied foliar insecticide application on numbers of aphids, incidence of BYD, and yield

	IST	Foliar	F value	df	P value
Aphids (number/meter row)	25.1	6.3	35.59	1, 92	<0.0001
BYD[a]	8.9	5.4	4.88	1, 95	0.0296
Yield (kg/ha)	5217	5387	4.83	1, 133	0.0297

Data were collected across 33 tests over an 11-yr period in west Tennessee.
[a]Symptomatic flag leaves/10 m^2.

University of Georgia's recommendations discuss the potential benefits of both seed treatments and foliar insecticide application to prevent BYD, and they suggest different timings of a foliar application based on geographic location within the state (Noland et al. 2017). Furthermore, these recommendations suggest managing BYD may be more valuable in the northern parts of Georgia. Implicit in these recommendations is that managing aphid infestations and BYD may be less beneficial in warmer climates where aphid colonization may continue over a longer period of time.

Assuming the most expensive treatment option of insecticide seed treatments ($37/ha) and an approximate yield response to this treatment of 300 kg/ha, expected economic returns would be $6.50/ha at a relatively modest commodity price of $147 per metric ton ($4/bu). The economic returns for a foliar application would be nearly three times higher considering insecticide and application costs ($11.10–18.60/ha) are approximately one-half that of insecticide seed treatments. Based on our average results, a positive return of investment would be made by making a foliar insecticide application even when insecticide seed treatments were used because yields were increased by an average of 196 kg/ha when this application was made. It should be considered that a foliar application in the fall, or a fall and late-winter application, may offer similar or better economic returns than insecticide seed treatments. This is particularly true if these foliar applications can be coapplied with herbicides or foliar fertilizer applications, thus reducing application costs. Resistance or tolerance to aphids and BYD varies among wheat varieties (Irwin and Thresh 1990, De Wolf et al. 2017), and the economic benefits of managing aphids with insecticides may vary depending on the variety grown. The two varieties most commonly used in our tests were moderately susceptible to BYD based on ratings of symptomology in variety trials performed in Tennessee (Allen et al. 2012, 2013). Thus, our results are probably representative of a 'typical' variety, but more research is needed to fully define how variety selection affects the value of aphid and BYD management in wheat.

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