Probability of Cost-Effective Management of Soybean Aphid (Hemiptera: Aphididae) in North America

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ABSTRACT Soybean aphid, *Aphis glycines* Matsumura (Hemiptera: Aphididae), is one of the most damaging pests of soybean, *Glycine max* (L.) Merrill, in the midwestern United States and Canada. We compared three soybean aphid management techniques in three midwestern states (Iowa, Michigan, and Minnesota) for a 3-yr period (2005–2007). Management techniques included an untreated control, an insecticidal seed treatment, an insecticide fungicide tank-mix applied at flowering (i.e., a prophylactic treatment), and an integrated pest management (IPM) treatment (i.e., an insecticide applied based on a weekly scouting and an economic threshold). In 2005 and 2007, multiple locations experienced aphid population levels that exceeded the economic threshold, resulting in the application of the IPM treatment. Regardless of the timing of the application, all insecticide treatments reduced aphid populations compared with the untreated, and all treatments protected yield as compared with the untreated. Treatment efficacy and cost data were combined to compute the probability of a positive economic return. The IPM treatment had the highest probability of cost effectiveness, compared with the prophylactic tank-mix of fungicide and insecticide. The probability of surpassing the gain threshold was highest in the IPM treatment, regardless of the scouting cost assigned to the treatment (ranging from $0.00 to $19.76/ha). Our study further confirms that a single insecticide application can enhance the profitability of soybean production at risk of a soybean aphid outbreak if used within an IPM based system.

KEY WORDS IPM, break-even analysis, gain threshold

Soybean aphid, *Aphis glycines* Matsumura (Hemiptera: Aphididae), is a significant insect threat to soybean, *Glycine max* (L.) Merrill, production in North America (Ragsdale et al. 2007). Advances in host plant resistance (Hill et al. 2004a,b; Liu et al. 2004; Mensah et al. 2005) and importation biological control (i.e., classical biological control; Heimpel et al. 2004) may make significant contributions to soybean aphid management in the future. However, current soybean production in North America relies on chemical control to prevent yield loss due to the soybean aphid. Consistent protection of soybean yield can be achieved with a single application of a foliar insecticide (Myers et al. 2005) applied during soybean aphid outbreaks (>500 aphids per plant) that occur in the reproductive stages of the plants growth. Approximately 423 aphids per plant are required to reduce soybean yield below an economic injury level (EIL) based on the following assumptions: control cost of $24.51/ha, market value of $238.83/ton, and a yield potential of 4.04 ton/ha (Ragsdale et al. 2007). To prevent this EIL from being reached, growers are recommended to apply a foliar insecticide when soybean aphid populations exceed an economic threshold (ET) of 250 aphids per plant (assuming a 4-d lag-time before the EIL is reached) between flowering (R1) and early seed set (R5). Left untreated, soybean aphid herbivory can result in yield losses exceeding 40% (Ragsdale et al. 2007).

Before the discovery of the soybean aphid in North America, there was limited use of insecticides for soybean production in the Midwest (NASS/USDA 1999). Since the arrival and establishment of the soybean aphid to the North Central region of the United States, the use of insecticides has increased (NASS/USDA

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2005). Currently soybean aphid management is primarily through the use of foliar-applied pyrethroid and organophosphate insecticides. Neonicotinoid insecticide seed treatments are available to North America soybean growers to manage bean leaf beetle, *Cerotoma trifurcata* (Förster), as well as soybean aphids. However, a limitation of seed treatments is the loss of insecticidal activity between 35–42 d after planting (V2–V4), before when soybean aphid outbreaks or colonization typically occur in North America (McCornack and Ragsdale 2006, Johnson et al. 2008). However, given the ease of use and the occasional need for protection from early season insect pests (Bradshaw et al. 2008), the adoption of seed treatments is increasing.

In addition to increased insecticide use, interest in fungicide application to soybean has also increased with the discovery of Asian soybean rust, *Phakopsora pachyrhizi* Sydow, in North America. *P. pachyrhizi* is an invasive fungal disease that can significantly reduce soybean yield (Kawuki et al. 2003, Miles et al. 2003). In the absence of *P. pachyrhizi,* inconsistent but positive yield responses are possible with the application of fungicide (Hanna et al. 2008) through control of various (or multiple) fungal pathogens present in North America soybean (Dashiell and Akem 1991). As a result, growers are increasingly exposed to marketing promotions that advise the application of tank-mixed pesticides (fungicides and insecticides) based on a calendar date or plant growth stage. Such an approach to pest management is inconsistent with integrated pest management (IPM) approach for soybean aphid, which relies on scouting and insecticide application only when an aphid population exceeds the ET. It is not clear how a prophylactic approach (either tank-mixes or insecticidal seed treatments) compares with use of IPM in managing soybean aphid outbreaks and protecting yield.

The occurrence of soybean aphid outbreaks in North America is highly variable, with orders of magnitude difference in aphid populations occurring among years and locations (Johnson et al. 2008, Schmidt et al. 2008). Aphid outbreaks can be suppressed by a community of predatory insects (Fox et al. 2004, 2005; Costamagna and Landis 2006; Schmidt et al. 2007, 2008; Gardiner et al. 2009), but this predator community is easily disrupted by the application of insecticides (Jeffries and Lawton 1984, Ohnesorg et al. 2009). Broad-spectrum insecticides applied for soybean aphid control in a prophylactic approach may flair secondary pest populations, or allow rapid recolonization of the primary pest, due to the creation of enemy-free space (Jeffries and Lawton 1984). Prophylactic insecticide applications for soybean aphid management may not protect yield if applied before aphid colonization and may instead cause resurgence in aphid populations or secondary pests such as twospotted spider mite, *Tetranychus urticae* Koch (Gerson and Cohen 1989, Johnson et al. 2008). The intensity and frequency of soybean aphid, colonization, summer migratory flights, and outbreaks are temporally and spatially variable. As a result, it is not clear that prophylactic applications of insecticide are effective in preventing yield losses from soybean aphids over several growing seasons. Our objective was to compare prophylactic soybean aphid management strategies to an IPM approach, determining which resulted in the most consistent reduction in plant exposure to soybean aphids and soybean yield, while maintaining overall profitability. We conducted this experiment across multiple of locations in the North Central region of the United States where soybean aphids are established and cause considerable damage to soybean.

Materials and Methods

In 2005, 2006, and 2007, a common experimental approach was used at two locations each year in three states (Iowa, Michigan, and Minnesota). At each location, a soybean variety adapted for that area was planted between late April to late May, depending on weather conditions (Table 1). Plots were 0.20–0.40 ha (0.50–1.0 acres) in size with a row spacing of 76.2 cm (30 inches). Conventional production practices and a glyphosate-based weed control program were employed at all locations. Three management approaches were compared with an untreated control: 1) an insecticidal seed treatment (the "seed treatment" was included at all locations in 2006 and 2007), 2) a preventative tank-mix of an insecticide with a fungicide, applied regardless of aphid abundance (the "prophylactic treatment"), and 3) an IPM-based approach that used scouting and an economic threshold of 250 aphids per plant (Ragsdale et al. 2007) to time a foliar-applied insecticide (the "IPM treatment").

Treatments were arranged in a randomized block design and replicated four to six times within each location-year, depending on available space. The timing of treatment applications varied among locations and years, depending largely on planting date and the level of aphid infestation in any given location-year (Table 1). The seed treatment was thiamethoxam at 56.3 g active ingredient (AI)/100 kg seed (CruiserMaxx, Syngenta Crop Protection, Greensboro, NC) applied commercially to the seed. The prophylactic treatment was a tank mix of the insecticide lambda-cyhalothrin at 28.0 g (AI)/ha (Warrior with Zeon Technology, Syngenta Crop Protection), and the fungicide pyraclostrobin at 89.6 g (AI)/ha (Headline, BASF Corporation, Research Triangle, NC). The prophylactic treatment was applied regardless of aphid pressure once the reproductive growth stage (R1–R2) was reached (averaged across all blocks). Soybean growth stages (Pedersen 2004) were noted each week in all plots. The IPM treatment was scouted weekly (see below) and was treated with the foliar insecticide lambda-cyhalothrin at 28.0 g (AI)/ha once the ET (250 aphids per plant) was crossed (aphids per plant averaged across all blocks at a given location). The prophylactic treatment was applied as plants reached the predetermined growth stage and the IPM treatment was applied within 5 d after reaching 250 aphids

Table 1. Experimental locations, dates of planting and treatment applications

Yr	Location (county, state)	Planting	Prophylactic	IPM[a]	Variety
2005	Story, IA	23 May	7 July	NA	Prairie Brand 2494
	Lucas, IA	5 May	8 July	NA	Pioneer 93M90
	Kalamazoo, MI	23 May	19 July	NA	Pioneer 92M70
	Saginaw, MI	10 May	13 July	13 July	Pioneer 91B64
	Redwood, MN	31 May	13 July	27 July	Asgrow 2007
	Dakota, MN	24 May	13 July	4 Aug	Pioneer 91B91RR
2006	Story, IA	11 May	11 July	NA	Prairie Brand 2494
	Lucas, IA	28 April	12 July	NA	Pioneer 93M95
	Kalamazoo, MI	26 May	26 July	NA	Asgrow AG2703
	Saginaw, MI	4 May	14 July	NA	Pioneer 91M60
	Redwood, MN	22 May	18 July	27 July	NK S19-L7
	Dakota, MN	19 May	27 July	NA	NK S19-R5
2007	Story, IA	3 May	18 July	18 July	Prairie Brand 2494
	Lucas, IA	15 May	20 July	NA	Pioneer 93M95
	Kalamazoo, MI	15 May	24 July	NA	Dekalb 27–53
	Saginaw, MI	7 May	13 July	NA	Pioneer 91M61
	Redwood, MN	28 May	6 July	7 Aug	NK S19-L7
	Dakota, MN	19 May	23 July	NA	Pioneer 92M02

[a] The IPM treatment was only applied if naturally occurring soybean aphid populations exceeded an average of 250 aphids per plant. NA, not applied.

per plant. All foliar insecticides were applied using ground-based equipment.

Aphid Sampling and Soybean Yield. Soybean aphid populations at all locations originated from natural populations. Plots were sampled once a week by using either in situ or destructive whole-plant counts to estimate the average number of aphids per plant in each plot. In 2005, 10 plants were randomly selected from locations in each plot. The aphid sampling protocol was modified in 2006 because our understanding of how spatial distribution of soybean aphids varied with population density improved (Hodgson et al. 2004). In 2006 and 2007, the number of plants sampled ranged from five to 20, determined by the proportion of infested plants on the previous sampling date. When 0 to 80% of plants were infested, 20 plants were counted; when 81 to 99% of plants were infested, 10 plants were counted; and at 100% infestation, five plants were counted. The seasonal exposure of soybean to soybean aphid was reported in units of "cumulative aphid-days," calculated based on the number of aphids per plant between two sampling dates (Hanafi et al. 1989). Summing aphid days for the growing season, or cumulative aphid-days (CAD), provided a measure of the seasonal aphid exposure to soybean plants in a treatment (Hodgson et al. 2004). Yield was estimated either by harvesting the entire plot with a small combine, or by harvesting a randomly selected two row section with a two row plot combine, and adjusting seed moisture to 13%. For analysis, treatment averages of season long cumulative aphid-days and yield were compared.

Data Analysis. To determine the effectiveness of the soybean aphid management approaches, we compared plant exposure to aphids and yield data using the PROC MIXED procedure in SAS statistical software version 9.1 (SAS Institute, Cary, NC). The statistical model for both aphid exposure and yield considered treatment and location as fixed effects, whereas year and blocks (nested within both year and location) were considered random effects. Average aphid-days accumulated each week were calculated for each treatment throughout the growing season. The effect of insecticide treatments on accumulation of aphid-days was determined using natural log-transformed data to meet the assumptions for analysis of variance (ANOVA). Differences in aphid exposure were determined by analyzing cumulative aphid days in a one-way ANOVA in PROC MIXED and using *F*-protected least-squares means test for mean separation. Yield differences were analyzed in the same way.

The effectiveness of each management plan was also analyzed based on break-even yield gain analysis. A yield gain threshold (GT) was calculated based on insecticide and application costs, expected crop price, and expected yield. The GT is expressed in kg per ha and calculated as estimated control costs (C) [$ per unit area] divided by expected crop price (P) [$ per unit sold] (Pedigo et al. 1986), which is equivalent to the following:

$$GT = \frac{C}{P}. \qquad [1]$$

Average retail price of pesticides and their associated application costs were obtained from an informal phone survey of multiple elevators from across the three states in which the experiment was conducted (Table 2). Treatment costs were remarkably consistent across the three participating states with the exception of scouting cost, which ranged from $0.00 to $19.76 per ha, depending on the scouting service. Low-cost scouting ($0.00/ha) was provided to growers by some firms contingent on the purchase of inputs, whereas higher-cost scouting ($19.76/ha) was provided by full-service firms that scouted weekly for insects, weeds, and diseases for the full season. Four soybean prices ranging from $6.00 to $12.00/27.2 kg (1

Table 2. Treatment costs and yield gain thresholds at four soybean prices

Management tactic	Cost (US$/ha)	Gain thresholda (kg/ha) by soybean price[a]			
		$6.00	$8.00	$10.00	$12.00
Untreated control	0.00	0	0	0	0
IPM (lowest scouting cost)	35.82[b]	162	121	101	81
Scouting (low)	0.00	0	0	0	0
lambda-Cyhalothrin	19.76	90	67	54	47
Application	16.06	73	54	47	34
IPM (highest scouting cost)	55.58[b]	252	188	155	121
Scouting (high)	19.76	90	67	54	47
lambda-Cyhalothrin	19.76	90	67	54	47
Application	16.06	73	54	47	34
Prophylactic	58.06[b]	263	196	161	135
lambda-Cyhalothrin	19.76	90	67	54	47
Pyraclostrobin	22.24	101	74	61	54
Application	16.06	73	54	47	34
Thiamethoxam	23.47	106	81	67	54

[a] Soybean prices in US$/27.2 kg (1 U.S. bushel).
[b] Includes the cost of both pesticides and application.

U.S. bushel) were selected to represent the range of recent futures prices (Table 2).

Without clear understanding of how combinations of insecticides and fungicides would interact to affect yield, we analyze the cost-effectiveness by using Bayesian statistical methods to calculate the probability that an aphid management strategy is cost effective rather than using a traditional ANOVA. Bayesian statistical methods provide intuitive and meaningful inferences, which are well suited for decision-making problems (Ellison 1996, Johnson 1999). The Bayesian approach to statistical analysis is that a parameter (e.g., the difference in mean yields between two treatments) has a probability distribution. A hypothesized prior distribution describes the knowledge about the parameter before the data are collected. The posterior distribution describes the knowledge about the parameter after the data are collected. Following Munkvold et al. (2001), we present the probability that the yield gain from a treatment exceeded the GT at each of the four soybean prices. Given an appropriate choice of prior distributions, the posterior distribution of the difference in yield is a rescaled t-distribution (Box and Tiao 1973). The probability that the yield difference exceeds a specified gain threshold is the integral of the posterior distribution of yield difference from the gain threshold to infinity. This probability can be calculated using SAS software by calculating a recentered t-quantile, t(GT):

$$t(GT) = \frac{GT - (\bar{y}_t - \bar{y}_c)}{s\sqrt{1/n_t + 1/n_c}} \qquad [2]$$

then calculating the one-tailed probability that a random variable with a T distribution exceeds t(GT). This can be calculated in SAS by the following equation:

$$P_{net} = 1 - PROBT[t(GT), df_e] \qquad [3]$$

where df_e is the error df associated with the pooled standard deviation, s. Replacing GT with ΔGT in equation 2 gives the probability that yield gains from one treatment exceed those from a second treatment.

Table 3. Overall treatment effects on aphid exposure and yield

Treatment	Cumulative aphid days	Yield (kg/ha)
Control	1,582 ± 5.0c	1,271 ± 52a
Prophylactic	402 ± 5.0a	1,380 ± 52b
Seed-treatment	471 ± 5.1a	1,366 ± 52b
IPM	807 ± 5.0b	1,369 ± 52b

Means and standard errors are from least squares means in Proc Mixed. Mean ± SE labeled with a unique letter were significantly different ($P < 0.05$).

Results

Aphid Exposure and Yield. Across location-years, we observed significant differences in CAD among the management approaches in soybean exposure to aphids (Table 3). All three management approaches reduced aphid exposure compared with the untreated control ($F = 24.25$; df = 3,211; $P < 0.0001$). Despite a significant difference in aphid exposure between the IPM (807 CADs) treatment and both the prophylactic (402 CADs) and seed treatment (471 CADs) approaches there was no evidence of a difference in soybean yield among the management treatments ($F = 12.68$; df = 2,211; $P < 0.0001$) (Table 3).

Aphid populations and consequent aphid exposure varied significantly from year to year, with the highest levels of aphid exposure to soybean aphids in 2005 and 2007 (Table 4). Among the locations, Minnesota farms consistently experienced high aphid populations compared with Iowa and Michigan (Table 5) and applied the IPM treatment with greater frequency (Table 1). The abundance of aphids in 2005 and 2007 resulted in 50% of the locations in 2005 and 33% of the locations in 2007 reaching the ET, leading to an application of the IPM treatment.

Significant treatment differences in both aphid exposure and yield were observed among treatments. Over all locations and years, soybean treated with thiamethoxam or the prophylactic treatment had the

Table 4. Treatment effects on aphid exposure and yield by year

Yr	Treatment	Cumulative aphid days	Yield (kg/ha)
2005	Control	15,214 ± 1.2c	1,225 ± 30a
	Prophylactic	3569 ± 1.2a	1,407 ± 30b
	IPM	5825 ± 1.2b	1,393 ± 30b
2006	Control	98 ± 1.4c	1,423 ± 19a
	Prophylactic	20 ± 1.4a	1,434 ± 19a
	Seed-treatment	27 ± 1.4a	1,437 ± 19a
	IPM	58 ± 1.4b	1,410 ± 19a
2007	Control	2,940 ± 2.2c	1,148 ± 14a
	Prophylactic	1,098 ± 2.2a	1,285 ± 14b
	Seed-treatment	936 ± 2.2a	1,268 ± 14b
	IPM	1,716 ± 2.2b	1,295 ± 14b

Means and standard errors are from least squares means in Proc Mixed. Mean ± SE labeled with a unique letter were significantly different ($P \le 0.05$).

Table 5. Treatment effects on aphid exposure and yield by state

State	Treatment	Cumulative aphid days	Yield (kg/ha)
Iowa	Control	1703 ± 4c	1467 ± 117a
	Prophylactic	962.9 ± 4ab	1557 ± 114b
	Seed-treatment	750 ± 4a	1584 ± 117b
	IPM	1012 ± 4b	1611 ± 109b
Michigan	Control	478 ± 19.7c	1119 ± 177a
	Prophylactic	67 ± 19.7a	1227 ± 177b
	Seed-treatment	119 ± 19.7ab	1225 ± 177b
	IPM	290 ± 19.7b	1187 ± 177a
Minnesota	Control	5167 ± 1.6c	1217 ± 95a
	Prophylactic	1054 ± 1.6a	1334 ± 95b
	Seed-treatment	1097 ± 1.6a	1279 ± 98a
	IPM	1901 ± 1.6b	1306 ± 95a

Means and standard error of the means are from least squares means in Proc Mixed. Mean ± SEM labeled with a unique letter were significantly different ($P < 0.05$).

lowest levels of aphid exposure. The IPM treatment had an intermediate level of aphid exposure, and the untreated control had the highest levels of aphid exposure (Table 3). Soybean yield varied significantly among treatments, years, and locations (Tables 3–5). Differences in soybean yield were less variable with only two levels of separation being detected with significantly lower yields in the untreated control treatment overall (Table 3), as well as across locations and years (Tables 4 and 5).

Cost-Effectiveness Analysis. Overall, as crop price increased, the probability of recouping the cost of any given treatment increased (Table 6). Although there was little difference in yield among the three insecticide treatments, there was a large difference among the probability of recouping treatment costs. The Bayesian break-even yield gain analysis indicates that regardless of scouting cost, the IPM treatments had the highest probability of recouping treatment cost (Table 6). The seed treatment (thiamethoxam) consistently had the lowest probability of recouping its cost with between 43% probability (at $6.00/27.2 kg) and 51% probability (at $12.00/27.2 kg) of exceeding the cost of the treatment. The IPM treatment was more likely to give a higher yield gain than either the prophylactic treatment or the thiamethoxam seed treatment, even at the higher scouting cost (Tables 6 and 7). As the crop price increased, the cost-effectiveness of the IPM treatment declined compared with the prophylactic treatment (Table 7).

Table 6. Probability of yield gain from treatments exceeding the gain threshold at four soybean prices

Scouting cost	Treatment	Probability by soybean price per 27.2 kg[a]			
		$6.00	$8.00	$10.00	$12.00
$0.00 per ha	IPM	0.81	0.83	0.84	0.85
$19.76 per ha	IPM	0.69	0.74	0.77	0.79
NA	Prophylactic	0.51	0.63	0.70	0.74
NA	Seed-treatment	0.43	0.47	0.50	0.51

[a] 27.2 kg = 1 US bushel.

Table 7. Probability of yield gain from the IPM treatments exceeding the prophylactic and seed-treatments at four soybean prices

IPM treatment Scouting cost	Treatment	Probability by soybean price per 27.2 kg[a]			
		$6.00	$8.00	$10.00	$12.00
$0.00 per ha	Prophylactic	0.81	0.73	0.68	0.64
	Seed-treatment	0.84	0.83	0.82	0.81
$19.76 per ha	Prophylactic	0.67	0.62	0.58	0.56
	Seed-treatment	0.75	0.74	0.74	0.73

[a] 27.2 kg = 1 US bushel.

Discussion

Soybean aphid management should be based on scouting and applying an insecticide only when populations exceed the ET. Our data supports this recommendation (Ragsdale et al. 2007) that soybean fields be scouted weekly until aphid populations exceed an economic threshold. Preventative applications of insecticides, either applied to the seed or foliage, did not significantly reduce soybean exposure to soybean aphids or prevent yield lost compared with insecticides applied in an IPM approach. Our results are consistent with previous studies that show seed treatments do not provide significant protection against yield loss caused by soybean aphids (McCornack and Ragsdale 2006, Johnson et al. 2008). Although seed treatments are convenient and have limited impact to natural enemies (Ohnesorg et al. 2009), colonization by the soybean aphid usually occurs after the activity of the neonicotinoid-based seed treatments residual activity has declined. Due to the variability of soybean aphid phenology within the North Central region, timing the application of a foliar insecticide with a potential outbreak is critical for effective soybean aphid management. Locations in this study did not experience injury from early season insect pests, such as white grubs and bean leaf beetle. Such insects could justify the use of seed-applied insecticides (Bradshaw et al. 2008).

We defined our prophylactic application insecticide with a fungicide applied at the start of flowering (R1). As discussed earlier, the interest in fungicide use in soybean has increased with the arrival of *P. pachyrhizi* to North America, had influenced our decision to include a second class of pesticide. The application of herbicide, typically glyphosate, is a common practice by growers throughout the Midwest due to the rapid adoption of glyphosate-tolerant soybean. We are aware of no evidence that coapplication of glyphosate and insecticide are incompatible, and this practice is probably commonly used by growers interested in a preventative approach to soybean aphid management. The timing of such an application could vary due to weed management needs of a grower. Glyphosate applications are typically based on crop and weed development (Coulter and Nafziger 2007), and the application varies within a range from late May to early July in the Midwest. Johnson et al. (2008) explored whether the application of an insecticide timed with the emergence of the first generation of *C. trifurcata* protected soybean from *A. glycines.* They found little impact to *A. glycines* when insecticides were applied from mid June to early July and no yield protection. With the application of a fungicide we anticipated some yield protection and a potential economic benefit. Therefore, we elected to include a fungicide–insecticide combination timed to potential fungal pathogen as our preventative treatment. However, the application of pesticides does not ensure yield improvement and ecological backlash may work counter to crop production.

The objective of this study was to determine the economic viability of management practices targeting the soybean aphid, and not the ecological consequences due to these practices. Collectively, referred to as ecological backlash (Pedigo and Rice 2008), there are three types of negative consequences of insecticide use: resistance to the active ingredient, resurgence of the target pest, and replacement of the target pest by a insect that previously did not have significant pest status (Stern et al. 1959).

Regarding resurgence, this form of ecological backlash is possible within soybean. The insecticides used in soybean are toxic to soybean aphid natural enemies (Ohnesorg et al. 2009) and interfere with the biological control these beneficial insects provide. Although the effects of predatory insects on soybean aphid are well documented (Brown et al. 2003; Fox et al. 2004, 2005; Rutledge et al. 2004; Rutledge and O'Neil 2005; Brosius et al. 2007; Schmidt et al. 2007, 2008; Gardiner et al. 2009), the effects of entomopathogenic fungi are not. Latteur and Jansen (2002) demonstrated that many fungicides reduce the infectivity of *Erynia neoaphidis,* observed as a source of mortality of soybean aphid in North America (Nielsen and Hajek 2005). At one location (2007, Story County, IA), we observed higher populations of soybean aphid in plots treated with the prophylactic treatment 31 d after the treatment was applied. This was remarkable, given that the IPM treatment was applied at the same time, and showed no such increase. This suggests that the fungicidal component of the tank-mix may have prevented mortality from entomopathogenic fungi. Across our entire study, an increase in aphid populations in the prophylactic treatment was only observed at one location. Because this study was focused on issues of management and not ecology, it is not clear how much risk soybean growers face when using a preventative approach for soybean aphid management. We did not evaluate the risk of resurgence across the full range of products available to soybean growers in the North Central region of the United States. Furthermore, we did not control for the biotic and abiotic factors (temperature and humidity) that are additional aspects of the disease triangle required for epizootics to occur.

The risk of pest resurgence from a prophylactic approach is not limited to the soybean aphid; it could also include other potential insect pests of soybean such as spider mite and green cloverworm, *Plathypena scabra* (F.) whose populations may be limited by entomopathogenic fungi (Higley and Boethel 1994). However, we argue that this uncertainty only further supports the current IPM-based recommendations for soybean aphid management.

Willingness of growers to adopt any pest management approach could be increased if the cost of the treatment is reduced such that the gain threshold is more likely to be reached. The occurrence of any ecological backlash from a preventative approach would effectively increase the cost of the prophylactic treatment, further decreasing the probability of profitable soybean pest management. As our probability analysis indicates, the cost effectiveness of an IPM approach is revealed only over time. It may require several location-years before all forms of ecological backlash become apparent to a grower. We recommend the risk associated with a preventative approach to soybean aphid be communicated to growers to prevent growers from experiencing such events.

IPM approaches based on economic cost-benefit analyses are recognized for effectively managing pest populations (Stern 1973, Pedigo et al. 1986, Pedigo 1995, Ragsdale et al. 2007). This study shows that a single insecticide application can enhance the profitability of soybean production if used properly in an IPM-based system. In particular, the IPM treatment was most likely to provide yield protection that exceeded the gain threshold, covering the treatment cost. This finding held even at the high scouting cost of $19.76/ha, which shows it to be highly robust, as this scouting fee substantially exceeds the $5.00/ha rate reported by Song et al. (2006) as the proportion of a typical crop consultant commercial scouting fee in Michigan that is attributable to soybean aphid scouting visits. The finding is consistent with the analysis of Song and Swinton (2009), which finds that timely insecticide application resulted in soybean yield protection that fully offset yield loss when the soybean aphid population exceeded the economic threshold. It is important to mention that grower benefit from the $19.76/ha was not limited to information on aphid populations. The services provided for this fee at full service scouting agencies included monitoring all insect pest densities, weed densities, disease pressure, soil nutrient analysis, and offering management advice. Even using the conservative scouting fee of $19.76/ha the likelihood of exceeding the gain threshold was less with the prophylactic approach than with the IPM approach. The IPM approach was clearly the most profitable in our break-even analysis, which fits with findings across broad range of U.S. crops where IPM practices have been adopted (Fernandez-Cornejo et al. 1998).

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