

Potential for Integrated Management of Soybean Virus Disease

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ABSTRACT

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The recent introduction of the colonizing soybean aphid (*Aphis glycines*) to soybean in the northern United States has raised concern for potential increased disease caused by the nonpersistently aphid-transmitted *Soybean mosaic virus* (SMV). This study was conducted to examine the potential integration of host plant resistance and insecticide tactics for control of virus disease. Research from four location-years demonstrated that foliar application of the pyrethroid insecticide lambda-cyhalothrin (Warrior) or the organophosphate chlorpyrifos (Lorsban 4E) timed to suppress soybean aphid populations does not reduce SMV. Therefore, the introduction of a colonizing aphid to the array of migratory noncolonizing aphids that transmit SMV does not result in potential for disease control through vector suppression by foliar insecticides. Treatment also did not result in management of *Bean pod mottle virus* (BPMV), transmitted by the bean leaf beetle (*Cerotoma trifurcata*), presumably because of issues related to different phenologies of the insect vectors. Soybean cultivars with the lowest virus titer in seed produced the highest grain yield and, thus, were rated as field tolerant compared with cultivars with the highest virus titer in seed. Host plant resistance, not vector control, is the most effective tactic to control SMV.

To achieve best management practice, producers must integrate several tactics to achieve protection against multiple pests and pathogens. This is suggested because of recent problems associated with two soybean viruses and their associated insect vectors that are problematic for north-central United States producers (13). The two viruses, *Soybean mosaic virus* (SMV) and *Bean pod mottle virus* (BPMV), can induce leaf symptoms and seed coat mottling (hilum bleeding) that are indistinguishable. Both viruses can be transmitted through seed (11,23). However, the viruses belong to different virus families and have different insect vectors. The BPMV is vectored primarily by the bean leaf beetle (*Cerotoma trifurcata* Forster) and SMV by at least 32 different migratory aphid species in a nonpersistent manner (7,11). Recently, the introduction of the exotic soybean aphid (*Aphis glycines* Matsumura) into North American soybean-growing regions (30,32) has caused concern for potentially increased disease problems caused by SMV. Both viruses can cause significant yield loss, with estimates ranging from 8 to 35% for SMV (11) and up to 52% for BPMV (6). In addition, synergistic interaction of both viruses

can reduce yield by up to 75% (4). Unfortunately, no studies have effectively measured damage caused by the coincidence of either the bean leaf beetle-BPMV or soybean aphid-SMV complex, although economic threshold populations to reduce yield loss caused by direct feeding have been established for the bean leaf beetle and the soybean aphid (28,30).

The soybean aphid, an efficient vector of SMV (12), is the only aphid which colonizes soybean in North America. It can result in yield losses up to 50% and is controlled through insecticide applications that are timed relative to plant growth stage and insect population thresholds (30). One recommendation used to suppress aphid populations below threshold level employs foliar application of either a pyrethroid or organophosphate insecticide (27). This has been reported to manage the bean leaf beetle and may reduce damage caused by BPMV (20). Information is limited and conflicting, however, concerning the impact of insecticide application on disease caused by SMV in the presence of the soybean aphid (22). Lee-Burrows et al. (22) observed no effect of an insecticide on incidence of SMV-infected plants in a year of high soybean aphid activity, but did observe lower incidence of SMV-infected plants in a year of low soybean aphid activity. These results suggest that further experimentation is needed to determine the role of insecticides for control of SMV transmitted by the soybean aphid.

Historically, insecticides generally have not been effective for control of nonpersis-

tent viruses transmitted by noncolonizing aphids and, therefore, have not been used to control disease caused by SMV (17,29). Recent reports, however, have suggested that application of synthetic pyrethroids can result in reduced spread of nonpersistently transmitted viruses, but also may increase virus spread (18,31,34). Until the introduction of the colonizing soybean aphid, SMV has been transmitted exclusively by noncolonizing aphids in North America. The relative importance of colonizing versus noncolonizing aphids in field transmission of virus disease is unclear (17,19,29). Noncolonizing alate aphids, in a search for preferred hosts, are more likely than colonizing aphids to make short shallow probes and move more often in the field (1). This is important because, as suggested by Irwin (16), vector movement determines the scale of the SMV epidemic. In contrast, colonizing aphids make long deep probes of 30 min or more, which may reduce acquisition and transmission potential (2). They are less likely to take flight and perhaps allow more time for an insecticide to be beneficial (29). It is unknown if addition of a colonizing aphid to the array of emigrant noncolonizing aphids that transmit SMV to soybean plants in the field will have any impact upon the potential for suppression by insecticides of the disease caused by SMV.

Although vector suppression sometimes may offer potential for virus disease control of persistently transmitted viruses (25), host resistance or field tolerance to the pathogen is often the most effective long-term approach to minimize crop loss and maintain seed quality. The utilization of tactics to reduce vector populations integrated with field tolerance has potential to enhance pest and disease control. Anything that influences the population dynamics of virus vectors has potential to influence virus disease; therefore, the goal of this study was to evaluate the potential that application of insecticides to control virus vectors may be combined with disease tolerance to suppress the soybean aphid and SMV. Host morphology (for example, trichome density on leaves) has potential for disrupting transmission of SMV by migratory aphids (33). The simultaneous evaluation of multiple control tactics for this disease has not been reported.

For this study, soybean aphid population densities and the relative level of virus antigen in seed harvested from experimental plots was used to estimate the impact

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that insecticide treatment and soybean genotype has upon aphid populations and level of virus. The relative amount of virus antigen, along with percentage of seed coat mottling, previously were used to identify field tolerance to SMV and BPMV, and the antigen level correlates significantly with virus incidence in the field (13). Ancillary to this was parallel assessment of impact on BPMV, because both BPMV and SMV may be part of the same pathosystem and any treatment may affect both viruses and their vectors.

MATERIALS AND METHODS

Field study. A field study was conducted in 2004 and 2005 in Iowa and Wisconsin. In Iowa, this experiment was conducted in 2004 near Decorah, IA and in 2005 at the Iowa State University Agronomy Research Farm near Boone, IA. In Wisconsin, the experiment was conducted in both 2004 and 2005 at the University of Wisconsin West Madison Agricultural Research Station. The experimental design in both states was a randomized complete block in a split-plot arrangement with four replications. The main plot was foliar insecticide application of the pyrethroid insecticide lambda-cyhalothrin (Warrior; Syngenta Crop Protection, Greensborough, NC) at a rate of 27.6 g a.i. ha⁻¹, or the organophosphate insecticide chlorpyrifos (Lorsban 4E; Dow AgroSciences, Indianapolis, IN) at a rate of 1.17 kg a.i. ha⁻¹ when the mean aphid population density was approximately 100 aphids per plant. In Iowa, Warrior was applied on 18 July and 8 August in 2004 and on 23 July in 2005 using a CO₂-charged hand boomsprayer equipped with TeeJet XR8002 (Wheaton, IL) nozzles at 180 l ha⁻¹ at a pressure of 0.2 MPa. In Wisconsin, Warrior was applied on 5 July 2004 and Lorsban 4E was applied on 8 July 2005 using a tractor-mounted three-point sprayer equipped with TeeJet XR8002 nozzles at 180 l ha⁻¹ at a pressure of 0.2 MPa. The organophosphate insecticide chlorpyrifos (Lorsban 4E) was selected in 2005 due to low to moderate densities of two-spotted spider mite (*Tetranychus urticae* Koch) in the plots. The split plot was six soybean cultivars (NE3001, Colfax, W02-240, W02-176, H2494, and IA2021). NE3001 and Colfax were selected for their field tolerance to SMV (13).

Plot size of the subplot experimental units was 3.0 by 7.6 m. Seed was inoculated with *Bradyrhizobium japonicum* (Liphatech, Milwaukee, WI) and each plot was planted in four rows at 76-cm row spacing at 4-cm depth and at a rate of 300,000 seeds ha⁻¹ using an Almaco grain drill (Almaco, Nevada, IA). Tillage was accomplished by chisel plowing in the fall and field cultivation twice in the spring before planting. Plots were planted on 6 May 2004 and 5 May 2005 in Iowa and on 10 May 2004 and 15 May 2005 in Wisconsin.

Weed control in Iowa for both years was done with acifluorfen at 0.41 kg a.i. ha⁻¹ and sethoxydim (2-[i-(ethoxyimino)butyl]-5-[2-(ethylthio)propyl]-3-hydroxy-2-cyclohexen-1-one) at 0.31 kg a.i. ha⁻¹. In Wisconsin, Metribuzin (4-amino-6-[1,1-dimethylethyl]-3-[methylthio]-1,2,4-triazin-5[4H]-one) and pendimethalin ([N-(1-ethylpropyl)-3,4-dimethyl-2,6-dinitrobenzamine]) were incorporated with a soil groomer for weed control in 2004 at 0.42 kg and 1.39 kg a.i. ha⁻¹, respectively. In 2005, cloransulam-methyl (N-[2-carbomethoxy-6-chlorophenyl]-5-ethoxy-7-fluoro[1,2,4]triazole-[1,5-c]pyrimidine-2-sulfonamide) and S-metolachlor were applied prior to planting and incorporated with a soil groomer at a rate of 34.4 g a.i. ha⁻¹ and 2.09 kg a.i. ha⁻¹, respectively. Escaping weeds were removed by hand weeding throughout the growing season in both Iowa and Wisconsin.

Soybean aphids were assessed weekly beginning in early July or at approximately R1 (5). Five plants in each plot were randomly assessed (whole-plant counts) by counting the aphid population on both the leaflets and stem. Cumulative aphid days were determined using the methods described by Hanafi et al. (10) to report soybean aphid abundance over time. Grain yield was collected using an Almaco plot combine (Almaco), harvesting 6.1 m of the center two rows from each plot. Grain yield was adjusted to a moisture content of 130 g kg⁻¹.

Seed analyses. Samples of 100 seeds were evaluated from each replicate to determine the percentage of seed coat discoloration for a soybean seed sample. Any seed showing brown or black seed coat discoloration was counted as mottled. The relative amount of SMV or BPMV antigen in a sample of 100 seeds was determined by enzyme-linked immunosorbent assay (ELISA) in a manner similar to that previously described (13,21). In summary, batches of 100 seeds were ground at setting no. 6 for 1 min in 100 ml of 0.05 M sodium borate, pH 7.2, with a Brinkmann Polyron homogenizer and model no. PT 20 ST probe generator. Extracts were squeezed through two layers of cheesecloth and 0.1-ml samples were used per well. Positive and negative controls were included in each ELISA plate. Optical density at 405 nm (OD₄₀₅) was recorded at six timed intervals during a 20- to 150-min period after addition of the enzyme substrate. The mean OD₄₀₅ value of four replicate wells was used to generate a regression equation that relates hydrolysis time to OD. A standard hydrolysis time of 60 min after substrate addition was used to calculate the OD that corresponds to the amount of virus antigen in each homogenized seed sample (sample OD). A similar calculation was made for the negative healthy seed control (negative control OD). For each ELISA plate, the relative virus

antigen content of each sample was calculated as: relative amount of virus antigen in seed sample = (sample OD)/(negative control OD plus two standard deviations). Therefore, calculated values of virus antigen in seed samples are relative to 1.0, which designates no detectable antigen. Similar to previous reports, sample well-to-well variation was less than 5% and regression equations yielded coefficient of determination (R²) values greater than 0.99 (13,21).

Data analysis. All data were subjected to an analysis of variance using the PROC MIXED procedure (24) of SAS (35). Individual analysis by year using the restricted maximum likelihood method for variance component estimation indicated that error variances were heterogeneous. Block was treated as a random effect in the individual analysis by year and location. Cultivar and insecticide treatment were treated as a fixed effect in determining the expected mean square and appropriate *F* tests in the analysis of variance. Mean comparisons were made using Fisher's protected least significant difference test (*P* ≤ 0.05).

RESULTS AND DISCUSSION

In this study, insecticide applications were timed to suppress populations of the soybean aphid. In order to maximize the potential for soybean aphid suppression to mitigate indirect yield loss attributed to SMV transmission, applications were applied when soybean aphid populations approximated 100 per plant instead of the generally recommended direct yield loss threshold level of 250 per plant (30) valid through growth stage R5 (5). The application was timed to occur when a majority of the soybean aphids were apterous and before the onset of alate summer morphs (15). As shown by cumulative aphid days, used as a measure of seasonal aphid abundance, insecticide application significantly reduced aphid populations in 2004 (*P* = 0.001) and 2005 (*P* = 0.05) in Wisconsin and in Iowa in 2005 (*P* = 0.001) (Tables 1 and 2). Results are consistent with previous recommendations that application of foliar insecticides will suppress soybean aphid populations (27,30). Aphid populations on the lines NE 3001, IA 2021, H2494, and Colfax were significantly less (*P* ≤ 0.05) than on W02-176 and W02-240 in 2005 at the Iowa locations.

Relative antigen levels in a homogeneous mixture of seed harvested from infected plots recently has been shown to have a very high correlation with final virus incidence (13). Therefore, the relative antigen level suggested that SMV incidence was greater at the Wisconsin locations than at the Iowa locations for both years (Tables 1 and 2). This occurred despite higher soybean aphid populations in Iowa compared with Wisconsin in both years.

The time when the insecticide was applied does not eliminate potential impact

of numerous aphid species emigrating into plots with differing relative propensity for SMV transmission (8); therefore, it is probable that alate populations of several aphid species, including the soybean aphid, may transmit SMV. Previous studies, conducted before the introduction of the soybean aphid, demonstrated rapid increase of SMV incidence, presumably transmitted by diverse migratory aphid species (26,36).

In the work reported here, aphid emigrants into the soybean canopy were not monitored during the growing season. However, in a companion study to the initial report of Hill et al. (14) documenting the spread of disease caused by SMV in Iowa, Hammond and Pedigo showed that numerous aphid species were present, with no one species predominant during the time of greatest spread (9). It has been suggested recently that final incidence of SMV-infected plants reflect differences in the number of alate soybean aphids (22).

In contrast to the behavior exhibited by noncolonizing aphid species, colonizing aphids may settle quickly and, therefore,

contribute less to virus spread than noncolonizing aphids (1,17,34). Transmission of SMV by *A. glycines* allowed a 1-min acquisition probe is efficient at 35%; however, extended acquisition access times, as might be expected of colonizing aphids, resulted in a transmission rate of less than 1% (37). The data reported here support the suggestion that introduction of a colonizing aphid species to soybean plants has little impact upon the potential for reduction of disease caused by SMV through application of foliar insecticide. Relative antigen levels revealed no impact of insecticide treatment on disease caused by SMV (Tables 1 and 2). Chemical suppression of emigrant alate aphids typically has little impact on disease caused by nonpersistently transmitted viruses (16,31).

At the Iowa location in 2004 and 2005, apparent incidence of SMV was low and no effects of cultivar were observed. However, in Wisconsin in 2004 and 2005, when apparent levels of SMV were higher than in Iowa, the effect of cultivar was highly significant ($P = 0.001$), reflecting field

tolerance to SMV. In this study, the lines Colfax, NE 3001, W02-240, and H2494 had significantly ($P \leq 0.05$) lower relative antigen levels than IA 2021 and W02-176 (Table 2). The cvs. Colfax and NE 3001 previously were identified as tolerant to SMV, and IA 2021 has been reported as SMV sensitive (13). The relatively low SMV antigen level detected in H2494 was demonstrated previously. Percentage of seed coat mottling in H2494 occasionally can be high, however, as shown at the Wisconsin 2004 location. This trait, also previously demonstrated for this line, has been regarded as unacceptable in a field-tolerant line (13). The lines IA 2021 and W02-176 had high SMV-relative antigen in both years.

The effect of insecticide treatment upon seed coat mottling was not significant except at the Iowa location in 2005 ($P = 0.05$; Tables 1 and 2). For both SMV and BPMV, the correlation between relative antigen and percent mottling was inconsistent (*data not shown*). This confirms previous reports that have shown that seed coat mottling is inconsistent (21) and can

Table 1. Insecticide treatment and cultivar effect on grain yield, hilum bleeding, relative antigen for *Bean pod mottle virus* (RA BPMV), relative antigen for *Soybean mosaic virus* (RA SMV), and aphid days in Iowa 2004 and 2005^a

Main effect ^b	Grain yield (Mg ha ⁻¹)		Hilum bleeding (%)		RA BPMV		RA SMV		Aphid days	
	2004	2005	2004	2005	2004	2005	2004	2005	2004	2005
Treatment (T)										
Control	3.0	3.3	20	29	1.06	3.69	1.03	1.11	797	10,246
Insecticide	3.2	3.7	25	16	0.85	6.73	0.87	0.80	777	3,009
LSD (0.05)	NS	NS	NS	13	NS	NS	NS	NS	NS	1,023
Cultivar (Cv)										
Colfax	3.0	3.5	20	10	0.83	4.77	0.93	1.10	603	5,999
H2494	3.3	4.0	21	10	0.92	4.05	0.91	0.93	651	5,921
IA2021	3.0	3.5	20	26	0.94	7.32	0.99	0.93	872	5,628
NE3001	3.0	3.5	21	18	0.98	4.40	0.97	1.05	1,198	5,346
W02-176	3.3	2.8	26	25	0.96	3.93	0.94	0.86	582	7,635
W02-240	3.1	3.6	26	46	1.09	6.77	0.98	0.87	818	9,237
LSD (0.05)	NS	NS	NS	14	NS	1.64	NS	NS	NS	1,795
ANOVA										
T × Cv	NS	NS	*	**	NS	***	NS	NS	NS	NS

^a NS = differences not significant at $P \leq 0.05$; *, **, and *** = significant at the 0.05, 0.01, and 0.001 level.

^b LSD = least significant difference and ANOVA = analysis of variance.

Table 2. Insecticide treatment and cultivar effect on grain yield, hilum bleeding, relative antigen for *Bean pod mottle virus* (RA BPMV), relative antigen for *Soybean mosaic virus* (RA SMV), and aphid days in Wisconsin 2004 and 2005^a

Main effect ^b	Grain yield (Mg ha ⁻¹)		Hilum bleeding (%)		RA BPMV		RA SMV		Aphid days	
	2004	2005	2004	2005	2004	2005	2004	2005	2004	2005
Treatment (T)										
Control	3.4	4.4	50	25	0.81	0.99	1.41	2.32	163	1,428
Insecticide	3.5	4.4	52	24	0.79	0.96	1.32	2.43	83	727
LSD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS	35	591
Cultivar (Cv)										
Colfax	3.1	4.4	84	2	0.89	0.97	0.99	1.17	105	1,048
H2494	4.4	4.9	84	14	0.72	0.93	0.85	1.61	140	1,058
IA2021	3.8	4.5	13	40	0.84	1.14	2.51	4.14	104	1,158
NE3001	3.4	4.7	84	3	0.80	1.09	1.05	1.51	191	1,060
W02-176	2.3	3.8	32	53	0.76	0.81	1.81	3.84	101	1,058
W02-240	3.8	4.1	6	36	0.79	0.91	0.97	1.99	96	1,082
LSD (0.05)	0.3	0.4	13	10	NS	NS	0.55	0.98	NS	NS
ANOVA										
T × Cv	NS	NS	*	NS	NS	NS	NS	NS	NS	NS

^a NS = differences not significant at $P \leq 0.05$ and * = significant at the 0.05 level.

^b LSD = least significant difference and ANOVA = analysis of variance.

Table 3. Treatment–cultivar interaction on relative antigen for *Bean pod mottle virus* for Iowa in 2005

Treatment ^a	Cultivar					
	Colfax	H2494	IA2021	NE3001	W02-176	W02-240
Control	4.12	2.67	3.68	3.37	3.84	4.44
Insecticide	5.42	5.43	10.97	5.43	4.02	9.10

^a Least significant difference (0.05) = 4.79.

be an unreliable indicator for virus in seed (3,14,21).

Although bean leaf beetles, the principal vector of BPMV, were not the focus of this study and, therefore, were not monitored, the relative amount of BPMV antigen was measured because it can be a part of the same pathosystem and it is phenotypically indistinguishable from SMV. Insecticide treatment was associated with increased relative antigen levels of BPMV for all cultivars at the Iowa location in 2005 (Table 3). Although significant for only one cultivar, the numerical trend was consistent. Insecticide application previously has been shown to occasionally enhance virus spread by aphids (29,34). Perhaps more significantly, because aphids do not vector BPMV, application of the pyrethroid insecticide deltamethrin was reported in wheat to induce ladybird beetles to walk and groom significantly more frequently in sprayed plots than in the unsprayed plots. In addition, higher numbers of beetles were found toward the bottom of the plant canopy (38). In the case of soybean, insecticide application may induce some bean leaf beetles to preferentially move to the lower part of the plant canopy, where insecticide coverage presumably is less. This increased movement may result in enhancement of disease caused by BPMV. Little BPMV was detected at the other location years. Previously, well-timed applications of pyrethroid insecticide were shown to benefit yield and seed quality at one location when BPMV was prevalent (20). In that report, applications were made at growth stages VE to VC and approximately R2. That timing was not coincident with the single application made in this study. The data suggest that application time for the management of the soybean aphid will be not be effective for reduction of damage caused by BPMV and may be detrimental, presumably because of issues related to time of application.

Although application of insecticide did significantly reduce soybean aphid populations in three of the four location-years, there was no significant yield response. This supports previous results that suggest an economic benefit may not be measured by application of insecticide below threshold levels (30). Alternatively, elevated levels of SMV incidence may negate the expected benefits of an insecticide application for control of the soybean aphid, as previously demonstrated (22).

These results suggest, under the conditions of this study, that management of

both SMV and BPMV cannot be integrated through application of insecticide treatment. First, management of the aphid vector was successful as previously reported (30). However, management of disease caused by SMV is not amenable to chemical control through vector management despite the recent introduction of the colonizing soybean aphid. Second, issues related to timing of insecticide for viruses whose primary insect vectors have different phenologies preclude disease management through a single application. The results strengthen the argument that the best approach for management of disease caused by these viruses will incorporate use of soybean genotypes tolerant or resistant to virus disease. Previous results show that care must be exercised in using phenotypic foliar symptoms for selection of tolerant or resistant genotypes (13).

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