The effect of fungicides on soybean in Iowa applied alone or in combination with insecticides at two application growth stages on disease severity and yield

by

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ABSTRACT

The use of foliar fungicides on soybean, *Glycine max* [L.] Merr., has not been recommended in most years in Iowa. But with economic factors such as price of grain, rebate offers on early purchases of fungicides, and rising production costs, the use of fungicides and other pesticides has increased dramatically over the last decade. There is little information regarding the impact of spraying foliar fungicides in Iowa. We tested the effect of fungicide applications at growth stage R1 (beginning of flowering) and R3 (beginning of pod set) on disease control and yield responses. Diseases present in this study included Septoria brown spot, caused by *Septoria glycines* Hemmi, Cercospora leaf blight, caused by *Cercospora kikuchii* ((T. Matsu. & Tomoyasu) Gardener)), and frogeye leaf spot, caused by *Cercospora sojina* Hara. Insecticides also have been used increasingly in soybean production, primarily to manage soybean aphid, *Aphis glycines* Matsumura, which is a problem somewhere in Iowa most years. We also studied the yield benefit of adding a fungicide to an insecticide at R1 and R3 applications. Soybean grain prices are near record levels and the yield responses of pesticides needed to break even is as low as ever. We used Bayesian inference methods to determine the probabilities of fungicides providing an economic return under various estimated economic conditions designed to simulate application costs from airplane applied and ground applied fungicides.

The second portion of this thesis examines anthracnose stem blight, caused by *Colletotrichum truncatum* Schwein. Anthracnose stem blight can be a yield robbing disease, especially in the southern United States. However, it is not understood how anthracnose stem blight affects yield in Iowa and if fungicides are warranted for its control. We examined how various fungicides control anthracnose stem blight at applications R1 and R3. We also examined

how anthracnose stem blight severity (%) was related to yield and individual yield components, to determine if anthracnose stem blight was detrimental to yield in Iowa.

The third portion of this thesis discusses the importance of fungicide trials in applied research today, especially in light of fungicide use on soybean being relatively new in Iowa and other Midwestern states. The main objective was to answer questions surrounding the validity of small plot research since on-farm trial data are preferred by some growers and agribusiness professionals. Using analysis of variance (ANOVA) we compared yield responses of pyraclostrobin and premix products used in small plot and on-farm research trials in Iowa from 2008 to 2010.

CHAPTER 1.

GENERAL INTRODUCTION AND LITERATURE REVIEW

Thesis Organization

This Thesis is organized into five chapters. Chapter one is the general introduction. Chapter two is an article to be submitted to *Plant Disease* entitled "Effects of foliar fungicide application on Septoria brown spot and yield of soybean", where we describe disease control, yield response, and the economics of foliar fungicides applied at two application timings and either sprayed alone or tank-mixed with insecticides. Chapter 3 is an article to be submitted to *Plant Disease* titled "Management of late-season anthracnose stem blight: are management tactics necessary in Iowa?" This paper assesses how fungicides affect late-season anthracnose stem blight and subsequent effects on yield. Chapter 4 is an article to be submitted to *Plant Disease* titled "Analysis of on-farm and small plot fungicide research in Iowa." This article compares results from fungicide trials conducted within Iowa in small plot and on-farm trials during the growing seasons 2008 to 2010. Chapter 5 is the general conclusion of this thesis.

General Introduction

Soybean (*Glycine max* [L.] Merr.) is one of the most important agricultural commodities in and is the second highest yielding crop in the United States only to maize (*Zea mays* L.). Soybean has high concentrations of both oil and protein and can be used in a variety of ways. The oil and protein found in soybean grain can be extracted and used in the production of various foods (e.g., tofu, soymilk) and cooking oils. The oil from soybean has also been used in the production of biodiesel fuels to offset the need for fossil fuels. Globally, the United States leads the world in production of soybean (97 million tons in 2009) (http://faostat.fao.org). Iowa leads the United States in soybean production with Iowa producing 13.5 million tonnes in 2010 (www.ers.usda.gov). In Iowa, soybean is primarily used in rotation with corn.

Soybean production is threatened by a number of abiotic and biotic stresses. As with many crops in the United States, irrigation is used to alleviate drought stresses that occur from Nebraska to Texas. Despite some occasional problems with abiotic stresses, biotic stress is of much more concern to soybean growers in Iowa. The leading cause for loss of soybean production in the United States is soybean cyst nematode (SCN) caused by *Heterodera glycines* Ichinohe. Loss estimates from 2003 through 2005 ranged from 1.7 to 3.2 million tons in the northern United States alone (Wrather, 2006). Because of the severe loss potential, SCN is at the center of many soybean growers' crop management programs. SCN control is achieved via the use of differing SCN resistant cultivars in rotation with susceptible cultivars and alternate crops.

Other yield-limiting biotic stresses of soybean include various insects (that may or may not transmit viruses), bacteria, and fungi (Koenig, 2010). Two such examples of yield-limiting biotic stresses have been introduced to the United States in the past decade: soybean aphid (*Aphis glycines* Matsumura), an insect pest, and soybean rust (caused by *Phakopsora pachyrizi* Syd and P. Syd) a foliar disease (Alleman, 2002; Schneider, 2005). Since their introduction, insecticide and fungicide use has increased dramatically in the United States (and more specifically in Iowa, as well). Twenty years ago, insecticide and fungicide use on soybean was limited to a very few fields in Iowa and the upper Midwest. However, because soybean prices are nearing record highs, more and more growers are willing to invest in insecticides and fungicides to protect soybean yield.

In 2004, soybean rust (*Phakopsora pachyrizi*) was detected in the United States (40). In the years following, *P. pachyrizi* spread throughout the southern United States and occasionally reached the Midwest (25,42). *Phakopsora pachyrizi* overwinters in the Southern United States on legumes, such as kudzu (*Pueraria lobata* (Willd) Ohwi), a noxious weed found throughout the southern United States. Kudzu and its obligate parasite do not survive the winter months in the United States, except in the southern portions of Florida and Texas. Spores do not survive in plant residue, so each growing season soybean rust must survive in southern portions of the United States or Central America and then be transported north if it were to affect the production of soybeans in the Midwest. To help protect the vulnerable soybean germplasm in the United States, an emergency use label (Section 18) for soybean rust was granted to allow the sale of several foliar fungicides. Numerous studies were conducted by many researchers to understand the biology and management of soybean rust, including the deployment of foliar fungicides. Soybean germplasm was highly vulnerable to soybean rust and resistance to *P. pachyrizi* needed to be incorporated into modern cultivars (5,23). Research involving epidemiological modeling was conducted to understand how *P. pachyrizi* was going to spread. Over the years many of the fungicides with Section 18 labels have been granted a Section 3 label for full use on soybean and fungicide sales have risen in the United States. However, soybean rust only has been reported once and has never been documented to cause yield loss in Iowa.

Questions of application timing and tank-mixing with other pesticides still need to be addressed. Along with answering new questions regarding proposed plant health benefits from the application of fungicides without the presence of disease (Supplemental label for Headline®). The validity of research methods in conducting fungicide trials are being questioned by those in the private sector and general public. The purpose of this Thesis research is to answer the above questions regarding fungicide use on soybean in Iowa.

Fungicides have become a significant consideration in soybean management programs in the north central United States and Iowa. However, science-based information is lacking as to how new fungicide products fit into the management programs employed by soybean growers in Iowa. Moreover, questions surrounding issues concerning real and/or perceived plant health benefits have come to the forefront the last few years. Fungicide trials are conducted every year throughout the United States, however, the lack of coordinated test protocol as to how trials are conducted has been criticized. The goal of this thesis is to explore these questions through science-based research.

Literature Review

Soybean aphid. The soybean aphid was first detected in the United States in 2001in Wisconsin (1). Questions surrounded on how best to control the pest (e.g., application timing, use of thresholds, etc.). Since then an economic threshold to trigger insecticide use has been established. It is recommended to apply insecticides when aphid populations exceed 250 aphids per plant and are increasing (39). Soybean aphid outbreaks have occurred most years in some part of the North Central United States.

Soybean aphid has been an important factor in the increase of insecticide use on soybean in Iowa. In recent years, foliar fungicides have increased in use on soybean in Iowa as well. The increase of fungicide sprays has led to questions about how fungicides affect entomopathogenic fungi that might reduce aphid populations (26,28,29). Soybean aphid population peaks have been observed to have occurred with the use of fungicides (27). It is unclear how fungicide use on soybean affects these entomopathogenic fungi in the field and whether or not the use of fungicides can result in a failure of entomopathogenic fungi to keep soybean aphid population s in check.

Foliar diseases endemic to Iowa. There are numerous foliar diseases endemic to Iowa. These include diseases caused by bacteria, fungi, and oomycetes. Prevalent bacterial diseases include bacterial blight caused by *Pseudomonas syringae* pv. *glycinea* and bacterial pustule caused by *Xanthomonas campestris* pv. *glycines*. These diseases look very similar and are characterized by a brown necrotic lesions surrounded by a bright-yellow chlorotic halos. These diseases are most commonly found in the upper canopy and these pathogens are spread by hard driving precipitation events and wind (24). These diseases are not controlled by fungicides. Common fungal diseases in Iowa include Septoria brown spot (*Septoria glycines* Hemmi), Cercospora leaf blight (*Cercospora kikuchii* ((T. Matsu. & Tomoyasu) Gardener), frogeye leaf spot (*Cercospora sojina* Hara), and powdery mildew (*Microsphaera diffusa* Cke. & Pk.). An occasional fungal foliar disease, which can also cause stem lesions, is anthracnose stem blight (*Colletotrichum truncatum*). Downy mildew is another foliar disease and is caused by an oomycete pathogen ((*Peronospora manshurica* (Naum.) Syd). The four fungal diseases that may be effectively managed by foliar fungicides in Iowa are Septoria brown spot, Cercospora leaf blight, frogeye leaf spot and anthracnose stem blight.

Septoria brown spot. *Septoria glycines* is a ascomycete fungus belonging to the order Ascomycota that overwinters as conidia in plant residue. Septoria brown spot is the most prevalent fungal foliar pathogen in Iowa and the United States. Though it rarely causes economic losses in Iowa, documented yield losses have occured in Iowa and other states in the North Central United States (11,14,36,37). The disease is typically found first in the lower canopy. If environmental conditions are favorable (periods of heavy rain and high temperatures), Septoria brown spot can extend up the canopy, causing defoliation and reductions in yield. Recent research of Septoria brown spot has shown that disease severity tends to be lower in the North

Central United States (Cruz et al., 2010), compared to other studies conducted in the Southern United States (Backman et al., 1979). Symptoms of Septoria brown spot are brown necrotic lesions that are often surrounded by an area of diffuse yellowing. Management practices such as a non-host crop rotation and tillage help to manage this disease. Fungicides can also be used to supplement control when needed (2,11,13,37). In Iowa, such research has not been conducted to determine how foliar fungicides affect disease development and whether management of Septoria brown spot will help maintain high yield potentials. At present there are no economic thresholds for Septoria brown spot.

Cercospora leaf blight. *Cercospora kikuchii* belongs to the order Ascomycota and the pathogen overwinters within seed coats within infested plant residue. Cercospora leaf blight is a prevalent foliar disease of soybean that occurs throughout the United States. Symptoms of the disease include a purplish or bronze discoloration on the trifoliates that are exposed to sunlight in the upper canopy. This discoloration is caused by a phytotoxin, cercosporin, that reacts with ultraviolet light. This toxin is common in many *Cercospora* spp. (12). In the North Central United States, symptoms usually manifest themselves late in the growing season close to or even during crop senescence. However, Cai and Schneider (2005) have reported that symptoms can occur as early as growth-stage R3 (pod set). *Cercospora kikuchii* usually infects early in the season and has a latent period (9,10,31). Disease symptoms are the result of the phytotoxin and not the fungus itself, thus the fungus cannot be isolated from the symptomatic leaves. The fungus can sometimes be isolated from lesions found on the petioles. This pathogen can also infect soybean seed, resulting in a purple seed stain, reducing seed quality. This pathogen is of major concern to soybean seed producers due to international phytosanitary regulations that often prohibit the export of seed lots with purple seed stain. Cercospora leaf blight is not well understood. It is more of a concern in the southern states where it more consistently affects yield.

Frogeye leaf spot. *Cercospora kikuchii* is fungal pathogen belonging to the order Ascomycota that overwinters as conidia in plant residue. Frogeye leaf spot has a broad geographical range from the deep South through the north central United States (17,32,53). Disease symptoms are circular brown necrotic lesions with a dark purple border that resembles an eye. Symptoms often occur in the upper canopy where there has been new growth. Frogeye leaf spot is not generally considered a major economic threat to soybean production in Iowa. However, there have been cases of severe outbreaks of this disease in continuous soybean where moisture and humidity are high (e.g., fields in river bottoms, and/or in irrigated fields) (53). In the southern United States frogeye leaf spot is a common threat to soybean yield and often warrants chemical control (Wrather, 2010). Isolates of *C. sojina* have recently been detected with resistance to strobilurin fungicides in Illinois, Tennessee, Kentucky, (6) and most recently Missouri (Bradley, personal communication).

Anthracnose stem blight. *Colletotrichum truncatum* is a fungal pathogen in the order Ascomycota and causes anthracnose stem blight on soybean. Symptoms typically develop on stems and pods of plants during or after senescence as irregular black lesions (3). Infection occurs early in the season and has a latency period during the vegetative stages of soybean (22). Symptoms earlier in the season are the death and downward turning of leaves (Shepherd's crook) (30). This symptom is rare in the north central United States including Iowa. Yield losses caused by anthracnose stem blight in the southern United States have been documented as high as 26% in some cultivars (22,50,51). Fungicide control of anthracnose stem blight has been consistent in previous studies conducted in the Southern United States (Backman, 1979; Backman 1982).

Reports from the northern United States have not shown consistently positive yield responses with control of late-season anthracnose symptoms using fungicides (Wise, 2009). In Iowa, the impact of anthracnose stem blight on yield is unknown. Thus, it is unknown if use of fungicides to control anthracnose stem blight is warranted, in Iowa.

Foliar fungicide use on soybean. Foliar fungicides have been used on soybeans for decades, especially in the southern United States (2,3,37). Tropical and sub-tropical regions, like the southern United States are more likely to encounter yield limiting fungal pathogens because of the warm, wet climates (Koenigg, 2010). In some cases, fungicides have been the only option to control disease. This was the case when soybean rust was found in the United States in 2004 (Schneider, 2005) and United States soybean germplasm was highly vulnerable to this pathogen. Historically, fungicides have not been used on soybean in Iowa and other states in the North Central Region. Management of fungal diseases with fungicides was not economical due to factors such as grain and fungicide prices, and fungicide availability. More recently, with soybean grain prices rising and the more foliar fungicides available on the market, foliar fungicide applications have increased on soybean nationally, as well as Iowa. Fungicides can be taxonomically organized by mode of action and class of chemical. There can be multiple chemical classes per mode of action. The mode of action is the mechanism by which a fungicide interferes with normal fungal metabolic function, causing it to die.

Strobilurins. Strobilurins are a chemical class that is a part of a larger taxonomical group of quinone outside inhibitors (QoI), which interfere with cellular respiration at cytochrome bc1, thus interrupting the electron transport chain (21). This group includes many active ingredients used in fungicides for soybean (e.g., pyraclostrobin, azoxystrobin, and trifloxystrobin). Pyraclostrobin is a unique fungicide because it has a supplemental label for plant health benefits in the absence of disease (52). While other strobilurin fungicides do not have an official supplemental label, most growers and agribusiness professionals association plant health with all strobilurin products. The plant health phenomenon has been reported in multiple cropping systems. Proposed benefits include increased resistance to drought stress, induced plant resistance to protect against bacterial and viral infections, and longer photosynthetic period.

QoI fungicides are very susceptible to fungal pathogen populations developing and/or selecting for resistance. New fungicide-resistant isolates can arise from a single point mutation. There have been multiple point mutations discovered that also can result in resistance to a QoI (Brent and Holloman, 2007). If resistance is selected for in a fungal population via strobilurins, then that pathogen is resistant to all QoI fungicides. In soybean, *Cercospora sojina* is the only soybean pathogen reported to have developed resistance to QoI fungicides in the field.

Triazoles. Triazoles are another commonly used group of fungicides. The mode of action of triazoles is sterol biosynthesis inhibitors (SBI). Triazoles are in a subset of demethylation inhibitors. These fungicides inhibit cellular membrane formation. Common active ingredients in foliar fungicides labeled for use on soybean include propiconazole, prothioconazole, tebuconazole, and tetraconazole. SBI fungicides are rate medium risk for selecting for fungicide resistance. Resistance is gradual as multiple mutations are required for full resistance to SBIs(8,16).

Fungicide application timing. The timing and intervals for fungicide application research on soybeans has mostly been done for the soybean rust pathosystem. However, most recently there have been research studies conducted that have looked at Septoria brown spot and frogeye leaf spot pathosystems (11,13,41). Differences in disease levels in these studies have been negligible; however, yield responses have been greater when fungicides were applied at growth stage R3 (pod set) than at growth stage R1 (flowering) or R5 (grainfill) (15) in some cases. In the absence of high disease severity, Swoboda and Pedersen (2009) found that timing of fungicide application does not affect yield response, nor did any fungicide application when compared to an untreated control.

Fungicide resistance. The Fungicide Resistance Action Committee (FRAC) monitors fungicide resistance in all modern agrosystems. Virtually all common classes of fungicides have documented cases of resistance in lab or field settings (8). The risk of fungicide resistance is mode of action dependent. According to FRAC, a fungicide has a high risk of developing resistance if a single mutation can result in resistance to the fungicide (i.e., strobilurins and other quinone outside inhibitors) (8,16). Triazoles are rated as medium risk for resistance development because multiple mutations are necessary for resistance to develop fully and resistance is gradual (7,21,48).

Fungicide economics. Fungicide economics have been well studied in various agrisystems (35,4345). The main question is: Does it pay to spray? Bayesian inference can be used to determine the probability that a specific fungicide program will be profitable in controlling gray leaf spot of corn (35,43). This type of analysis can illustrate the economic risk/reward spraying fungicides can have. No such methods have been used to analyze the profitability of fungicide applications on soybean. Such analyses can be beneficial to understand how fungicides may perform under various economical and environmental conditions.

Fungicide trials. The recent interest in fungicide use on soybean can be found in the number of fungicide trials conducted over the last seven years. Land Grant Universities and their respective extension networks are conducting numerous fungicide trials each year .(4,11,13,1820,33,34,38,4649) across the north central United States. Prior to 2004, fungicide research trials were not a common practice for the North Central Region. Fungicide filed trials are conducted either in University or institutionally-run research farms in replicated small plot research trials, or on grower owned, on-farm trials. The validity of fungicide trials conducted on research farms has recently been criticized by some growers and by some in agribusiness. It is unclear as to the legitimacy of those concerns.

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CHAPTER 2.

EFFECTS OF FOLIAR FUNGICIDES ON SEPTORIA BROWN SPOT AND SOYBEAN YIELD

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Abstract

Pesticide input costs for soybean growers have increased with the introduction of invasive pests like soybean aphid (*Aphis glycines* Matsumura) and diseases like soybean rust (*Phakopsora pachyrizi* Syd. and P. Syd.). Strategic application of pesticides is paramount for growers to maximize profits while controlling diseases and pests. In Iowa, little is known regarding the yield impacts of fungicide timing on Septoria brown spot control and yield response. Furthermore, there are few data on the impacts of tank mixing a fungicide with an insecticide. We evaluated the effect of fungicides alone and in combination with insecticides at either growth stage R1(flowering) and R3 (podset) on foliar disease and yield of soybean at 13 locations in Iowa from 2008 to 2010. Septoria brown spot severity was low in 2008 and 2009, and moderate in 2010. Soybean aphid populations were high in 2008 and 2009, and very low in 2010. Disease severity was assessed at growth stage R5 at each of 13 trials. Although fungicides reduced Septoria brown spot severity, they did not always impact yield. Greater yields occurred with tank mix applications of an insecticides and fungicide when compared to the control, however the addition of a fungicide did not always increase yield compared to the insecticide alone. Bayesian

inference was done to assess the probability of an economic yield response for applications of fungicides alone. Products with a strobilurin as an active ingredient had higher probabilities of making an economic return than fungicides with a triazole as a lone active ingredient in this study.

Introduction

Pesticide use on soybean (*Glycine max* [L.] Merr.) has increased greatly in the United States in the past decade due in part to the introduction of two invasive species: soybean aphid (*Aphis glycines* Matsumura) and *Phakospora pachyrhizi* Syd. & P. Syd., which causes soybean rust. Soybean aphid first was reported in 2000 (1) and has since caused extensive yield losses across the United States, including Iowa (16). Soybean aphid is managed effectively by insecticides. Extensive research has led to the development of integrated pest management (IPM) practices to manage soybean aphid. Under current IPM recommendations, the use of insecticides to manage soybean aphid should be considered when aphid populations exceed 250 aphids per plant and are increasing (16).

Soybean rust first was reported in the United States in Louisiana in 2004 (17). Because soybean lines in the United States had no resistance to soybean rust there was concern for significant yield losses, and consequently, many foliar fungicides were given an emergency (section 18) label for use on soybean. Yield losses from soybean rust have been observed in southern states, but not in Iowa. Even so, fungicides are used sporadically in Iowa and other Midwestern states to manage foliar diseases of soybean endemic to the United States. In Iowa, three such diseases are Septoria brown spot (caused by *Septoria glycines* Hemmi), Cercospora leaf blight (caused by *Cercospora kikuchii* ((T. Matsu. & Tomoyasu) Gardener)), and frogeye leaf spot (caused by *Cercospora sojina* Hara). Septoria brown spot can reduce yields when left uncontrolled particularly when frequent periods of heavy rain, which favor infection, occur during the mid reproductive stages (2,12). Cercospora leaf blight is a common soybean disease that infects seedlings; however, symptoms appear late in the growing season as the soybean plant approaches senescence, and yield losses are minimal in the Midwest (8). Severe outbreaks of frogeye leaf spot can occur on select varieties and in continuous soybean fields that result in yield loss (18). There are no economic thresholds established for fungicide applications based on injury levels for all these diseases, which makes it difficult to recommend to soybean growers when to apply fungicides.

The majority of foliar fungicides labeled for soybean are triazoles or strobilurins. Triazoles inhibit sterol-biosynthesis, and prevent fungal cell wall formation and are a sub-grouping of demethylation inhibitors (10). Strobilurins are a subgroup of quinone outside inhibitors (QoI). QoI fungicides inhibit the electron transport chain and, therefore, respiration (11). Resistance risk, as assessed by the Fungicide Resistance Action Committee (FRAC), is based on factors such as the number of mutations needed for resistance to appear and the stability of that mutation (5). Triazoles are rated as a medium risk for resistance because resistance in a fungal population to this group requires multiple mutations and develops more slowly over time (4). Strobilurins are rated as a high risk for resistance because a single mutation will confer resistance in a population (11).

Two common groups of insecticide classes include pyrethroids and neonicotinoids. Pyrethroids act on sodium channel modulators inhibiting them from closing and as a result there is continual nerve stimulation which leads to involuntary convulsions, spasms, and then eventually death. Neonicotinoids are nicotinic acetylcholine receptor (nAChR) agonists.

Acetylcholine is a neurotransmitter and nAChR agonists mimic and bind at the site which normally acetylcholine would bind. However, unlike acetylcholine, these agonists stay bound and cause overstimulation which leads to death. Neonicotinoids used as insecticides have an affinity to acetylcholine produced by insects and not vertebrates.

The use of multiple pesticides in soybean production increases input costs for the grower. In some cases, growers need to strategize applying herbicides, insecticides, and fungicides for crop management practices. Tank mixing two or more pesticides can cut input costs by reducing the number of pesticides applications in a growing season. For instance, a grower might consider tank mixing a fungicide and/or insecticide with a herbicide applied at flowering (growth-stage R1) (9). Another strategy might be to apply a fungicide as a tank mix with an insecticide when soybeans are at the beginning of pod set (growth-stage R3) (9) when yield will be most affected by reduced photosynthesis due to affected leaf area (15). Although tank mixing pesticides can reduce application costs, there is a risk of disease and pest resurgence if a particular pesticide is applied before diseases or pests become an economical threat. Also, weeds may reduce yield if herbicide applications are delayed so they can be combined with other pesticides.

The goal of our research was to provide recommendations on pesticide use to improve soybean production across Iowa in a range of environmental conditions. Thus, our objectives were to: i) determine how growth-stage applications of fungicides and insecticides compare with current intergrated pest management recommendations, ii) if the addition of a fungicide to an insecticide results in an additive yield benefit. Furthermore, classes

Materials and Methods

Weather Data. Weather data for each growing season was recorded from weather stations located at each research farm to help explain disease outbreaks. Backman et al. (2)

showed that fungicides had the greatest effectiveness in yield protection when used during seasons where rainy conditions were present between R1 and R3 (grain fill). Data downloaded from the Iowa State University weather database (http://mesonet.agron.iastate.edu) included temperature (average high and low) and precipitation (mm).

Field trials. Field trials were conducted at three to five Iowa State University (ISU) research farms across Iowa over three years, 2008 to 2010. The research farms used were in various geographical locations across the state of Iowa. This was done in order to have varying environmental conditions within a year. Trials were conducted at Northwest ISU Research Farm (O'Brien County, 2008, 2009, 2010), Northern ISU Research Farm (Hancock County, 2008), Northeastern ISU Research Farm (Floyd County, 2008, 2009, 2010), Curtiss Research Farm (Story County, 2009, 2010), Armstrong Research Farm (Adair County, 2008), Neely-Kinyon Farm (Green County, 2009), and Southeastern ISU Research Farm (Washington County, 2008, 2009) (see Appendix A Fig. 1). In 2008, each plot was four rows wide (76.2-cm spacing) and 10.7 m long, while in 2009 and 2010, plots were six rows wide (76.2-cm spacing) and 10.7 to 15.2 m long, depending on location. The experimental design used at each location was a randomized complete block with five or six replications. Soybean cultivars used in this study are listed in Table 1.

We hypothesize that pesticides applied at R3 will yield higher than pesticides applied at R1 due to typical disease development cycles observed in Iowa and the protection of yield during the critical stages of grain fill (R3-R6). We also hypothesize that an application of a fungicide-insecticide tank-mix will have greater yields than insecticides alone by giving added protection. Types of pesticides used in this study were fungicides alone, insecticides alone, and fungicide + insecticide tank mixes, each being applied at growth-stage R1 or growth-stage R3. Various active ingredients were used for each type of pesticide (Table 1). Two controls were used in the study: an untreated control and an IPM control. The IPM control plots were sprayed with insecticide only if soybean aphid populations reached the economic threshold of 250 aphids per plant and were increasing (Table 1). Treatments were applied to the middle two rows of each plot in 2008 and the middle four rows of each plot in 2009 and 2010. All pesticide applications were done using a CO_2-powered backpack sprayer calibrated to spray at 187 liters per hectare using flat fan nozzles. The spray boom effectively applied pesticides to two rows at a time. Specific treatments applied for each site year are in Table 2.

Soybean aphids. Aphids were counted weekly or biweekly at each location to monitor aphid population changes throughout the season. If aphids were found to be >250 per plant and populations were increasing then the IPM control plot was sprayed with insecticide. Also, cumulative aphid days (CAD) were calculated from these data, which is an estimate of the soybean plants' exposure to aphids during the growing season. Methods used were in accordance to Ragsdale et al. (2007). A more extensive analysis of the CAD data can be seen in the work of Ritson et al. (2011).

Disease rating. The computer program Severity Pro® (14) was used to train personnel rating for foliar disease. Disease ratings were recorded as percent leaf area affected by disease. Ten leaflets were assessed in each of the upper and lower canopies of every plot. In 2008, disease data were collected from the middle two rows of each plot. In 2009 and 2010, disease data were collected from upper and lower canopies of the second and fifth rows to minimize disturbance of the yield rows. Disease severity was assessed during the grain fill period between growth stages R5 and R6 in the upper and lower canopy. (9). All fungal foliar diseases controlled by fungicides present were assessed. Other diseases such as white mold, sudden death syndrome and bacterial blight were also noted when observed.

Harvest. Yield data were collected from the center two rows of each plot using plot combines. Grain weight and grain moisture were recorded for each plot and yields were adjusted to 13% moisture for comparison.

Postharvest analysis. Disease and yield data were analyzed using SAS version 9.2 (SAS Institute, Inc., Cary, NC). Treatment means were calculated using the GLM procedure in SAS. Multiple linear models were used and we tested treatment interactions with location and year. Means comparisons were calculated using Fisher's protected Least Significant Difference (LSD) ($P \leq 0.05$) for disease severity and yield for each site year. A set of pre-planned contrasts were also calculated.

Regression analysis was also used to demonstrate the relationship between yield and brown spot severity in the lower canopy using the REG procedure in SAS. Each site year was analyzed separately for this analysis.

Profitability analyses. Bayesian inference methods were used to determine the probability yield response estimates of pyraclostrobin, trifloxystrobin + prothioconazole, and triazoles alone were high enough to elicit an economic return under various scenarios (13). Yield response estimates were calculated using PROC GLM in SAS (SAS Institute, Cary, NC).

Net returns (N), in dollars, for each treatment were calculated by using the following equation:

$$N = ((Y_f - Y_c)*P) - C_f$$

The yield response estimate ($Y_f - Y_c$), where Y_f is the yield estimate of a fungicide treatment and Y_c is the yield estimate of the untreated control, is multiplied by a price of grain per bushel (P) to calculate the estimated gross return of using a fungicide. The difference between the gross return and the cost of applying fungicides (C_f) gives the net return, N. This equation allows estimating net returns under infinite scenarios of soybean grain prices and costs of applying the fungicides. The cost of applying fungicide is the sum of cost of product (C_p) and cost estimate of application method (C_a). The estimated cost for each product ha^{-1} was $38.58, $39.29, and $22.23 for pyraclostrobin, trifloxystrobin + prothioconazole, and the triazole, respectively.

$$C_f = C_p + C_a + (D \cdot 202 \cdot P)$$

Using ground sprayers at or after growth stage R3 has been shown to negatively affect yield about 202 kg ha^{-1}. If fungicides are applied at or after R3 via ground application then D=1. If fungicides are applied before canopy closure, or are applied via airplane or helicopter, D=0. A Student's T distribution was then used to standardize the data under assumed normal distribution and by using a pooled variance from the model.

$$T = (B_0 - (Y_f - Y_c) / (s(1/n_f + 1/n_c)^{1/2})$$

B_0 = yield response needed to offset the costs of applying fungicides

S = the pooled variance

N_f = number of observations of treatment

N_c = number of observations control

The probability of breaking even or making a 50% return was then calculated using the ProbT function in SAS. The probability is a one tailed probability used to determine the probability a treatment would at least break even.

$$P = 1 - \text{ProbT}(T_{[Yf-Yc]}, df)$$

The probability of breaking even may not be a high enough benchmark for a grower to consider spraying a fungicide. We also chose to test these data under the circumstances that a grower would expect to receive a 50% return on investment (i.e., ½C_f).

Our data were tested using this process under various scenarios. First, three levels of soybean grain prices were use: 8, 12, and 16 bu^{-1} (27.2 kg). These three levels represent prices near the average of the last 5 years, near current prices, and a price level above the current levels to understand how the economic return probabilities change as prices go up. We also analyzed the data under two application methods (C_a): by air and by ground (cost estimates of \$24.70 and \$19.76 ha^{-1}, respectively). With both of these scenarios, we were operating under the assumption that the fungicides were applied by a co-op and not by the grower. And all of these scenarios were then put under the light of probability a treatment will result in breakings even, B_0, or 50% return of investment, B_{50}.

Results

Weather conditions. Rainfall and temperature varied between locations and years of this study (Appendix Table 2). In 2008, average high and low temperatures were near the 30-year averages during grain fill (July and August). Rainfall in July was above average in Floyd County and below average in Cass, Hancock, and O'Brien counties compared to 30-year averages for each location. During August, when the soybean crop is typically at grain fill growth stages, all locations had below average rainfall when compared to the respective 30-year averages. The difference ranged from 26 to 91 mm below the 30-year average. Cool weather characterized the 2009 grain fill period with the average high temperature ranging from 24.6-25.9 C° in July and 24.7-25.7 C° in August, which are both below the 30-year averages. In this growing season, Adair and Washington counties had rainfall accumulations of 214 and 218 mm, respectively. Rainfall during August in Floyd, O'Brien, and Story counties were considerably lower (93, 43, and 4 mm, respectively). In 2010, the grain fill period was very hot and wet, especially in Story County. In August of 2010, the average high temperature was 29.5 C° and the total rainfall was 336 mm (30-year average = 122 mm) (Appendix Table 2).

In the three weeks following a pesticide application weather data was also collected to monitor rainfall and temperature at each location during the three years of this study (Fig. 1). In 2008, at all locations except for Cass County, days where rainfall exceeded >2mm accumulations were greater than 5 days in the three weeks after the R1 growth stage application of pesticides. In the three weeks following the R3 application of pesticides all locations had less than 5 total days where rainfall exceeded 2mm accumulation.

In 2009, during the three week period after the R1 application of pesticides only one location, (O'Brien County) had greater than 5 days of rainfall accumulation > 2mm. In the three week period following the R3 application all locations had greater than 5 days of rainfall >2mm accumulation, except for Story County.

In 2010, in the three weeks following the R1 application of pesticides all locations had greater than 5 days where >2mm rainfall accumulated. During that time Story County had the greatest number of days where rainfall >2mm (8 days). In the three weeks following the R3 pesticide applications O'Brien County and Story County both had greater than 5 days where >2mm rainfall accumulation occurred (8 and 12, respectively). The site at Story Count in 2010 had the largest number of days where rainfall exceeded 2mm and temperatures were greater than 30 degrees Celsius (12 and 10 days, respectively).

Soybean aphids. Soybean aphids reached economic threshold at about half of the locations during this study. In 2008, at four out of the five sites soybean aphids reached economic threshold and an IPM spray was warranted. The exception was the Cass County site. In this year, the O'Brien County site had 92,281 CAD, which was the highest level throughout this study. Soybean aphid populations were lower in 2009 and only reached economic threshold at sites in Floyd, O'Brien, and Story counties, where the IPM plots were sprayed. The economic threshold for aphids was not met in the two southern locations. In 2010, economic thresholds for soybean aphid were not reached at any location and thus no IPM sprays were applied.

Statistical Analysis. Each site-year was considered to be a unique environment and each was analyzed separately. This was supported statistically by testing the significance of **'**Location' and 'year' ($P < 0.0001$) when running PROC GLM (Appendix Table 3 and 4). Sources of variance for each site year can be seen in Appendix Table 5.

Disease severity. Of the common foliar diseases in Iowa, the only one found consistently at all locations was Septoria brown spot. Frogeye leaf spot and Cercospora leaf blight were found at most locations each year, but at very low levels in all treatments and/or there was no treatment effect (Appendix Tables 6-11) that was correlated with a yield response. Other diseases such as bacterial blight, bacterial pustule, and downy mildew were seen sporadically, but were not affected by fungicides. Low incidences of sudden death syndrome and/or white mold were occasionally seen, but no differences in disease incidence were seen among treatments and no correlation was observed with yield.

Septoria brown spot was prevalent in all three years of the study. The average brown spot disease severity in the lower canopy of UTC for all locations in 2008 was 8.0%. In 2009, average brown spot severity in the UTC fell to 5.4% and in 2010, it was rose back to 8.0%.

In 2008, Septoria brown spot mean severity was less than 10% in the lower canopy of the untreated control at all trial locations except in Floyd County (12%). All fungicide treatments reduced Septoria brown spot severity in the lower canopy at this location ($P < 0.05$). In Cass and Hancock counties, mean brown spot severity was 4.2% and 7.4%, respectively, and only pyraclostrobin reduced Septoria brown spot severity regardless of application timing ($P < 0.05$) (Table 3). Treatments had no effect on Septoria brown spot severity in O'Brien and Washington counties ($P > 0.05$).

Septoria brown spot severity also was less than 10% at all locations in 2009. All fungicide treatments with the exception of tetraconazole reduced brown spot severity in Floyd, O'Brien, and Story counties ($P < 0.05$). In Adair and Washington counties, there were no treatment effects on Septoria brown spot severity ($P > 0.05$) (Table 4).

Septoria brown spot severity was reduced by fungicide treatments in 2010 at trials located in O'Brien and Story counties where the mean brown spot severity of the untreated controls were 9.7% and 7.6%, respectively (Table 5). At the Floyd county location, treatment had no effect on Septoria brown spot severity ($P > 0.05$).

Yield. Mean yield in the UTC across all locations in 2008 was 3298 kg ha^{-1}, which was the lowest for all three years. In 2009 and 2010, the mean yield in the UTC was 4041 and 3880 kg ha^{-1}, respectively, across all locations.

Fungicides applied at R1 were greater than the control ($P < 0.05$) at the sites at Floyd County in 2008 and Story County in 2010 only, while fungicides applied at growth stage R3 were greater than the control at the sites in Floyd, O'Brien, and Washington Counties in 2008 and at the site in Story County in 2010. At the site in Washington County fungicides applied at growth stage R3 were greater than fungicides applied at growth stage R1 ($P < 0.05$). This was the only location during the entire study where fungicides applied at growth stage R3 were statistically greater than fungicides applied at growth stage R1 (Fig. 2; Table 6, 7, 8). A fungicide-insecticide tank mix when applied at growth stage R1 was greater than an insecticide alone at R1 at the sites in Washington County in 2008. Insecticides applied alone were greater than a fungicide-insecticide tank mix applied at growth stage R1 at the site in O'Brien County in 2010. Fungicide-insecticide tank mixes applied at growth stage R3 were greater than insecticides alone applied at growth stage R3 at Washington County in 2008, and Story County in 2009 (Fig. 3; Tables 6, 7, 8). Applications of insecticides alone applied at R3 were greater than insecticides applied at R1 at sites in Floyd, O'Brien, and Washington Counties, in 2008, and in Story County in 2009. Applications of fungicide-tank mixes applied at growth-stage R3 were greater than applications at growth stage R1 ($P < 0.05$) at the sites in Cass, Floyd, O'Brien, and Washington Counties in 2008, Story County in 2009, and in O'Brien County in 2010 (Fig. 3; Tables 6, 7, 8).

Yield responses of fungicides varied between products and treatments during this study. Applications of pyraclostrobin at growth stages R1 and R3 had the largest mean yield response when compared to the other fungicides, 188.9 and 275.6 kg ha^{-1}, respectively. Triazoles had the smallest mean yield response of all fungicides applied at R1 (76.1 kg ha^{-1}) and penthiopyrad had the smallest yield response of fungicides applied at R3 (-69.3 kg ha^{-1}) (Fig. 4). Yield responses of a fungicide added to an insecticide were generally lower than fungicides compared to an untreated control. Penthiopyrad + esfenvalerate applied at R1 had a yield response of 152.2 kg ha^{-1} when compared to esfenvalerate alone at R1. This was the largest yield response observed for tankmixes applied at R1. The largest yield response of tank mixes applied at R3 was trifloxystrobin + prothioconazole + imidicloprid applied at growth stage R3 had a yield response of 136.9 kg ha^{-1} averaged across all years of this study. The lowest yield responses of tank mixes applied at growth stage R1 and R3 were the triazoles plus an insecticide (3.1 kg ha^{-1}) and picoxystrobin + esfenvalerate (7.4 kg ha^{-1}), respectively (Fig. 5).

In 2008, across all locations only one of the fungicides applied alone (pyraclostrobin) protected yield (Table 9). At the trials located in O'Brien and Washington counties, pyraclostrobin applied at R3 resulted in greater yields than compared to its R1 application. Soybean yields were greater ($P < 0.05$) for the treatments trifloxystrobin + prothioconazole + imidicloprid applied at R1 (4701 kg ha^{-1}) and R3 (5002 kg ha^{-1}) compared with imidicloprid alone (R1 = 4464 kg ha^{-1}, R3 = 4638 kg ha^{-1}) at the Washington County location (Table 7).

In 2009, no fungicide application at either timing significantly increased yield when compared to the untreated control ($P > 0.05$) (Table 7). Similar to 2008, soybean yields were greater for fungicide + insecticide tank mixes compared to the IPM control ($P < 0.05$), but the application had a limited benefit when compared to the corresponding insecticide applications alone (Table 10). Pyraclostrobin + esfenvalerate applied at R3 at trials at O'Brien (4208 kg ha^{-1}) and Story (5186 kg ha^{-1}) counties protected more yield compared to esfenvalerate alone, 3917 and 3878 kg ha^{-1}, respectively (P<0.05). Tetraconazole applied at R1 with clothianidin resulted in greater yields than the R1 application of clothianidin alone in O'Brien County ($P < 0.05$). In Washington County, greater yield occurred with an R1 application of picoxystrobin and esfenvalerate compared to an R1 application of esfenvalerate alone ($P < 0.05$).

In 2010, fungicides applied alone had no effect on yield at trials in Floyd or O'Brien counties ($P > 0.05$) (Table 11). Fungicide applications at the trial in Story County did have positive yield responses ($P < 0.05$). Greater yields occurred with applications of trifloxystrobin + prothioconizole at R1 (4767 kg ha^{-1}) and R3 (4835 kg ha^{-1}), and pyraclostrobin at R3 (4798 kg ha^{-1}), compared to the untreated control (4937 kg ha^{-1}). There were no other detectable differences between soybeans treated with fungicide + insecticide and insecticide alone at Story County (P > 0.05) (Table 11).

Four sites had rains exceeding 100 mm in August (2009: Adair and Washington Counties; 2010: Story and O'Brien Counties). With the exception of Washington County in 2009, a significant relationship between Septoria brown spot severity and yield was detected using regression analysis ($P < 0.05$) at these locations. Story County, which had the highest rainfall accumulation in this study during August, 2010, had the highest R^2 (0.11) of the locations where treatment had a significant effect on Septoria brown spot severity and yield ($P <$ 0.05).

Profitability. The probability of making a net return on a fungicide application ranged from <0.01 to 0.99 and increased as grain price parameters were increased (Tables 12-17). Probability of making a net return was highest when a fungicide was applied at growth stage R3 via airplane. An R3 application of fungicide that was applied with a ground sprayer greatly reduced the probability of a fungicide making a positive return due to the estimated loss of 202 kg ha^{-1}. For example, in 2009 at the Story County location, an R3 application of pyraclostrobin had a probability equal to 0.81 of making a positive net return when applied via airplane and grain prices estimated at \$8 bu^{-1}, but the probability was reduced to 0.51 when applied via ground spray equipment. Probabilities of making an economic return of R1 sprays were similar when comparing aerial and ground application methods despite ground equipment being nearly \$5 ha^{-1} cheaper. Ground application methods ranged 1 to 4 percentage points higher than similar aerial methods for R1 fungicide applications. Although the cost of applying a triazole was approximately \$17 ha^{-1} cheaper than an application of pyraclostrobin and trifloxystrobin + prothioconazole, the probabilities of triazoles netting an economic return were the lowest of the three fungicides tested in this study. For example, when beans are estimated at \$8 bu^{-1} and pesticides are applied with an airplane at R3 the probability of a triazole breaking even ranged from 0.04 to 0.53. While pyraclostrobin and trifloxystrobin + prothioconazole had probability ranges of 0.08 to 0.98 and 0.11 to 0.99, respectively.

Discussion

This was the first study in Iowa to determine if a fungicide is a valuable management option when applied at growth stage R1 or R3 alone or with an insecticide application. This also is the first report to compare triazole and strobilurin fungicides for management of soybean foliar diseases, and to assess if fungicide classes differ in their ability to protect yield. Furthermore, we calculated the probabilities of making a profitable return when using fungicides on soybean.

Fungicides reduced the severity of Septoria brown spot throughout this study, and our data concur with other studies that have evaluated the effect of fungicides on Septoria brown - spot in other states (2,6,7,12,15). However, we did not see yield loss associated with the levels of

Septoria brown spot observed at most site-years in this study. Swoboda and Pedersen (2009) did not find that fungicides provided a yield benefit when compared to the control. At many of our trials we found similar results. However, at some locations, like in Story County in 2010, the uses of fungicides were associated with yield gains that were also associated with the reduction of Septoria brown spot severity. This highlights the importance of using fungicides only when they are warranted.

Throughout this study Septoria brown spot remained in the lower canopy and at low levels (>10%) where photosynthetic impact is low (3). However, when Septoria brown spot reached the mid canopy during growth stage R5, as was the case in Story County 2010, yield responses to fungicide applications averaged 240 kg ha^{-1}. Frequent rains of > 2mm accumulation, what Backman described as a “wet” event, and high temperatures provided a conducive environment for disease development (2). Accordingly, fungicides sprayed at the Story County site were most effective in protecting yield.

We had originally hypothesized that fungicides applied at the growth-stage R3 would control disease and protect yield more effectively than fungicides applied at growth stage R1. Statistically our data do not support this. Differences in disease severity in between fungicide treatments were undetectable. The same goes for differences in yield between fungicides applied at growth stage R1 and R3. However, in general, R3 applied pesticides averaged higher yields than R1 applied pesticides, though not always significantly higher. Yield differences between R1 and R3 application of fungicides were only detectable at the site in Washington County in 2008, making it difficult to determine a definitive advantage. However, yield responses of fungicides were generally greater when the fungicide was applied at growth stage R3 and based on disease development patterns common in Iowa it is likely the best timing to spray a fungicide (Fig 2).

As pesticide regimens become increasingly more complicated for soybean growers, understanding how fungicides fit into a crop management strategy remains ever important. Tank-mixing fungicides with insecticides is a strategy that some growers have been suggested to cut down the number of times pesticides are applied to a field, which cuts costs. Our research showed that yield was significantly increased only 10% of the time over the course of this study when a fungicide was tank mixed with an insecticide compared to the insecticide treatment alone (Tables 6, 7, 8). Dorrance et al (2010) reported similar findings when comparing tank mixes of azoxystrobin + lambda-cyhalothrin compared to lambda-cyhalothrin alone. In our study, the mean yield response of adding a fungicide to an insecticide was < 200 kg ha^{-1} which would make a return on investment unlikely.

In traditional fungicide research, it can be difficult to detect yield differences between treatments that would be significant to growers due to high variance and error in the study, especially when working with numerous treatments. The general performance of application timing and products can be determined based on the probabilities of our economic analysis. Products that contain a strobilurin more consistently protected soybean yields compared to products that contain a triazole alone. Growth stage R3 applications of fungicides had higher probabilities of being profitable than R1 applications, although we did not detect this difference in our generalized linear model. We detected little differences in the probabilities of profitability for pyraclostrobin and trifloxystrobin + prothioconazole. However, triazoles had much lower probabilities than the strobilurins and premix products, which is consistent with results by Cruz et al. (2010).

This analysis and its implications should be used with caution. The probabilities reported are not predictors of how fungicides will perform in the future. The probabilities reported are, instead, showing the likelihood of the product making a return at a particular location. Also, since the analysis is heavy on pre-estimated economic conditions there are endless scenarios in which the data can be put through. Economic scenarios should be limited to not lose the meaning of the research. As soybean grain prices fluctuate so will the probabilities in this type of analysis. Risk aversion is very high with soybean growers, and consequently fungicides are more likely to be sprayed at times when grain prices are high and similarly the probabilities of making a return are high. If grain prices continue to stay near record highs or continue to grow, the number of growers who decide to spray may well increase in the coming years.

Products with a triazole as the only active ingredient were not associated with increased yields. However, disease severity over the course of this research was very low and in most cases the use of fungicides were not warranted. Higher yields with products that contained a strobilurin as an active ingredient only occurred when disease pressure was severe. Despite this, using strobilurins as the only active ingredient year after year can lead to resistance developing in a pathogen population (4). Alternating active ingredients or using premix fungicides with two active ingredients as a disease management strategy is still recommended to lower the risk of pathogens developing resistance in a population (4).

We conclude it is in the best interest of growers, economically, to use a broad-based, integrated approach when managing diseases. Even when grain prices are high and returns are likely, the risk of fungicide resistance development is a concern and consequently the use of resistant varieties and crop rotations, in combination with need-based use of chemicals, is an effective way to manage foliar disease in Iowa. Further research needs to be done in order to develop accurate thresholds for fungal foliar diseases found in Iowa. There remains still no clear advantageous time to use fungicides in the protection of yield based on disease severity.

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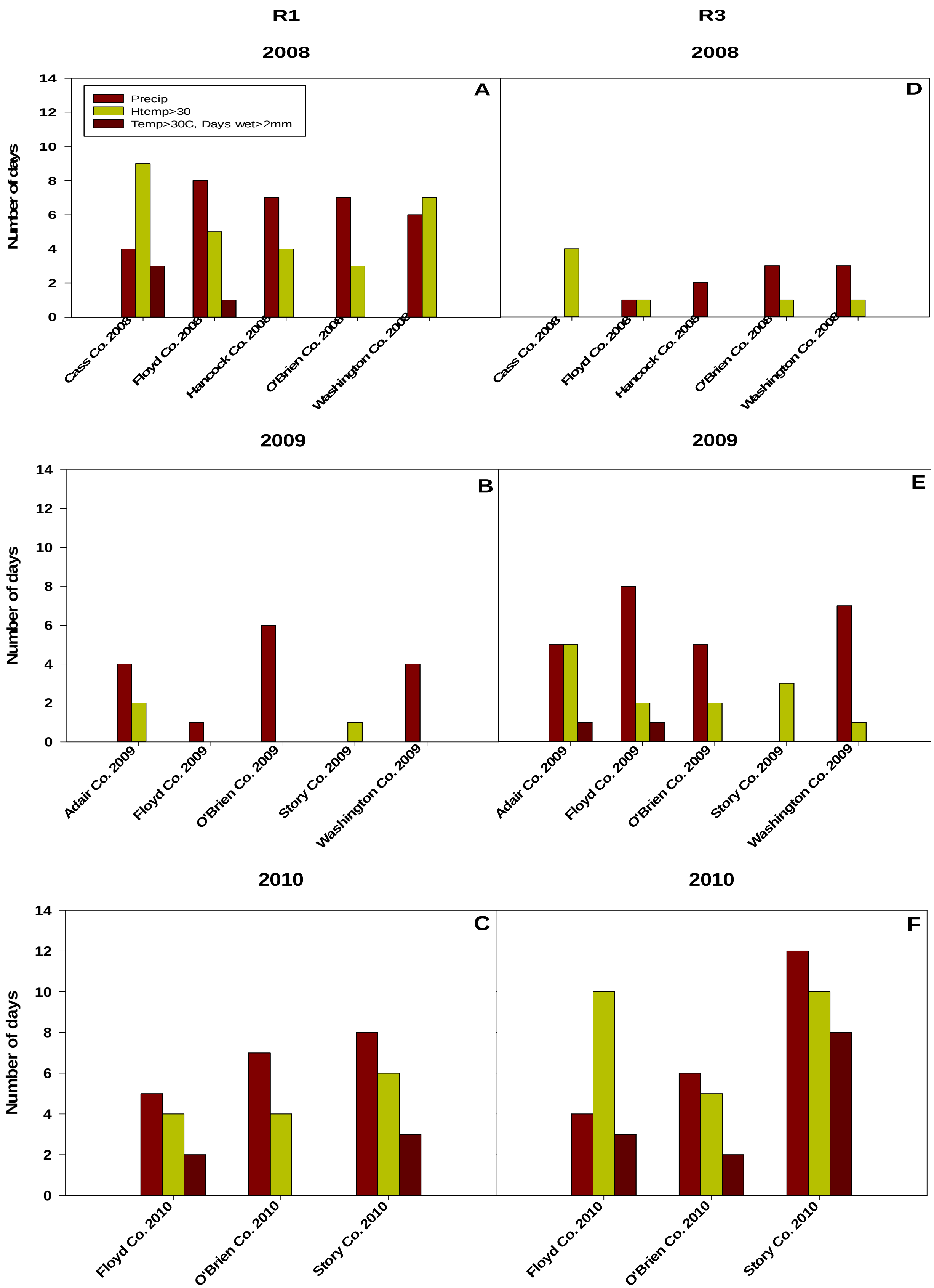
R1
R3
2008
2008
A
D
Precip
Htemp>30
Temp>30C, Days wet>2mm
Number of days
0
2
4
6
8
10
12
14
Cass Co. 2008
Floyd Co. 2008
Hancock Co. 2008
O'Brien Co. 2008
Washington Co. 2008
2009
2009
B
E
Adair Co. 2009
Floyd Co. 2009
O'Brien Co. 2009
Story Co. 2009
Washington Co. 2009
2010
2010
C
F
Floyd Co. 2010
O'Brien Co. 2010
Story Co. 2010

Figure 1. Weather data recorded during the three week period after a pesticide application at growth stages R1 or R3 in (**A,D**) 2008, (**B,E**), 2009, and (**C,F**) 2010. Recorded data includes the number of days where rainfall accumulation > 2mm, days temperature > 30 degrees Celsius, and number of days both occur.

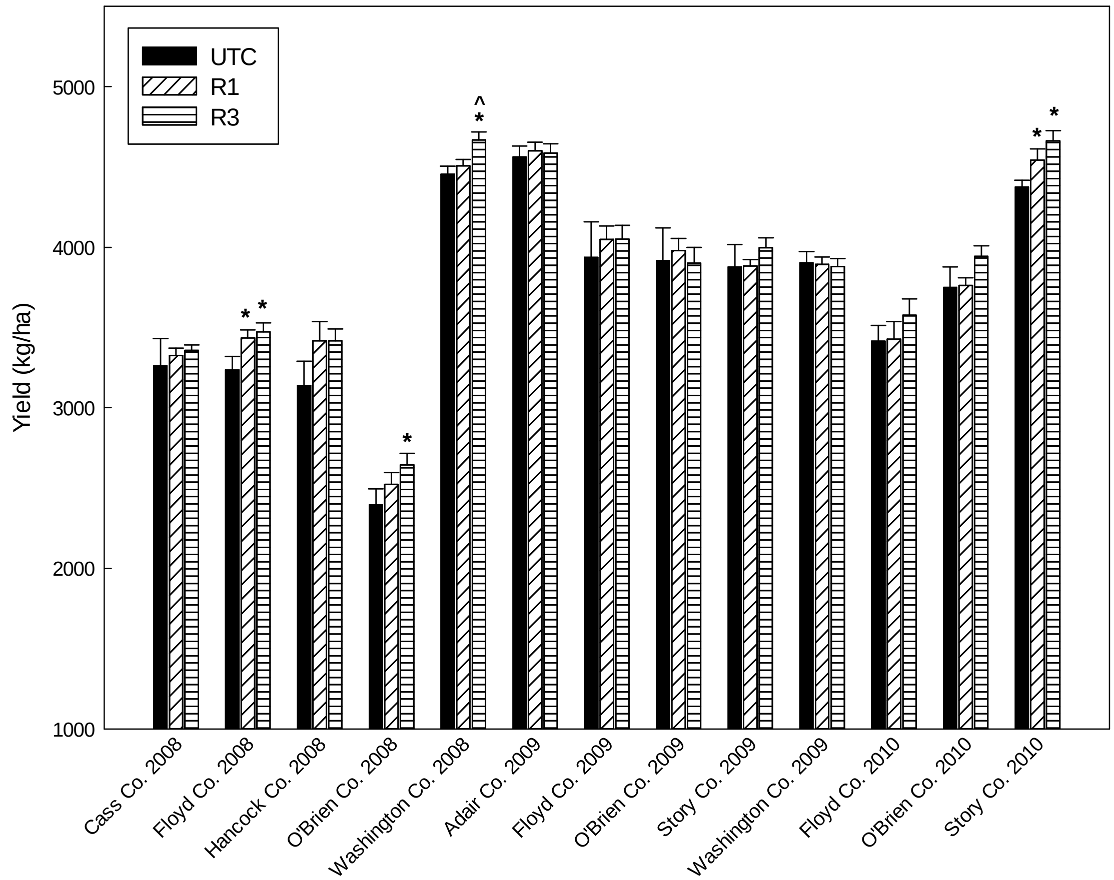

Figure 2. Yield (kg ha^{-1}) of fungicides applied at growth stages R1 (flowering) or R3 (podset) and untreated controls (UTC) at 13 site-years across a three-year period from 2008-2010 in Iowa. Differences between fungicide treatments and the UTC are denoted with *. Differences between application timings of a fungicide are denoted with ^.

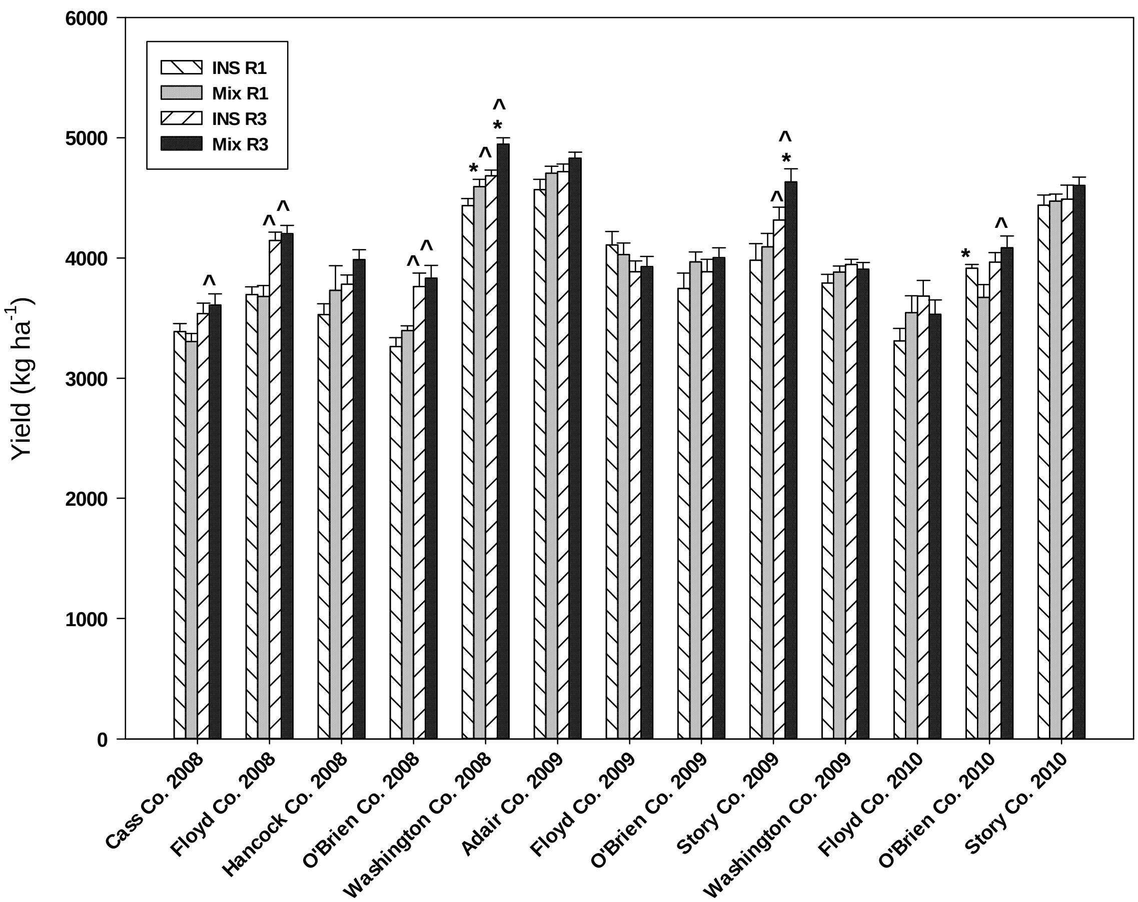

Figure 3. Yield (bu/ha) of insecticides applied alone and tankmixes of insecticides plus fungicides at growth stages R1 (flowering) or R3 (podset) at 13 site-years over a three-year period in Iowa. Significant differences (P < 0.05) between a insecticide and tankmix pair are denoted with *. Differences between application timings (P < 0.05) within the same type of application (insecticide alone or tank mix) are denoted with ^.

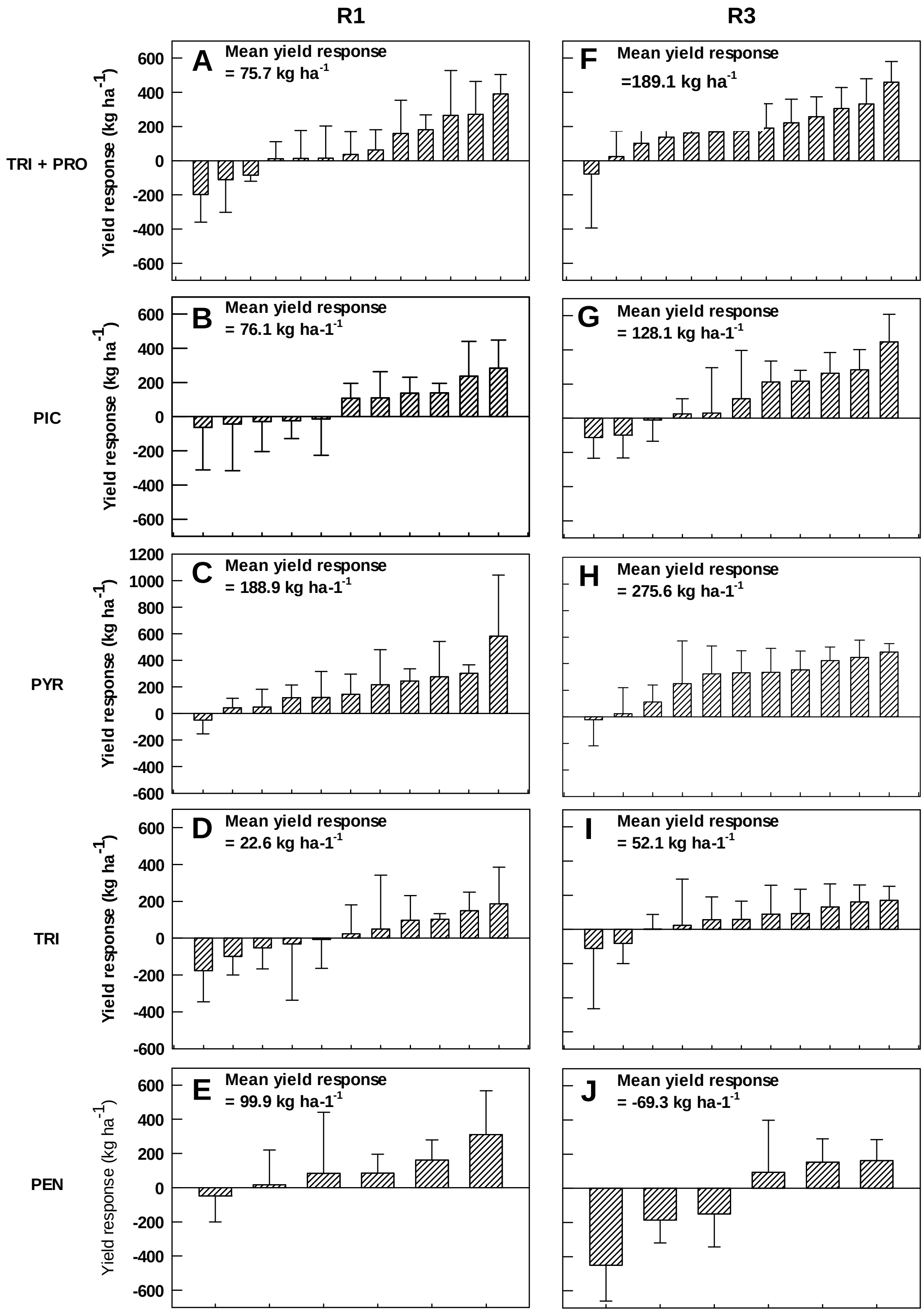
R1
R3
TRI + PRO
PIC
PYR
TRI
PEN
Yield response (kg ha-1)
A Mean yield response = 75.7 kg ha-1
B Mean yield response = 76.1 kg ha-1-1
C Mean yield response = 188.9 kg ha-1-1
D Mean yield response = 22.6 kg ha-1-1
E Mean yield response = 99.9 kg ha-1-1
F Mean yield response =189.1 kg ha-1
G Mean yield response = 128.1 kg ha-1-1
H Mean yield response = 275.6 kg ha-1-1
I Mean yield response = 52.1 kg ha-1-1
J Mean yield response = -69.3 kg ha-1-1
600
400
200
0
-200
-400
-600
1200
1000
800

Figure 4. Yield responses of fungicides against an untreated control at various locations over a three year period in Iowa from 2008-2010. Yield responses are reported for (**A, F**) trifloxystrobin + prothioconazole (TRI + PRO), (**B, G**) picoxystrobin (PIC), () pyraclostrobin (PYR), (**D, I**) flusilazole (2008) and tetraconazole (2009, 2010) (TRI), and (**E, J**) penthiopyrad (PEN). Panels in the same column represent fungicide applications at the same growth stage, R1 (flowering) (column 1) or R3 (podset) (column 2). Error bars show the standard error of the yield response at an individual site year. Mean yield responses are also reported for each product within each panel.

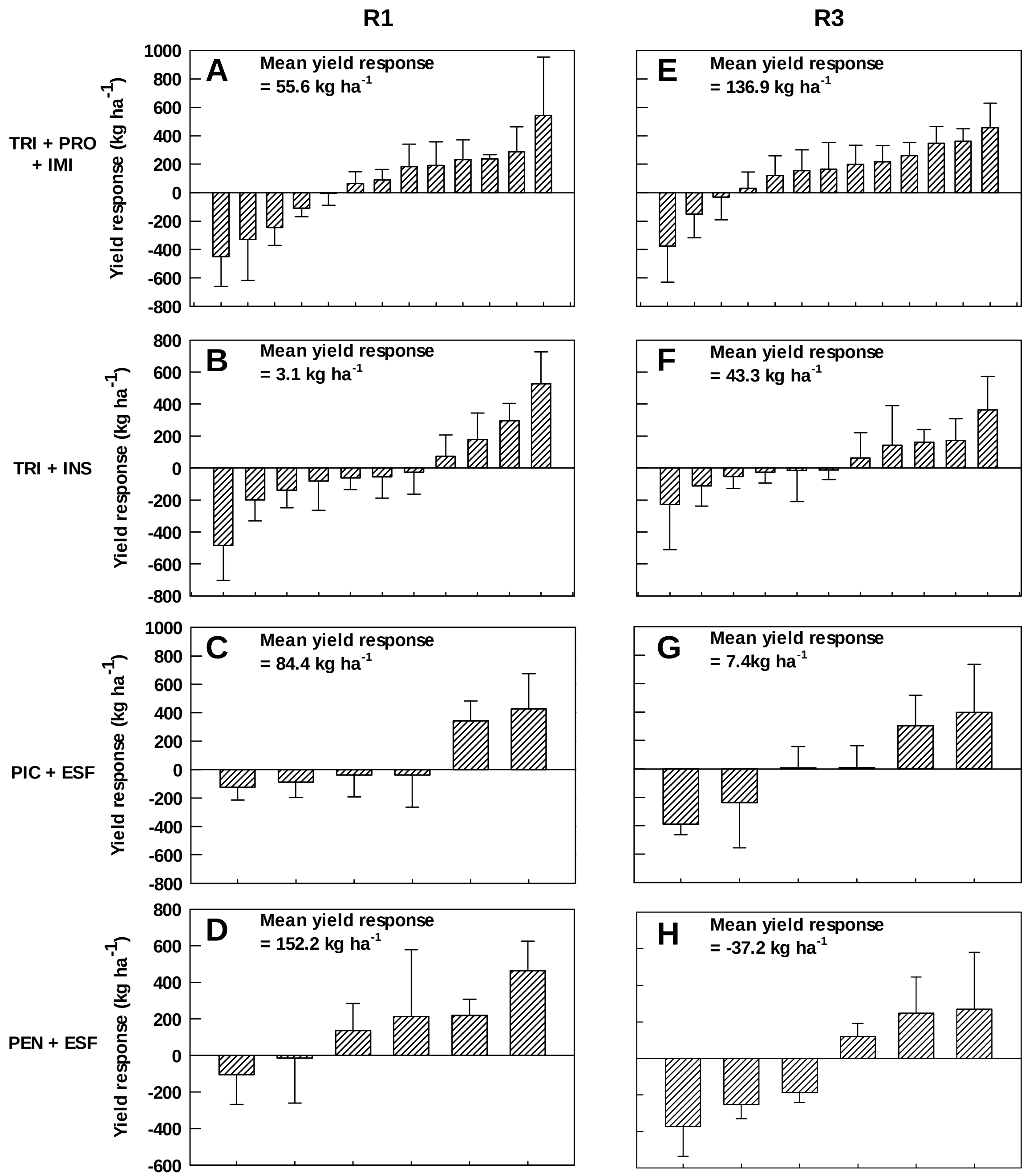

Figure 5. Yield responses of fungicides tanked mixed with insecticides against an insecticide alone at various locations across Iowa over a three year period from 2008-2010. Yield responses are reported for (**A, E**) trifloxystrobin + prothioconazole +imidicloprid (TRI + PRO +IMI), (B, F) flusilazole + esfenvalerate (2008) and tetraconazole + clothianidin (2009, 2010) (TRI + INS) (**C, G**) picoxystrobin + esfenvalerate (PIC + ESF) and (**E, J**) penthiopyrad (PEN). Panels in the

same column represent fungicide applications at the same growth stage, R1 (flowering) (column 1) or R3 (podset) (column 2). Error bars show the standard error of the yield response at an individual site year. Mean yield responses are also reported for each product within each panel.

TABLES

Table 1. Locations, varieties used, and planting and pesticide application dates for fungicide-insecticide trials in Iowa during 2008, 2009 and 2010.

Location	Variety	Planting date	R1	R3 application	IPM	Harvest date
2008						
Cass Co.	DSR 3155RR	12 May	2 Jul	30 Jul	N/A	20 Oct
Floyd Co.	Asgrow 2107	17 May	13 Jul	4 Aug	29 Aug	19 Oct
Hancock Co.	Asgrow 2107	19 May	14 Jul	6 Aug	15 Aug	27 Oct
O'Brien Co.	Asgrow 2107	13 May	9 Jul	31 Jul	31 Jul	30 Sep
Washington Co.	DSR 3155RR	22 May	7 Jul	5 Aug	5 Sep	3 Oct
2009						
Adair Co.	Cherokee 1029RR2Y	19 May	15 Jul	31 Jul	N/A	3 Nov
Floyd Co.	Navaho 720RR	20 May	16 Jul	29 Jul	22 Aug	2 Nov
O'Brien Co.	Navaho 720RR	14 May	13 Jul	28 Jul	14 Aug	27 Oct
Story Co.	Navaho 720RR	22 May	15 Jul	27 Jul	13 Aug	13 Oct
Washington Co.	Cherokee 1029RR2Y	21 May	17 Jul	30 Jul	N/A	28 Oct

[z]R1 and R3 applications were timed based on the growth stage of soybean. Growth stage R1 is at bloom and growth stage R3 is at pod set (Fehr and Caviness, 1978).
[y]IPM applications of insecticides were timed based on an economic threshold of 250 aphids plants^{-1} (Ragsdale et al., 2007).
N/A = no application.

Table1 (continued)

Location	**Variety**	**Planting date**	**R1**	**R3 application**	**IPM**	**Harvest date**
2010						
Floyd Co.	AG2430	19 May	6 Jul	28 Jul	N/A	6 Oct
O'Brien Co.	AG2430	17 May	6 Jul	28 Jul	N/A	6 Oct
Story Co.	AG2430	19 May	7 Jul	21 Jul	N/A	13 Oct

Table 2. Fungicide and insecticide treatments applied to soybean in 2008, 2009, and 2010 across several locations in Iowa.

Active ingredient(s)	Trade name	Rate (mL ha^{-1})	Pesticide	Class(es)	Year used		
					2008	2009	2010
picoxystrobin	Aproach®[x]	438	Fungicide	Strobilurin	X	X	X[y]
pycraclostrobin	Headline®[w]	438	Fungicide	Strobilurin	X	X	X[y]
flusilazole	Punch®[x]	292	Fungicide	Triazole	X	---	---
tetraconazole	Domark®[v]	292	Fungicide	Triazole	---	X	X[y]
trifloxystrobin + prothioconazole	Stratego® YLD[u]	292	Fungicide	Strobilurin + triazole	X	X	X
penthiopyrad	Vertisan®[x]	1168	Fungicide	Carboximide	---	X	X[y]
clothianidin	Belay®[v]	219	Insecticide	Neonicotinoid	---	X	X[y]
imidacloprid	Leverage®[u]	275	Insecticide	Neonicotinoid	X	X	X
esfenvalerate	Asana®[x]	702	Insecticide	Pyrethroid	X	X	X[y]

[z] Syngenta Crop Protection, Greensboro, NC
[y] Products were used at the Ames location only in 2010.
[x] Du Pont Crop Protection, Wilmington, DE
[w] BASF Crop Protection, Beaumont, TX
[v] Valent, Walnut Creek, CA
[u] Bayer CropScience Research Triangle Park, NC

Table 3. Septoria brown spot severity in the lower canopy of soybean plots treated with various pesticides at five locations across Iowa in 2008.

	Septoria brown spot severity (%)[z]									
	Cass Co.		**Floyd Co.**		**Hancock Co.**		**O'Brien Co.**		**Washington Co.**	
Treatment[y]	**R1[x]**	**R3**	**R1**	**R3**	**R1**	**R3**	**R1**	**R3**	**R1**	**R3**
PIC	3.0 a-e	1.9 de	10.8 ab	5.1 e-h	6.9 a-c	8.3 a	5.6 a-d	4.5 b-e	6.2	5.3
PYR	1.9 de	2.3 c-e	2.6 h	4.5 e-h	2.7 de	5.5 b-d	3.6 c-e	6.4 a-c	6.7	3.6
FLU	3.4 a-e	5.0 a	7.0 c-f	6.2 d-g	7.7 ab	7.1 a-c	6.9 ab	6.6 ab	5.6	7.9
TRI + PRO	2.2 c-e	4.0 a-d	4.5 f-h	4.3 gh	1.9 e	6.2 a-c	4.2 b-e	4.1 b-e	5.3	3.2
ESF	3.6 a-e	3.4 a-e	8.9 b-d	7.2 c-e	7.1 a-c	7.0 a-c	5.3a-e	5.1 a-e	5.8	6.5
IMI	4.4 a-c	1.9 de	9.1 bc	8.2 b-d	7.1 a-c	6.0 a-c	7.7 a	5.3a-e	9.3	5.4
FLU + ESF	3.7 a-e	2.6 b-e	8.6 b-d	6.4 c-g	8.4 a	6.3 a-c	7.6 a	5.1 a-e	5.9	9.3
TRI +PRO + IMI	2.4 b-e	1.5 e	2.6 h	4.9 e-h	1.0 e	4.8 cd	3.3 de	2.5 e	5.2	4.7
IPM	4.6 ab		10.1 ab		8.0 ab		5.4 a-e		9.5	
CON	4.2 a-c		12.0 a		8.7 a		7.4 a		7.9	
$LSD_{(0.05)}$[w]	2.2		2.7		2.8		2.9		NS	

[z]Mean of severity is from10 visually assessed leaflets in the lower canopy of each plot at R5 to R6.
[y]PIC=picoxystrobin (Approach®, Du Pont Crop Protection, Wilmington, DE), PYR=pyraclostrobin (Headline®, BASF Crop Protection, Beaumont, TX), FLU=flusilazole (Punch®, Du Pont Crop Protection, Wilmington, DE), TRI +PRO = trifloxystrobin + prothioconazole (Stratego® YLD, Bayer CropScience, Research Triangle Park, NC), ESF=esfenvalerate (Asana®, Du Pont Crop Protection, Wilmington, DE), IMI=imidicloprid (Leverage®, Bayer CropScience, Research Triangle Park, NC), IPM=integrated pest management (only sprayed aphids exceed economic threshold), CON=untreated control.

[x]Growth stage R1 is the beginning of flowering; growth stage R3 is the beginning of pod set.
[w]Least significant difference between means within columns under the same location heading when alpha =0.05.

Table 4. Septoria brown spot severity in the lower canopy of soybean plots treated with various pesticides applied at growth stage R1 or R3 at five locations across Iowa in 2009.

	Septoria brown spot severity (%)[z]									
	Adair Co.		Floyd Co.		O'Brien Co.		Story Co.		Washington Co.	
Treatment[y]	R1[x]	R3[x]	R1	R3	R1	R3	R1	R3	R1	R3
PIC	2.3	2.5	2.6 e-k	5.1 a-b	5.3 c-e	4.6 c-h	4.7 b-g	7.2 a-c	1.5	1.3
PYR	3.3	2.1	1.2 g-k	2.4 e-k	2.0 g-i	2.0 hi	2.5 fg	4.5 b-g	1.1	1.0
TET	2.5	2.9	2.8 d-j	3.7 c-g	5.4c-e	5.8 c-e	5.5 a-f	4.0 c-g	1.1	0.9
TRI + PRO	1.1	2.1	0.8 k	1.6 h-k	3.9 d-i	4.0 c-i	3.8 d-g	3.8 d-g	1.0	2.1
PEN	1.9	2.5	1.8 h-k	4.3 b-e	3.5 e-i	3.4 e-i	4.1 c-g	4.0 c-g	1.1	1.9
CLO	2.5	2.9	3.5 c-h	5.1 a-c	9.2 a	4.9 c-f	7.0 a-d	4.7 b-g	3.5	2.3
ESF	3.3	1.4	4.5 b-d	4.9 a-c	4.6 c-g	6.9 a-c	7.2 a-c	8.2 a	2.8	1.5
IMI	2.7	3.0	4.1 b-f	4.9 a-b	5.4c-e	6.3 b-d	6.1 a-e	7.4 ab	2.8	1.7

[z]Brown spot severity is visually estimated as percent diseased area of 10 leaflets in each plot at R5-R6.
[y]PIC=picoxystrobin (Approach®, Du Pont Crop Protection, Wilmington, DE), PYR=pyraclostrobin (Headline®, BASF Crop Protection, Beaumont, TX), TET=tetraconazole (Domark®, Valent, Walnut Creek, CA), TRI +PRO = trifloxystrobin + prothioconazole (Stratego® YLD, Bayer CropScience, Research Triangle Park, NC), PEN=penthiopyrad (Vertisan®, Du Pont, Wilmington, DE), CLO=clothianidin (Belay®, Valent, Walnut Creek, CA), ESF=esfenvalerate (Asana®, Du Pont Crop Protection, Wilmington, DE), IMI=imidicloprid (Leverage®, Bayer CropScience, Research Triangle Park, NC), IPM=integrated pest management (only sprayed aphids exceed economic threshold), CON=untreated control.
[x]Growth stage R1 is the beginning of flowering; growth stage R3 is the beginning of pod set.
[w]Least significant difference between means within the same column when alpha = 0.05.

Table 4 (continued)

	Septoria brown spot severity (%)[z]									
	Adair Co.		**Floyd Co.**		**O'Brien Co.**		**Story Co.**		**Washington Co.**	
Treatment[y]	**R1[x]**	**R3[x]**	**R1**	**R3**	**R1**	**R3**	**R1**	**R3**	**R1**	**R3**
PIC + ESF	2.2	1.7	1.5 i-j	3.4 c-i	3.4 e-i	2.6 f-i	3.9 e-g	3.5 e-g	2.1	1.6
PYR + ESF	---	1.8	---	1.5 jk	---	2.0 hi	---	1.7 g	---	1.6
TET + CLO	4.8	3.7	2.8 d-j	3.3 c-j	4.3 c-i	4.9 c-f	5.7 a-f	4.2 a-g	2.2	3.2
TRI + PRO + IMI	2.3	1.1	0.8 k	2.2 f-k	1.9 i	2.4 f-i	4.0 c-g	3.4 e-g	0.8	1.5
PEN + ESF	1.4	3.0	4.3 b-e	3.4 c-i	5.5 c-e	4.0 d-i	5.6 a-f	6.4 a-e	1.5	1.4
IPM	2.1		6.5 a		5.2 c-e		4.9 a-g		2.9	
CON	2.8		5.9 ab		8.6 ab		8.1 a		2.3	
$LSD_{(0.05)}$[w]	NS		1.9		2.6		3.3		NS	

Table 5. Septoria brown spot severity in the lower canopy of soybean plots treated with various pesticides applied at growth stage R1 or R3 at three locations across Iowa in 2010.

	Septoria brown spot severity (%)[z]					
	Floyd Co.		O'Brien Co.		Story Co.	
Treatment	R1[x]	R3	R1	R3	R1	R3
PIC	---	---	---	---	14.1 a	7.0 c-h
PYR	---	---	---	---	3.9 e-h	1.5 h
TET	---	---	---	---	7.1 c-g	9.4 a-e
TRI + PRO	4.8	4.5	3.9 c	3.2 c	2.4 gh	2.0 gh
PEN	---	---	---	---	7.9 b-f	5.8 c-h
CLO	---	---	---	---	13.2 ab	8.4 b-e
ESF	---	---	---	---	6.2 ab	5.7 c-h
IMI	7.8	2.3	3.1 c	5.4 bc	4.9 d-h	8.6 a-e
PIC + ESF	---	---	---	---	11.0 a-c	8.5 c-e
TET + CLO	---	---	---	---	6.5 c-h	5.0 d-h
TRI + PRO + IMI	5.7	7.2	4.3 c	3.9 c	2.4 gh	4.8 d-h
PEN + ESF	---	---	---	---	7.5 c-g	5.2 d-h
IPM	8.3		8.7 ab		9.8 a-d	
CON	6.9		9.7 a		7.6 c-g	
$LSD_{(0.05)}$[w]	NS		4.5		5.5	

[z]Septoria brown spot severity is visually estimated as percent diseased area of 10 leaflets in each plot between R5 and R6.
[y]PIC=picoxystrobin (Approach®, Du Pont Crop Protection, Wilmington, DE), PYR=pyraclostrobin (Headline®, BASF Crop Protection, Beaumont, TX), TET=tetraconazole (Domark®, Valent, Walnut Creek, CA), TRI +PRO = trifloxystrobin + prothioconazole (Stratego® YLD, Bayer CropScience, Research Triangle Park, NC), PEN=penthiopyrad (Vertisan®, Du Pont, Wilmington, DE), CLO=clothianidin (Belay®, Valent, Walnut Creek, CA), ESF=esfenvalerate (Asana®, Du Pont Crop Protection, Wilmington, DE), IMI=imidicloprid (Leverage®, Bayer CropScience, Research Triangle Park, NC), IPM=integrated pest management (only sprayed aphids exceed economic threshold), CON=untreated control.
[x]Growth stage R1 is the beginning of flowering; growth stage R3 is the beginning of pod set.
[w]Least significant difference between means under the same location when alpha = 0.05.

Table 6. Yield of soybean treated with a combination of fungicides, insecticides, or both at different application timings (R1 and R3) and plots not treated with pesticides (UTC). *P* > F values from one-way ANOVAs comparing pesticides against each other and the UTC at five locations across Iowa in 2008.

ANOVA source of variation[z]	**Cass Co.**	**Floyd Co.**	**Hancock Co.**	**O'Brien Co.**	**Washington Co.**
R1 vs. R3	0.0088	<0.0001	0.1312	<0.0001	<0.0001
Fungicide R1 vs. R3	0.6505	0.5584	0.9938	0.0789	0.0042
Insecticide R1 vs. R3	0.1225	<0.0001	0.1337	<0.0001	0.0021
Tank mix R1 vs. R3	0.0022	<0.0001	0.1314	<0.0001	<0.0001
Fungicide vs. UTC	0.4303	0.0258	0.1176	0.0716	0.1164
Fungicide R1 vs. UTC	0.5447	0.0521	0.1380	0.2452	0.5676
Fungicide R3 vs. UTC	0.3731	0.0218	0.1367	0.0245	0.0170
Insecticide vs. UTC	0.0659	<0.0001	0.0069	<0.0001	0.2325
Insecticide R1 vs. UTC	0.2894	0.0001	0.0597	<0.0001	0.8417
Insecticide R3 vs. UTC	0.0220	<0.0001	0.0023	<0.0001	0.0188
Tank mix vs. UTC	0.0725	<0.0001	0.0002	<0.0001	0.0005
Tank mix R1 vs. UTC	0.7158	0.0002	0.0047	<0.0001	0.1561
Tank mix R3 vs. UTC	0.0042	<0.0001	<0.0001	<0.0001	<0.0001

[z]R1 and R3 denote the growth stage a pesticide was applied and is based on the growth stages described by Fehr and Caviness. Growth stage R1 is when flowering occurs and growth stage R3 is when pod set formation occurs.

Table 6. (continued)

ANOVA source of variation[z]	Cass Co.	Floyd Co.	Hancock Co.	O'Brien Co.	Washington Co.
Fungicide vs. insecticide	0.0454	<0.0001	0.0230	<0.0001	0.5826
Fungicide vs. insecticide (R1)	0.4715	0.0016	0.4459	<0.0001	0.3087
Fungicide vs. insecticide (R3)	0.0344	<0.0001	0.0141	<0.0001	0.8079
Fungicide vs. tank mix	0.0545	<0.0001	<0.0001	<0.0001	0.0002
Fungicide vs. tank mix (R1)	0.7888	0.0029	0.0322	<0.0001	0.2031
Fungicide vs. tank mix (R3)	0.0034	<0.0001	0.0002	<0.0001	<0.0001
Insecticide vs. tank mix	0.9440	0.7572	0.0864	0.1385	0.0003
Insecticide vs. tank mix (R1)	0.3928	0.8641	0.2250	0.1682	0.0489
Insecticide vs. tank mix (R3)	0.4498	0.5433	0.2216	0.4698	0.0012
Strobilurin a.i.s. vs triazole	0.5061	0.1583	0.1257	0.3704	0.9795
Strobilurin alone vs. triazole	0.8964	0.2248	0.0575	0.5393	0.4606

Table 7. Yield of soybean treated with a combination of fungicides, insecticides, or both at different application timings (R1 and R3) and plots not treated with pesticides (UTC). *P* > F values from one-way ANOVAs comparing pesticides against each other and the UTC at five locations across Iowa in 2009.

ANOVA source of variation	**Adair Co.**	**Floyd Co.**	**O'Brien Co.**	**Story Co.**	**Washington Co.**
R1 vs. R3	0.0037	0.9058	0.9537	0.4692	0.0563
Fungicide R1 vs. R3	0.0003	0.0164	0.1425	0.1026	0.5864
Insecticide R1 vs. R3	0.1858	<.0001	0.1206	0.2655	0.1039
Tank mix R1 vs. R3	0.0407	0.0295	0.9497	0.5225	0.1970
Fungicide vs. UTC	0.7545	0.2850	0.1399	0.3063	0.8111
Fungicide R1 vs. UTC	0.4420	0.0860	0.0669	0.6118	0.9428
Fungicide R3 vs. UTC	0.1726	0.7449	0.3211	0.1474	0.6996
Insecticide vs. UTC	0.4022	0.0630	0.6534	0.4528	0.9738
Insecticide R1 vs. UTC	0.7525	0.8231	0.8958	0.2735	0.5431
Insecticide R3 vs. UTC	0.2112	0.0003	0.3322	0.7578	0.5845
Tank mix vs. UTC	0.3235	0.2216	0.3461	0.2481	0.7054
Tank Mix R1 vs. UTC	0.0914	0.0616	0.4144	0.3283	0.4080
Tank mix R3 vs. UTC	0.7433	0.5575	0.3342	0.2292	0.9828

[z]R1 and R3 denote the growth stage a pesticide was applied and is based on the growth stages described by Fehr and Caviness. Growth stage R1 is when flowering occurs and growth stage R3 is when pod set formation occurs.

Table 7. (continued)

ANOVA source of variation	Adair Co.	Floyd Co.	O'Brien Co.	Story Co.	Washington Co.
Fungicide vs. insecticide	0.0180	0.0838	0.0399	0.6099	0.5797
Fungicide vs. insecticide (R1)	0.5123	0.0038	0.0034	0.3309	0.2858
Fungicide vs. insecticide (R3)	<0.0001	<0.0001	0.9641	0.0920	0.7749
Fungicide vs. tank mix	0.0033	0.7143	0.2244	0.7516	0.1592
Fungicide vs. tank mix (R1)	0.1178	0.7515	0.1007	0.4224	0.1358
Fungicide vs. tank mix (R3)	0.0038	0.6509	0.9633	0.6658	0.5282
Insecticide vs. tank mix	0.7956	0.1678	0.3344	0.4383	0.4913
Insecticide vs. tank mix (R1)	0.0463	0.0024	0.1647	0.8213	0.7697
Insecticide vs. tank mix (R3)	0.1375	<0.0001	0.9324	0.1879	0.4056
Strobilurin a.i.s. vs. triazole alone	0.0587	0.1479	0.0533	0.0045	0.0500
Strobilurn alone vs triazole alone	0.2409	0.1953	0.0202	0.6053	0.3787

Table 8. Yield of soybean treated with a combination of fungicides, insecticides, or both at different application timings (R1 and R3) and plots not treated with pesticides (UTC). *P* > F values from one-way ANOVAs comparing pesticides against each other and the UTC at five locations across Iowa in 2010.

ANOVA source of variation	**Floyd Co.**	**O'Brien Co.**	**Story Co.**
R1 vs. R3	0.0460	0.0026	0.1065
Fungicide R1 vs. R3	0.3029	0.1237	0.1022
Insecticide R1 vs. R3	0.0126	0.6752	0.5881
Tank mix R1 vs. R3	0.9302	0.0009	0.6032
Fungicide vs. UTC	0.5127	0.3760	0.0004
Fungicide R1 vs. UTC	0.9251	0.9171	0.0210
Fungicide R3 vs. UTC	0.2618	0.1013	<.0001
Insecticide vs. UTC	0.5101	0.0656	0.1954
Insecticide R1 vs. UTC	0.4695	0.1609	0.4396
Insecticide R3 vs. UTC	0.0672	0.0716	0.1691
Tank mix vs. UTC	0.3233	0.2099	0.0709
Tank Mix R1 vs. UTC	0.3682	0.4987	0.2056
Tank mix R3 vs. UTC	0.4160	0.0062	0.0707
Fungicide vs. insecticide	0.9542	0.2962	0.0208
Fungicide vs. insecticide (R1)	0.4143	0.1931	0.2149
Fungicide vs. insecticide (R3)	0.4617	0.8634	0.0406
Fungicide vs. tank mix	0.7260	0.7653	0.0456
Fungicide vs. tank mix (R1)	0.4197	0.4357	0.3548
Fungicide vs. tank mix (R3)	0.7534	0.2324	0.0550
Insecticide vs. tank mix	0.6835	0.4530	0.6449
Insecticide vs. tank mix (R1)	0.1088	0.0411	0.7078

[z]R1 and R3 denote the growth stage a pesticide was applied and is based on the growth stages described by Fehr and Caviness. Growth stage R1 is when flowering occurs and growth stage R3 is when pod set formation occurs.

Table 8. (continued)

ANOVA source of variation	**Floyd Co.**	**O'Brien Co.**	**Story Co.**
Insecticide vs. tank mix (R3)	0.2957	0.3049	0.7818
Strobilurin a.i.s. vs. triazole alone	---	---	0.0037
Strobilurn alone vs triazole alone	---	---	0.0145

Table 9. Mean soybean yield for various fungicide and/or insecticide treatments applied at growth stage R1 or R3 in 2008 at five locations in Iowa.

	Yield (kg ha^{-1})[z]									
	Cass Co.		**Floyd Co.**		**Hancock Co.**		**O'Brien Co.**		**Washington Co.**	
Treatment[y]	**R1**[x]	**R3**	**R1**	**R3**	**R1**	**R3**	**R1**	**R3**	**R1**	**R3**
PIC	3249 ed	3252 ed	3374 ef	3447 d-f	3422 c-f	3422 c-f	2504 de	2422 e	4595 c-g	4672 b-f
PYR	3382 a-e	3374 a-e	3479 c-f	3589 c-e	3722 a-d	3587 a-f	2513 de	2885 c	4497 f-h	4787 ab
FLU	3255 ed	3352 b-e	3385 ef	3367 ef	3326 d-f	3195 ef	2594 de	2565 de	4559 d-h	4617 c-g
TRI + PRO	3422 a-d	3453 a-d	3508 c-e	3494 c-e	3202 ef	3471 c-f	2577 de	2702 cd	4594 c-g	4594 c-g
ESF	3442 a-d	3460 a-d	3725 c	4109 ab	3638 a-e	3888 a-c	3266 b	3805 a	4409 gh	4730 b-d
IMI	3331 c-e	3611 ab	3656 cd	4181 ab	3418 d-f	3673 a-d	3260 b	3720 a	4464 f-h	4638 c-f
FLU + ESF	3388 a-e	3634 a	3699 cd	4056 b	3501 b-f	3951 ab	3445 b	3789 a	4483 e-h	4890 ab
TRI +PRO + IMI	3222 ed	3581 a-c	3661 cd	4356 a	3963 ab	4020 a	3349 b	3875 a	4701 b-e	5001 a
IPM	3147 e		3557 c-e		3564 a-f		3813 a		4414 gh	
CON	3262 ed		3236 f		3139 f		2396 e		4456 f-h	
$LSD_{(0.05)}$[w]	268		256		468		272		218	

[z]Yields were standardized to 13% moisture for comparisons.
[y]PIC=picoxystrobin (Approach®, Du Pont Crop Protection, Wilmington, DE), PYR=pyraclostrobin (Headline®, BASF Crop Protection, Beaumont, TX), FLU=flusilazole (Punch®, Du Pont Crop Protection, Wilmington, DE), TRI +PRO = trifloxystrobin + prothioconazole (Stratego® YLD, Bayer CropScience, Research Triangle Park, NC), ESF=esfenvalerate (Asana®, Du Pont Crop Protection, Wilmington, DE), IMI=imidicloprid (Leverage®, Bayer CropScience, Research Triangle Park, NC), IPM=integrated pest management (only sprayed aphids exceed economic threshold), CON=untreated control.

[x]Growth stage R1 is the beginning of flowering; growth stage R3 is the beginning of pod set.
[w]Least significant difference between means within the same column when alpha = 0.05

Table 10. Mean soybean yields for various fungicide and/or insecticide treatments applied at growth stage R1 or R3 in 2009 at 5 locations in Iowa.

Treatment	Yield (kg ha^{-1})[z]									
	Adair Co.		Floyd Co.		O'Brien Co.		Story Co.		Washington Co.	
	R1[y]	R3[x]	R1	R3	R1	R3	R1	R3	R1	R3
PIC	4542 e-i	4451 f-i	3875	4053	3874 a-g	4364 a	3986 e-h	3907 f-h	3876	3805
PYR	4710 b-f	4888 a-c	4155	4189	4193 a-c	3894 a-g	3926 f-h	4212 d-f	3854	3928
TET	4589 e-g	4622 c-g	3989	3829	3887 a-g	3942 a-g	3700 ij	3796 gh	3806	3908
TRI + PRO	4580 d-h	4589 d-g	4204	4159	3720 c-g	3839 b-g	3766 gh	4040 e-g	3942	4009
PEN	4582 d-h	4377 g-i	4024	4034	4229 ab	3467 fg	4038 e-g	4030 e-g	3989	3754
CLO	4260 i	4564 e-h	4115	3982	3443 g	3979 a-e	3408 hi	3806 gh	3989	3948
ESF	4859 a-d	4818 a-e	3722	4167	3789 b-g	3789 b-f	4311 c-e	4458 b-d	3595	3992
IMI	4586 d-g	4775 a-e	4495	3942	4012 a-e	3965 a-f	4310 c-e	4536 b-d	3793	3900

[z]Yields were standardized to 13% moisture for comparisons.
[y]PIC=picoxystrobin (Approach®, Du Pont Crop Protection, Wilmington, DE), PYR=pyraclostrobin (Headline®, BASF Crop Protection, Beaumont, TX), TET=tetraconazole (Domark®, Valent, Walnut Creek, CA), TRI +PRO = trifloxystrobin + prothioconazole (Stratego® YLD, Bayer CropScience, Research Triangle Park, NC), PEN=penthiopyrad (Vertisan®, Du Pont, Wilmington, DE), CLO=clothianidin (Belay®, Valent, Walnut Creek, CA), ESF=esfenvalerate (Asana®, Du Pont Crop Protection, Wilmington, DE), IMI=imidicloprid (Leverage®, Bayer CropScience, Research Triangle Park, NC), IPM=integrated pest management (only sprayed aphids exceed economic threshold), CON=untreated control.
[x]Growth stage R1 is the beginning of flowering; growth stage R3 is the beginning of pod set.
[w]Least significant difference between means within the same column when alpha = 0.05.

Table 10. (continued)

Treatment	Yield (kg ha^{-1})^{z}									
	Adair Co.		Floyd Co.		O'Brien Co.		Story Co.		Washington Co.	
	R1[y]	R3[x]	R1	R3	R1	R3	R1	R3	R1	R3
PIC + ESF	4735 b-f	4826 a-e	3685	3930	4216 a-c	4109 a-d	4221 d-f	4762 b	3937	4000
PYR + ESF	---	4797 a-e	---	3769	---	4208 a-c	---	5186 a	---	3956
TET + CLO	4557 e-h	4555 e-h	3631	3757	3970 a-f	4122 a-c	3327 j	3781	3791	3838
TRI + PRO + IMI	4770 a-e	5035 a	4046	4197	3683 d-g	3589 e-g	4376 cd	4735 b	3987	3935
PEN + ESF	4757 a-e	4938 ab	4187	3794	4001a-e	3981 a-e	4447 b-d	4705 b	3814	3805
IPM	4293 hi		3972		4076 a-e		4564 bc		3622	
CON	4564 e-h		3940		3918 a-g		3878 gh		3905	
$LSD_{(0.05)}$[w]	291		NS		506		325		NS	

Table 11. Mean soybean yield for which various fungicide and/or insecticide treatments were applied at growth stage R1 or R3 in 2010 at 3 locations in Iowa.

	Yield (kg ha^{-1})^{z}					
	Floyd Co.		O'Brien Co.		Story Co.	
Treatment	R1[y]	R3[x]	R1	R3	R1	R3
PIC	---	---	---	---	4613 a-f	4639 a-e
PYR	---	---	---	---	4678 a-d	4798 a
TET	---	---	---	---	4323 fg	4468 b-g
TRI + PRO	3429	3584	3762 b-d	3924 a-c	4767 ab	4835 a
PEN	---	---	---	---	4328 fg	4538 a-g
CLO	---	---	---	---	4454 c-f	4276 g
ESF	---	---	---	---	4396 d-g	4646 a-e
IMI	3311	3584	3915 a-c	3964 ab	4470 b-g	4547 a-g
PIC + ESF	---	---	---	---	4358 e-g	4258 g
TET + CLO	---	---	---	---	4393 d-g	4639 a-e
TRI + PRO + IMI	3545	3532	3671 d	4084 a	4756 a-c	4764 ab
PEN + ESF	---	---	---	---	4381 d-g	4393 d-g
IPM	3357		3720 cd		4395 d-g	
CON	3515		3750 b-d		4376 d-g	
$LSD_{(0.05)}$[w]	NS		224		306	

[z]Yields were standardized to 13% moisture for comparisons.
[y]PIC=picoxystrobin (Approach®, Du Pont Crop Protection, Wilmington, DE), PYR=pyraclostrobin (Headline®, BASF Crop Protection, Beaumont, TX), TET=tetraconazole (Domark®, Valent, Walnut Creek, CA), TRI +PRO = trifloxystrobin + prothioconazole (Stratego® YLD, Bayer CropScience, Research Triangle Park, NC), PEN=penthiopyrad (Vertisan®, Du Pont, Wilmington, DE), CLO=clothianidin (Belay®, Valent, Walnut Creek, CA), ESF=esfenvalerate (Asana®, Du Pont Crop Protection, Wilmington, DE), IMI=imidicloprid (Leverage®, Bayer CropScience, Research Triangle Park, NC), IPM=integrated pest management (only sprayed aphids exceed economic threshold), CON=untreated control.
[x]Growth stage R1 is the beginning of flowering; growth stage R3 is the beginning of pod set.
[w]Least significant difference between means within the same column when alpha = 0.05.

Table 12. Probability of returning a positive profit with pyraclostrobin applied via airplane at a total cost of $63.28 ha^{-1} at locations across Iowa in 2008, 2009, and 2010.

			Net return = $0/ha[y]			Net return = 50% of application cost/ha		
Timing[z]	**Location**	**Year**	**$8**	**$12**	**$16**	**$8**	**$12**	**$16**
R1	Story Co.	2009	0.117	0.247	0.335	0.027	0.117	0.209
	Story Co.	2010	0.772	0.911	0.950	0.428	0.772	0.885
	Cass Co.	2008	0.193	0.412	0.541	0.037	0.193	0.351
	Washington Co.	2008	0.084	0.207	0.297	0.015	0.084	0.169
	Washington Co.	2009	0.027	0.078	0.122	0.004	0.027	0.061
	Adair Co.	2009	0.323	0.503	0.595	0.125	0.323	0.456
	Hancock Co.	2008	0.910	0.944	0.957	0.830	0.910	0.937
	Floyd Co.	2008	0.516	0.557	0.578	0.454	0.516	0.547
	Floyd Co.	2009	0.500	0.601	0.649	0.350	0.500	0.576
	O’Brien Co.	2008	0.226	0.419	0.529	0.061	0.226	0.366
	O’Brien Co.	2009	0.590	0.692	0.738	0.427	0.590	0.667
R3	Story Co.	2009	0.807	0.915	0.947	0.536	0.807	0.894
	Story Co.	2010	0.959	0.989	0.995	0.801	0.959	0.985
	Cass Co.	2008	0.176	0.386	0.514	0.032	0.176	0.326
	Washington Co.	2008	0.821	0.930	0.960	0.525	0.821	0.910
	Washington Co.	2009	0.078	0.186	0.265	0.015	0.078	0.152
	Adair Co.	2009	0.758	0.877	0.917	0.501	0.758	0.852
	Hancock Co.	2008	0.804	0.868	0.893	0.678	0.804	0.853
	Floyd Co.	2008	0.579	0.619	0.638	0.517	0.579	0.609
	Floyd Co.	2009	0.547	0.645	0.691	0.395	0.547	0.621
	O’Brien Co.	2008	0.978	0.994	0.997	0.895	0.978	0.991
	O’Brien Co.	2009	0.183	0.263	0.309	0.096	0.183	0.241

[z]Timing is soybean growth stage-based. R1 is the beginning of flowering and R3 is the beginning of pod set.
[y]Grain pricing is based on US bushel. 1 bushel= 27.2 kg.

Table 13. The probability of returning a profit with trifloxystrobin + prothioconazole applied via airplane at a total cost of \$63.99 ha^{-1} at locations across Iowa in 2008, 2009, and 2010.

			Net return = \$0/ha[y]			Net return = 50% of application cost/ha		
Timing[z]	**Location**	**Year**	**\$8**	**\$12**	**\$16**	**\$8**	**\$12**	**\$16**
R1	Story Co.	2009	0.011	0.035	0.059	0.002	0.011	0.027
	Story Co.	2010	0.929	0.980	0.990	0.709	0.929	0.972
	Cass Co.	2008	0.299	0.551	0.676	0.069	0.299	0.486
	Washington	2008	0.010	0.037	0.065	0.001	0.010	0.027
	Washington	2009	0.090	0.208	0.294	0.018	0.090	0.172
	Adair Co.	2009	0.097	0.201	0.272	0.025	0.097	0.170
	Hancock Co.	2008	0.283	0.379	0.431	0.166	0.283	0.354
	Floyd Co.	2008	0.530	0.571	0.592	0.467	0.530	0.561
	Floyd Co.	2009	0.567	0.665	0.711	0.413	0.567	0.641
	O'Brien Co.	2008	0.389	0.608	0.709	0.134	0.389	0.554
	O'Brien Co.	2009	0.060	0.098	0.123	0.026	0.060	0.087
R3	Story Co.	2009	0.346	0.551	0.652	0.120	0.346	0.499
	Story Co.	2010	0.996	1.000	1.000	0.917	0.996	0.999
	Cass Co.	2008	0.402	0.658	0.768	0.112	0.402	0.596
	Washington	2008	0.261	0.477	0.592	0.068	0.261	0.419
	Washington	2009	0.195	0.374	0.480	0.050	0.195	0.324
	Adair Co.	2009	0.107	0.218	0.293	0.028	0.107	0.185
	Hancock Co.	2008	0.662	0.753	0.793	0.507	0.662	0.732
	Floyd Co.	2008	0.516	0.557	0.578	0.453	0.516	0.547
	Floyd Co.	2009	0.505	0.607	0.655	0.354	0.505	0.582
	O'Brien Co.	2008	0.750	0.888	0.931	0.437	0.750	0.861
	O'Brien Co.	2009	0.132	0.199	0.239	0.065	0.132	0.180

[z]Timing is soybean growth stage-based. R1 is the beginning of flowering and R3 is the beginning of pod set.
[y]Grain pricing is based on US bushel. 1 bushel= 27.2 kg

Table 14. The probability of returning a profit with triazoles (fluisazole in 2008 and tetraconazole in 2009 and 2010) applied via airplane at a total cost of $46.93 ha^{-1} at locations across Iowa in 2008, 2009, and 2010.

			Net return = $0/ha[y]			Net return = 50% of application cost/ha		
Timing[z]	**Location**	**Year**	**$8**	**$12**	**$16**	**$8**	**$12**	**$16**
R1	Story Co.	2009	0.010	0.023	0.035	0.002	0.010	0.019
	Story Co.	2010	0.036	0.087	0.128	0.008	0.036	0.071
	Cass Co.	2008	0.070	0.155	0.218	0.016	0.070	0.129
	Washington Co.	2008	0.324	0.489	0.573	0.139	0.324	0.446
	Washington Co.	2009	0.030	0.066	0.094	0.008	0.030	0.055
	Adair Co.	2009	0.190	0.297	0.359	0.084	0.190	0.268
	Hancock Co.	2008	0.540	0.617	0.653	0.423	0.540	0.598
	Floyd Co.	2008	0.494	0.525	0.540	0.448	0.494	0.517
	Floyd Co.	2009	0.347	0.419	0.456	0.249	0.347	0.401
	O’Brien Co.	2008	0.317	0.473	0.554	0.140	0.317	0.432
	O’Brien Co.	2009	0.234	0.300	0.337	0.153	0.234	0.283
R3	Story Co.	2009	0.044	0.090	0.124	0.013	0.044	0.076
	Story Co.	2010	0.280	0.451	0.542	0.104	0.280	0.406
	Cass Co.	2008	0.261	0.436	0.532	0.090	0.261	0.390
	Washington Co.	2008	0.503	0.668	0.741	0.264	0.503	0.629
	Washington Co.	2009	0.120	0.216	0.279	0.041	0.120	0.189
	Adair Co.	2009	0.255	0.376	0.443	0.121	0.255	0.344
	Hancock Co.	2008	0.351	0.426	0.465	0.250	0.351	0.407
	Floyd Co.	2008	0.484	0.514	0.529	0.438	0.484	0.507
	Floyd Co.	2009	0.168	0.219	0.248	0.108	0.168	0.206
	O’Brien Co.	2008	0.530	0.685	0.753	0.296	0.530	0.648
	O’Brien Co.	2009	0.303	0.377	0.416	0.207	0.303	0.358

[z]Timing is soybean growth stage-based. R1 is the beginning of flowering and R3 is the beginning of pod set.
[y]Grain pricing is based on US bushel. 1 bushel= 27.2 kg.

Table 15. Probability of returning a profit with pyraclostrobin applied with a ground sprayer at a total cost of \$58.39 ha^{-1} at locations across Iowa in 2008, 2009, and 2010.

			Net return = \$0/ha[y]			Net return = 50% of application cost/ha		
Timing[z]	**Location**	**Year**	**\$8**	**\$12**	**\$16**	**\$8**	**\$12**	**\$16**
R1	Story Co.	2009	0.141	0.273	0.358	0.039	0.141	0.235
	Story Co.	2010	0.813	0.925	0.957	0.514	0.813	0.904
	Cass Co.	2008	0.237	0.452	0.571	0.057	0.237	0.394
	Washington Co.	2008	0.106	0.233	0.320	0.023	0.106	0.195
	Washington Co.	2009	0.035	0.090	0.135	0.007	0.035	0.072
	Adair Co.	2009	0.363	0.532	0.616	0.161	0.363	0.489
	Hancock Co.	2008	0.919	0.948	0.960	0.852	0.919	0.942
	Floyd Co.	2008	0.526	0.564	0.582	0.469	0.526	0.554
	Floyd Co.	2009	0.524	0.616	0.660	0.384	0.524	0.593
	O'Brien Co.	2008	0.266	0.453	0.554	0.086	0.266	0.403
	O'Brien Co.	2009	0.615	0.706	0.748	0.465	0.615	0.684
R3[x]	Story Co.	2009	0.508	0.690	0.769	0.243	0.508	0.647
	Story Co.	2010	0.777	0.906	0.944	0.463	0.777	0.881
	Cass Co.	2008	0.027	0.084	0.137	0.003	0.027	0.064
	Washington Co.	2008	0.493	0.696	0.781	0.209	0.493	0.648
	Washington Co.	2009	0.013	0.038	0.061	0.002	0.013	0.029
	Adair Co.	2009	0.475	0.643	0.720	0.240	0.475	0.603
	Hancock Co.	2008	0.665	0.748	0.785	0.524	0.665	0.728
	Floyd Co.	2008	0.512	0.549	0.568	0.455	0.512	0.540
	Floyd Co.	2009	0.381	0.473	0.520	0.256	0.381	0.450
	O'Brien Co.	2008	0.881	0.952	0.971	0.668	0.881	0.939
	O'Brien Co.	2009	0.090	0.136	0.165	0.044	0.090	0.123

[z]Timing is soybean growth stage-based. R1 is the beginning of flowering and R3 is the beginning of pod set.
[y]Grain pricing is based on US bushel. 1 bushel= 27.2 kg.

[x]Driving in the field at R3 will result in yield losses estimated at 202 kg ha^{-1}.

Table 16. The probability of returning a profit with trifloxystrobin + prothioconazole applied with a ground sprayer at a total cost of \$59.05 ha^{-1} at locations across Iowa in 2008, 2009, and 2010.

			Net return = \$0/ha[y]			Net return = 50% of application cost/ha		
Timing[z]	**Location**	**Year**	**\$8**	**\$12**	**\$16**	**\$8**	**\$12**	**\$16**
R1	Story Co.	2009	0.015	0.042	0.066	0.002	0.015	0.033
	Story Co.	2010	0.946	0.984	0.992	0.778	0.946	0.978
	Cass Co.	2008	0.354	0.591	0.702	0.103	0.354	0.531
	Washington Co.	2008	0.014	0.044	0.073	0.002	0.014	0.034
	Washington Co.	2009	0.111	0.233	0.316	0.027	0.111	0.197
	Adair Co.	2009	0.116	0.221	0.291	0.035	0.116	0.191
	Hancock Co.	2008	0.304	0.395	0.443	0.190	0.304	0.372
	Floyd Co.	2008	0.539	0.577	0.596	0.482	0.539	0.568
	Floyd Co.	2009	0.590	0.679	0.721	0.448	0.590	0.658
	O’Brien Co.	2008	0.439	0.640	0.731	0.179	0.439	0.591
	O’Brien Co.	2009	0.067	0.106	0.130	0.032	0.067	0.095
R3[x]	Story Co.	2009	0.108	0.223	0.301	0.027	0.108	0.189
	Story Co.	2010	0.899	0.982	0.993	0.495	0.899	0.971
	Cass Co.	2008	0.098	0.241	0.343	0.017	0.098	0.197
	Washington Co.	2008	0.060	0.149	0.219	0.011	0.060	0.121
	Washington Co.	2009	0.044	0.109	0.162	0.008	0.044	0.088
	Adair Co.	2009	0.025	0.060	0.089	0.005	0.025	0.049
	Hancock Co.	2008	0.494	0.592	0.639	0.350	0.494	0.568
	Floyd Co.	2008	0.448	0.486	0.506	0.392	0.448	0.477
	Floyd Co.	2009	0.342	0.433	0.480	0.223	0.342	0.410
	O’Brien Co.	2008	0.410	0.613	0.707	0.161	0.410	0.563
	O’Brien Co.	2009	0.061	0.096	0.119	0.028	0.061	0.086

[z]Timing is soybean growth stage-based. R1 is the beginning of flowering and R3 is the beginning of pod set.
[y]Grain pricing is based on US bushel. 1 bushel= 27.2 kg.
[x]Driving in the field at R3 will result in yield losses estimated at 202 kg ha^{-1}.

Table 17. The probability of returning a profit with triazoles (fluisazole in 2008 and tetraconazole in 2009 and 2010) applied with a ground sprayer at a total cost of \$41.99 ha^{-1} at locations across Iowa in 2008, 2009, and 2010.

			Net return = \$0/ha^{y}			Net return = 50% of application cost/ha		
Timing^{z}	**Location**	**Year**	**\$8**	**\$12**	**\$16**	**\$8**	**\$12**	**\$16**
R1	Story Co.	2009	0.013	0.028	0.039	0.004	0.013	0.023
	Story Co.	2010	0.049	0.103	0.143	0.013	0.049	0.086
	Cass Co.	2008	0.092	0.180	0.241	0.027	0.092	0.154
	Washington Co.	2008	0.374	0.524	0.600	0.187	0.374	0.486
	Washington Co.	2009	0.039	0.077	0.105	0.012	0.039	0.065
	Adair Co.	2009	0.221	0.322	0.379	0.111	0.221	0.295
	Hancock Co.	2008	0.565	0.632	0.665	0.460	0.565	0.616
	Floyd Co.	2008	0.504	0.531	0.545	0.463	0.504	0.524
	Floyd Co.	2009	0.369	0.435	0.468	0.278	0.369	0.418
	O’Brien Co.	2008	0.364	0.507	0.579	0.187	0.364	0.470
	O’Brien Co.	2009	0.254	0.315	0.348	0.176	0.254	0.300
R3^{x}	Story Co.	2009	0.007	0.015	0.022	0.002	0.007	0.012
	Story Co.	2010	0.058	0.120	0.165	0.016	0.058	0.101
	Cass Co.	2008	0.048	0.104	0.147	0.012	0.048	0.087
	Washington Co.	2008	0.176	0.290	0.359	0.069	0.176	0.259
	Washington Co.	2009	0.022	0.047	0.066	0.006	0.022	0.039
	Adair Co.	2009	0.080	0.134	0.169	0.033	0.080	0.118
	Hancock Co.	2008	0.208	0.261	0.290	0.142	0.208	0.247
	Floyd Co.	2008	0.417	0.444	0.457	0.377	0.417	0.437
	Floyd Co.	2009	0.086	0.114	0.131	0.054	0.086	0.107
	O’Brien Co.	2008	0.205	0.322	0.390	0.088	0.205	0.290
	O’Brien Co.	2009	0.169	0.218	0.245	0.110	0.169	0.205

[z]Timing is soybean growth stage-based. R1 is the beginning of flowering and R3 is the beginning of pod set.
[y]Grain pricing is based on US bushel. 1 bushel= 27.2 kg.
[x]Drving in the field at R3 will result in yield losses estimated at 5 US bushels ha^{-1}.

CHAPTER 3.

CONTROL OF LATE-SEASON ANTHRACNOSE STEM BLIGHT: IS IT NECESSARY IN IOWA?

A paper to be submitted to *Plant Disease*

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Abstract

Anthracnose stem blight, caused by *Colletotrichum truncatum*, is responsible for yield losses of soybean (*Glycine max*) in subtropical and tropical growing regions. There are inadequate data regarding the effect of anthracnose stem blight on yield in Iowa and if fungicides are warranted to control the disease. Field studies were conducted from 2008 to 2010 to determine the effect of fungicide application timing on late-season anthracnose stem blight severity. We also investigated the effect of anthracnose stem blight on yield and specific yield components. Fungicides were effective in reducing late-season symptoms of anthracnose stem blight when compared to the untreated control, but no impacts on yield and yield components were found. While foliar fungicides can reduce late-season anthracnose stem blight development, this disease should be a low priority when designing a crop management strategy involving foliar fungicides in Iowa.

Introduction

Anthracnose stem blight is an important disease of soybean (*Glycine max*) in commercial growing regions throughout the world and in the United States (13,18). In Iowa, the disease is primarily caused by *Colletotrichum truncatum* (Schwein) but it also can be caused by other *Colletotrichum* spp. (9). Yield loss due to anthracnose stem blight has been documented primarily in tropical or sub-tropical environments (1,2,10,18). While yield losses as high as 25% due to anthracnose stem blight have been reported in the southern United States (2), the disease has not historically impacted soybean yield in the north central United States. In Iowa, symptoms of anthracnose stem blight typically only occur as the crop begins to senesce.

Anthracnose stem blight symptoms on soybean may occur prior to physiological maturity as reddening of veins of leaves at the top of the plant, followed by necrosis of the leaf lamina, resulting in a characteristic “shepherds crook”, which is a downward turning of necrotic leaves at the top of the plant. More often, symptoms occur later in the season as soybean plants mature and senesce. Symptoms are irregular black lesions that form along the main stem and on pods. Lesions often coalesce and can cover a very large portion of the stem. Lesions on soybean pods may lead to seed infection, which can decrease seed quality. *Colletotrichum truncatum* can overwinter in infected seed or infested plant residue and some isolates can survive as microsclerotia in the soil for up to four years (12). Cultural control measures for anthracnose stem blight include crop rotation and tillage. However, crop rotation has limitations because of the broad host range of *Colletotrichum* spp. including several weeds common in soybean fields that serve as alternate hosts (9). Tillage may not be a viable management option for all growers, especially those who practice soil conservation tillage practices. The use of fungicides can be effective (1,2), and various classes of fungicides including strobilurins (quinone outside inhibitors), triazoles (sterol demethylation inhibitors), and contact fungicides are labeled for anthracnose stem blight management.

Recently, foliar fungicides have increasingly been applied to commercial soybeans for various reasons (5). Initially this increase in foliar fungicide use was due to the introduction of *Phakopspora pachyrhizi* Syd and P. Syd. (8,11,14,15). However, soybean prices have increased recently (www.nass.usda.gov), which has led to fungicides being used to reportedly improve plant health and manage other foliar diseases. Growers and agronomists in Iowa have noted less symptoms of late-season anthracnose stem blight at harvest on soybean crops that have been sprayed with foliar fungicide. Consequently, there have been questions regarding the effect of foliar fungicide applications on anthracnose stem blight and grain yield. The objectives of this research were to evaluate: (i) the effect of foliar fungicides applied at different growths stages on anthracnose stem blight severity and, (ii) the impact of late-season anthracnose stem blight development on soybean grain yield.

Materials and Methods

Fungicide field trials. Field trials were established at four locations in Iowa in 2008, four locations in 2009 and three locations in 2010. Locations, planting date, previous crop and variety are summarized in Table 1. Two fungicide products were tested: pyraclostrobin (Headline®, BASF, Florham Park, NJ) and a premix of trifloxystrobin + prothioconazole (Stratego® YLD. Bayer CropScience, Triangle Park, NC). The treatments used in this study are a subset of treatments that were used in a larger study assessing the effect of fungicide and insecticides on certain fungal diseases and yield in Iowa. Fungicides were applied using a CO_2-powered backpack sprayer system (R&D Sprayers, Opelousas, LA) calibrated to spray 187 L ha^{-1} either at growth stage R1 (beginning flowering) or R3 (beginning pod set) (6). A randomized complete block design was used with five or six replications. Plots were 10.6 to 15.2 m long and 4 to 6 rows wide (0.76 m row spacing) depending on the location.

Disease severity. Anthracnose stem blight severity was determined by estimating the percentage of total area of the main stem and all pods covered by anthracnose stem blight lesions at full maturity (R8) (6) on 20 consecutive plants in each plot. The starting point for these 20 plants was arbitrarily selected. Plot combines were used to harvest the middle two rows of each plot. Yield data were standardized to 13% moisture for comparison. A subsample of 100 seeds from each plot was also visually assessed for infection.

Yield component study. From each field location in each year, 50 to 100 plants in untreated plots were hand harvested. These plants are not representative of the overall anthracnose stem blight severity because they were specifically chosen to represent the full range of disease severity present in each field. On each plant, anthracnose stem blight severity was estimated as a percentage of lesions covering the stem and pods. The number of pods per plant, seeds per plant, seeds per pod, and seed weight were determined for each plant.

Statistical analysis. There were significant interactions between treatment and location and year for anthracnose stem blight, so each site year was analyzed separately (Table 2 and 3). Furthermore, we also analyzed each location separately because not all treatments were used at each location each year. Means from both studies were calculated using the GLM procedure in SAS (SAS Institute, Cary, NC). Means comparisons for the fungicide study were calculated using Fisher's protected least significant difference. For the field study, the relationship between yield and anthracnose stem blight severity was calculated using REG procedure in SAS for each site year. Also for the yield component study, regression analysis determined the relationship between anthracnose stem blight severity and each of the yield components collected.

Results

Fungicide field trials. Late-season (growth stage R7 to R8) anthracnose stem blight symptoms occurred on stems and pods at all locations in all years. The average anthracnose stem blight severity in the untreated control plots ranged from 6.4 to 14.7% (2008); 6.9 to 53.4% (2009); and 5.9 to 33.5% (2010). Anthracnose stem blight was most severe in the untreated control in 2009 and 2010 at sites in central and southern Iowa (Story, Adair, and Washington Counties) (range 20.5 to 53.4%) (Tables 5 and 6). Shepherds crook symptoms of anthracnose stem blight were not observed during reproductive growth stages R3 to R6 in any of the trials. Also, visual assessment of the seed showed no characteristic symptoms of *Colletotrichum* spp. seed infection during any site year of this study (data not shown).

Generally, an application of fungicide at growth stage R3 reduced percent anthracnose stem blight severity ($P < 0.0001$) when compared to the untreated control in 2008 (Table 4). Pyraclostrobin applied at R3 at locations in Washington and Floyd counties reduced anthracnose stem blight severity, while an application at R1 reduced disease at the site in Washington County but not Floyd County. Trifloxystrobin + prothioconazole reduced anthracnose stem blight severity at all locations and at both application timings, except an R1 application at the Cass County location. Applications of either fungicide product at either R1 or R3 had no effect on yield (Table 4).

In 2009, foliar fungicide applications at growth stages R1 and R3 reduced anthracnose stem blight severity compared to the control at three of five locations. At the site in Floyd

County location, applications of pyraclostrobin had no effect on anthracnose stem blight severity, but applications of trifloxystrobin + prothioconazole at both timings reduced disease compared to the control (Table 5). Apart from one treatment at one location, yield for all treatments at all locations was not affected by fungicide application. Increased yields were recorded following an application of pyraclostrobin at R3 at the site in Adair County.

In 2010, fungicides effectively reduced anthracnose stem blight disease severity levels at the Story County location, while applications of fungicide at the other locations had no effect on anthracnose stem blight severity (Table 6). Yields at the Story County site were greater with an application of pyraclostrobin at R3, or an application of trifloxystrobin + prothioconazole at either R1 or R3 compared to the control. Fungicides had no effect on yield at sites in Floyd and O'Brien counties (Table 4).

There was no significant relationship between anthracnose stem blight severity and yield at any location ($P > 0.05$), except at the trial at Story County in 2010 ($P = 0.0072$). At this location, the intercept and slope were 4924 and -13.8, respectively, with a R^2=0.23.

Yield component study. While soybean plants were purposely selected to represent a range of anthracnose stem blight severity in each field, mean anthracnose stem blight severity still varied between locations. For example, mean anthracnose stem blight severity was 56 and 9.9% in 2009 in Floyd and Adair counties, respectively (Table 7). Yield was highly dependent on the location for each year. Differences were detected in the number of pods per plant across locations. Seeds per pod were nearly identical in each year (Table 7). No negative relationships occurred between percent anthracnose stem blight severity and any of the yield components at any location in any year (Table 8).

Discussion

In our study, we found that late-season anthracnose stem blight had no effect on soybean yield in Iowa. Our results differ from those of Backman et al. (1,2) who found anthracnose stem blight did reduce soybean yields; however, this study was done was in the southern United States. Our results are consistent with a report (17) from Indiana in which a reduction in late-season stem symptoms did not result in a yield response.

Our results were consistent with observations by farmers and agribusiness professionals reporting reductions in late-season anthracnose stem blight after foliar fungicide applications. In our study, fungicides reduced late-season symptom development on soybean stems by 12-88% across the 11 site years. When broken down, there was a 27 to 74% percent reduction when fungicides were applied at growth stage R1 and a 32 to 88% reduction when applied at growth stage R3. However, we did not detect differences in reduction of anthracnose stem blight severity between the two fungicides we tested, pyraclostrobin (51% reduction across all locations) and trifloxystrobin + prothioconazole (59% reduction across all locations). Pyraclostrobin is a QoI (strobilurin) fungicide that is one of the more commonly used fungicides in Iowa, and has been linked to many of the anecdotal reports involving reduction of anthracnose stem blight with a fungicide application. The other product, trifloxystrobin + prothioconazole is a premix of two different chemical classes – strobilurin and triazole. A similar product, trifloxystrobin + propiconazole (Stratego®, Bayer CropSciences) has been linked with reduced anthracnose stem blight by farmers and agribusinesses. We did not test a triazole fungicide alone; however, *Anthracnose* spp. are listed on labels of triazole fungicides (e.g., tetraconazole, Domark®, Valent, Walnut Creek, CA). We anticipate that triazole fungicides can reduce late-season anthracnose stem blight similarly to strobilurin fungicides.

This reduction of anthracnose stem blight found across most site years, though, does not result in an added yield benefit. We found no relationship between anthracnose stem blight severity and yield response in the fungicide studies. We also so no relationship between anthracnose stem blight and yield components. Reduction of anthracnose stem blight late during grain fill does not affect yield potential. Soybean yield is mostly determined between growth stages R1 (beginning flowering) and R6 (full seed), and consequentially stressors have the most impact when they occur during those stages, especially between R3 (beginning pod set) and R6 when seed fill is occurring (16). Anthracnose stem blight symptoms in Iowa usually occur on maturing plants at growth stage R7 (full maturity), which is after yield is determined.

Early-season symptoms of anthracnose stem blight are not common in Iowa. Although we found a significant relationship between the reduction of anthracnose stem blight and yield at the trial in Story County in 2010, no “shepherds crook” symptoms indicating development of anthracnose stem blight earlier in the reproductive growth stages occurred. Septoria brown spot was associated with yield loss using regression analysis of plots at elevated severity levels (3). The reason for the rare occurrence of early-season anthracnose stem blight symptoms in Iowa is not known but it is possible that early season environmental conditions in this state may not be conducive for infection and/or early disease development of anthracnose stem blight. Anthracnose disease development is favored during periods of frequent rain and warm temperatures. Furthermore, in order for *C. truncatum* to cause severe symptoms, infection early in the reproductive growth stages may be necessary. Lastly, since virulence between *C. truncatum* and other *Colletotrichum* spp. populations vary in other agrisystems (4,7), it could be that the population of *C. truncatum* in Iowa is not as virulent as it is in the Southern states.

From this study, farmers in Iowa should not have to consider late-season anthracnose stem blight when designing a crop management strategy. While a number of fungicides are labeled for anthracnose stem blight management and are effective at reducing severity on soybean, the results of this study indicate that a fungicide application for late-season anthracnose stem blight control in Iowa is not warranted. These fungicide products, however, are labeled for numerous other diseases of soybean including Septoria brown spot (*Septoria glycines* Hemmi), frogeye leaf spot (*Cercospora sojina* Hara) and Cercospora leaf blight (*Cercospora kikuchii* (T. Matsu. & Tomoyasu) Gardener)), and all have the potential to reduce soybean yields in the Midwest (5,18). Consequently an application of fungicide may be necessary in some years to protect yield. Although we found late-season development of anthracnose stem blight did not impact yield in this study, given the proper environmental conditions and if disease gets established earlier in the growing season, anthracnose stem blight can possibly reduce soybean yield (1,2,13,18).

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Table 1. Locations, soybean varieties used, and planting and pesticide application dates for fungicide trials in Iowa during 2008, 2009 and 2010.

Year, Location	Variety	Planting date	R1 application[z] date	R3 application date	Harvest date
2008					
Cass Co.	DSR[y] 3155RR	12 May	2 Jul	30 Jul	20 Oct
Floyd Co.	Asgrow 2107	17 May	13 Jul	4 Aug	19 Oct
O'Brien Co.	Asgrow 2107	13 May	9 Jul	31 Jul	30 Sep
Washington Co.	DSR 3155RR	22 May	7 Jul	5 Aug	3 Oct
2009					
Adair Co.	Cherokee 1029RR2Y	19 May	15 Jul	31 Jul	3 Nov
Floyd Co.	Navaho 720RR	20 May	16 Jul	29 Jul	2 Nov
Story Co.	Navaho 720RR	22 May	15 Jul	27 Jul	13 Oct
Washington Co.	Cherokee 1029RR2Y	21 May	17 Jul	30 Jul	28 Oct
2010					
Floyd Co.	Asgrow430	19 May	6 Jul	28 Jul	6 Oct
O'Brien Co.	Asgrow2430	17 May	6 Jul	28 Jul	6 Oct
Story Co.	Asgrow2430	19 May	7 Jul	21 Jul	13 Oct

[z]R1 and R3 applications were timed based on the growth stage of soybean. Growth stage R1 is at bloom and growth stage R3 is at pod set (Fehr and Caviness, 1978).
[y]DSR = Dairyland Seed Research.

Table 2. Analysis of variance (ANOVA) for main effects of year, location, treatment and their interactions with anthracnose stem blight severity and yield from data collected from fungicide-insecticide trials conducted across Iowa in 2008, 2009 and 2010.

Source of variation	**DF**	**F-value**	***P* > F**
Anthracnose stem blight severity			
Treatment	4	23.10	<0.0001
Year	2	25.54	<0.0001
Location	5	16.82	<0.0001
Treatment*Year	8	1.44	0.1808
Treatment*Location	18	2.28	0.0029
Yield			
Treatment	4	2.07	0.0857
Year	2	28.45	<0.0001
Location	5	30.28	<0.0001
Treatment*Year	8	1.18	0.3114
Treatment*Location	18	1.70	0.0404

Table 3. Analysis of variance (ANOVA) for main effects of treatment, location and their interactions on anthracnose stem blight severity[z] and yield[y] from data collected from fungicide trials conducted across Iowa in 2008, 2009, and 2010.

	2008			2009			2010		
Source	**DF**	**F-value**	***P* > F**	**DF**	**F-value**	***P* > F**	**DF**	**F-value**	***P* > F**
Anthracnose stem									
Treatment	4	23.87	<0.0001	4	29.85	<0.0001	4	7.01	0.0001
Location	3	11.49	<0.0001	4	29.85	<0.0001	2	30.52	<0.0001
Treatment*Location	8	2.16	0.0414	16	2.66	0.0045	4	4.54	0.0031
Yield									
Treatment	4	2.31	0.0671	4	1.54	0.1961	4	3.45	0.0138
Location	3	162.60	<0.0001	4	29.89	<0.0001	2	95.06	<0.0001
Treatment*Location	8	0.56	0.8066	16	0.52	0.8960	4	1.73	0.1572

[z]Anthracnose stem blight symptom severity was estimated as a percentage of stem showing symptoms.
[y]Yield was adjusted to 13% moisture before analysis.

Table 4. Mean percent anthracnose stem blight severity and yield of soybean with various foliar fungicide applications at four locations in Iowa in 2008.

	Cass Co.		Floyd Co.		O'Brien Co.		Washington Co.	
Product, Timing[z]	**Severity[y]**	**Yield[x]**	**Severity**	**Yield**	**Severity**	**Yield**	**Severity**	**Yield**
Pyraclostrobin, R1	7.0	3381	3.6	3478	---	---	---	---
Pyraclostrobin, R3	1.7	3374	1.0	3588	---	---	---	---
trifloxystrobin + prothioconazole, R1	7.6	3422	3.9	3507	1.4	2577	3.4	4594
trifloxystrobin + prothioconazole, R3	1.6	3452	1.7	3493	0.9	2702	1.9	4372
untreated control	13.2	3262	8.4	3235	5.4	2395	6.4	4455
LSD (*P*<0.05)[w]	3.7	NS	2.4	NS	2.3	NS	NS	153

[z]Fungicide application timings were based on growth stage and were applied at R1 (flowering) and R3 (pod formation).
[y]Mean percent anthracnose stem blight severity visually estimated on 20 consecutive plants per plot.
[x]Yield in kg ha^{-1} standardized at 13% moisture.
[w]Least significant difference between means. When treatment effects had a significance $P > 0.05$ effects were considered not significant (NS).

Table 5. Anthracnose stem blight severity (%) and mean yield of soybean after application of various foliar fungicide treatments at five locations in Iowa in 2009.

	Adair Co.		Floyd Co.		Story Co.		Washington Co.	
Product, Timing[z]	**Severity**[y]	**Yield**[x]	**Severity**	**Yield**	**Severity**	**Yield**	**Severity**	**Yield**
Pyraclostrobin, R1	29.4	4709	11.9	4154	14.4	3926	32.2	3855
Pyraclostrobin, R3	19.5	4888	10.8	4187	5.1	4213	23.1	3928
trifloxystrobin + prothioconazole, R1	17.1	4580	7.8	4203	13.7	3766	29.1	3941
trifloxystrobin + prothioconazole, R3	12.9	4589	7.5	4159	13.5	4040	19.7	4007
untreated control	48.7	4564	13.5	3938	20.5	3877	53.5	3904
LSD ($P < 0.05$)[w]	9.8	NS	5.7	NS	7.1	291	14.0	NS

[z]Fungicide application timings were based on growth stage and were applied at R1 (flowering) and R3 (pod formation).
[y]Mean percent anthracnose stem blight severity visually estimated on 20 consecutive plants per plot.
[x]Yield in kg ha^{-1} standardized at 13% moisture.
[w]Least significant difference between means. When treatment effects had a significance $P > 0.05$ effects were considered not significant (NS).

Table 6. Anthracnose stem blight severity (%) and mean yield of soybean after application of various foliar fungicide treatments at three locations in Iowa in 2010.

	Floyd Co.		O'Brien Co.		Story Co.	
Product, Timing[z]	**Severity**[y]	**Yield**[x]	**Severity**	**Yield**	**Severity**	**Yield**
Pyraclostrobin, R1	---	---	---	---	12.0	4678
Pyraclostrobin, R3	---	---	---	---	10.6	4798
trifloxystrobin + prothioconazole, R1	5.9	3429	14.5	3762	19.3	4767
trifloxystrobin + prothioconazole, R3	4.4	3577	11.6	3944	11.8	4868
untreated control	5.9	3415	20.8	3750	33.5	4305
LSD ($P < 0.05$)[w]	NS	NS	6.3	NS	10.2	345

[z]Fungicide application timings were based on growth stage and were applied at R1 (flowering) and R3 (pod formation).
[y]Mean percent anthracnose stem blight severity visually estimated on 20 consecutive plants per plot.
[x]Yield in kg ha^{-1} standardized at 13% moisture.
[w]Least significant difference between means. When treatment effects had a significance $P >$ 0.05 effects were considered not significant (NS).

Table 7. Mean pods per plant, seeds per plant, seeds per pod, 100 seed weight (g) and percent anthracnose stem blight severity of soybean at various locations in Iowa in 2008, 2009 and 2010.

***Year*, Location**	**Mean percent anthracnose stem blight severity (low-high)**	**Pods/plant**	**Seeds/plant**	**Seeds /pod**	**100 seed weight (g)**
2008					
Cass Co.	18.3 (5-60)	33.0	83.3	2.5	12.4
Washington Co.	33.5 (5-90)	45.3	113.8	2.5	11.2
Floyd Co.	20.3 (0-85)	30.5	70.2	2.3	14.7
2009					
Story Co.	15.3 (1-80)	22.9	56.7	2.5	---
Washington Co.	55.9 (5-95)	31.1	75.8	2.4	---
Adair Co.	9.9 (1-74)	30.9	74.0	2.4	---
Floyd Co.	56.0 (3-95)	28.3	68.7	2.4	---
O'Brien Co.	23.3 (2-90)	34.5	83.2	2.4	---
2010					
Story Co.	43.1 (10-80)	53.9	97.2	1.8	14.8
Floyd Co.	10.5 (1-55)	39.7	82.4	2.1	12.2
O'Brien Co.	28.0 (2-60)	41.5	82.9	2.0	12.7

Table 8. Regression analysis[z] of anthracnose stem blight severity (%) and the yield components[y] pods plant^{-1}, seeds plant^{-1}, seeds pod^{-1} and 100 seed wieght (g) of individual soybean plants from various locations across Iowa in 2008, 2009, and 2010.

	Pods/plant				**Seeds/plant**			
***Year* location**	**Slope**	***b***	**R^2**	**P>F**	**Slope**	***b***	**R^2**	**P>F**
2008								
Cass Co.	NS	NS	NS	0.14	NS	NS	NS	0.33
Floyd Co.	NS	NS	NS	0.40	NS	NS	NS	0.77
Washington Co.	NS	NS	NS	0.21	NS	NS	NS	0.17
2009								
Adair Co.	NS	NS	NS	0.60	NS	NS	NS	0.74
Floyd Co.	NS	NS	NS	0.27	NS	NS	NS	0.30
Story Co.	0.26	19.1	0.23	<0.01	0.61	47.4	0.21	<0.01
Washington Co.	0.11	25.2	0.06	0.01	0.36	55.7	0.10	<0.01
2010								
Floyd Co.	NS	NS	NS	0.11	NS	NS	NS	0.15
O’Brien Co.	NS	NS	NS	0.21	NS	NS	NS	0.21
Story Co.	NS	NS	NS	0.11	-0.43	115.7	0.08	0.05

[z]NS = non-significant regression; ---, data not available.
[y]Yield components were determined from hand harvested plants in the untreated control plot.

Table 8. (continued)

	Seeds/pod				100 seed weight (g)			
***Year* location**	**Slope**	***b***	**R^2**	**P>F**	**Slope**	***b***	**R^2**	**P>F**
2008								
Cass Co.	NS	NS	NS	0.30	0.04	11.8	0.10	0.01
Floyd Co.	NS	NS	NS	0.18	0.03	14.1	0.09	0.01
Washington Co.	NS	NS	NS	0.56	NS	NS	NS	0.64
2009								
Adair Co.	NS	NS	NS	0.88	---	---	---	---
Floyd Co.	NS	NS	NS	0.46	---	---	---	---
Story Co.	NS	NS	NS	0.57	---	---	---	---
Washington Co.	0.00	2.2	0.09	<0.01	---	---	---	---
2010								
Floyd Co.	NS	NS	NS	0.88	NS	NS	0.06	0.08
O'Brien Co.	NS	NS	NS	0.87	NS	NS	NS	0.20
Story Co.	NS	NS	NS	0.27	NS	NS	0.07	0.06

CHAPTER 4.

COMPARISON OF ON-FARM AND SMALL PLOT FUNGICIDE RESEARCH IN IOWA

A paper to be submitted to *Plant Disease*

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Abstract

Research on foliar fungicides on soybean in the Midwest has increased in recent years in response to increased availability of fungicide products. Most fungicide trials are conducted through university extension personnel in small plots (i.e., 4 rows by 9 meters long) using a hand boom sprayer. Data collected include disease severity and yield. Some growers and agribusiness professionals have questioned the validity of data generated in small plots. Field-scale comparisons (i.e., on-farm research) using equipment more representative of growers' equipment has been suggested as a more valid representation of the effect of fungicides particularly on soybean yield. We compared yield responses of soybean after an application of pyraclostrobin (Headline®) from small plot and on-farm research data in Iowa from 2008 through 2010. Yield responses of pyraclostrobin were not statistically different in on-farm and small plot research. Overall, our data show that small plot research using a hand boom sprayer are representative of data collected in large scale field trials with commercial sprayers.

Introduction

The introduction of soybean rust (*Phakopsora pachyrizi* Syd and P.Syd) in the United States (30) resulted in several fungicides becoming available for use on soybean (*Glycine max* [L.] Merr.). Soybean germplasm in the United States was very susceptible to the disease and foliar fungicides were the only tool available for soybean rust management. Soon after the discovery of soybean rust in the United States, the Environmental Protection Agency (EPA) issued emergency section 18 labels for foliar fungicides to control soybean rust. Over the past several years, many of these fungicides either have been removed from the market or have transitioned to full labels (Section 3) for soybean. University scientists have played an important role in evaluating foliar fungicides for management of soybean rust as well as other soybean diseases (7,8,17,22,24). The increase of foliar fungicide research in soybeans is documented in the number of research reports contributed to Plant Disease Management Reports (formerly Fungicide & Nematicide Tests) (http://www.plantmanagementnetwork.org/pub/trial/pdmr). Specifically, in 2004, the year soybean rust was first detected in the United States, two reports on soybean foliar fungicide trials were published. From 2006 through 2011, there have been over 100 soybean fungicide trial reports published, and another 20 have been published in a special section on soybean rust.

Soybean rust has been estimated to cause some soybean yield losses in southern states (20), but no documented yield losses have been reported in Iowa. Foliar fungicide use on soybean in the state, however, has become widespread. Grain prices have increased over the past 5 years (http://www.nass.usda.gov), and this has likely contributed to growers’ willingness to apply foliar fungicides. Additionally, other foliar diseases endemic to the north central United States, such as Septoria brown spot (*Septoria glycines* Hemmi), Cercospora leaf blight

(*Cercospora kikuchii* ((T. Matsu. & Tomoyasu) Gardener)), and frogeye leaf spot (*Cercospora sojina* Hara) can be managed using foliar fungicides. Many fungicides that received an emergency section 18 label for soybean rust management have since received a section 3 label for full use on soybean; this label includes Septoria brown spot, Cercospora leaf blight and frogeye leaf spot. Consequently soybean researchers have been tasked with quickly gathering information on efficacy of these products for disease control and also yield responses.

Fungicide research is usually conducted in controlled environments in laboratories and greenhouses as well as less predictable environments in the field. Lab and greenhouse research is useful determining fungicide efficacy for very specific needs, such as establishing baseline sensitivity to specific fungicides (3,34). This information is useful in monitoring the development of fungicide resistance. Field fungicide trials test fungicide efficacy of disease control and yield response under growing conditions. These trials, which are commonly reported in the Plant Disease Management Reports, can offer fungicide efficacy data under the unique growing conditions of that year and location (4,911,15,16,27,28,33). Pesticide application strategies (e.g., application timing, tank mixing) that may affect fungicide efficacy are often included in university research trials (5,6,23,24).

Fungicide field trials traditionally are conducted in what we will refer to as 'small plot research'. These trials are typically conducted at universities or institutionally run research stations. Small plot research usually is laid out as a randomized complete block experimental design and treatments are applied to small plots that range from four to 10 rows wide and 5 m to 25 m long within a uniform section of a field (i.e., block). Each block is assigned a random order of treatments. By blocking and replicating, researchers are more likely to detect differences due to treatment effects. Because the research is conducted at centralized locations the collection of agronomic data and other metadata (e.g., disease notes, climate data) are typically recorded. These metadata are important to help explain treatment effects of the fungicides.

Small plot research is an accepted practice in the scientific community; however, some agribusiness professionals and growers have questioned the validity of small plot research methodology, especially as university and data used for marketing fungicide products to growers do not always corroborate. The questions pertaining to the validity of small plot research include research plots are not on soybean grower's fields, are too small in scale, and are not using equipment that is representative of what growers use. An alternative to small plot fungicide research that addresses many of these concerns is replicated large-scale (on-farm) research.

On-farm fungicide trials vary greatly in implementation from small plot research; however, the goals are primarily the same. On-farm research partners growers with researchers and/or industry to evaluate and develop agricultural technologies (25,29,31) for two general purposes, namely developing improved technology and gathering information that will improve agricultural practices (29). On-farm fungicide trials achieve the latter. Because plot size is larger and is implemented on production fields, on-farm research is typically simplified and tests a single hypothesis (e.g., non-treated control vs. fungicide treatment). A plot often runs the length of a field and its width is determined by equipment used by the farmer or applicator (e.g., the width of a spray boom or combine). Like small-plot research, on-farm research still needs to be replicated in a field; however, treatments are often not truly randomized and usually alternate across the field. Because growers and agribusiness professionals are often involved in on-farm trials, and they have responsibilities beyond collecting metadata to complement yield data, many on-farm studies lack metadata, such as disease notes.

It has been argued that small plot trials fail to represent the environment of a grower's field, and thus the data are not representative of what a grower will experience (21). Our objective was to compare the yield response and variability of small plot and on-farm research using pyraclostrobin (Headline ®, BASF Research Triangle Park, NC) using an unmatched (data accessed from across all of Iowa) and matched data set (data only from a specified region in Iowa). Our aim is to determine if small plot fungicide research is representative of real growing conditions that are captured by on-farm fungicide trials.

Materials and Methods

Data collection. Data were collected from fungicide trials that occurred in 2008, 2009 and 2010 from studies conducted throughout Iowa. On-farm fungicide trial data was collected from research conducted by Iowa State University (ISU) faculty and staff, and the Iowa Soybean Association On-Farm Network®. Data from ISU faculty and staff were collected via publications and direct access to data with permission by researchers. Fungicide trial data from the Iowa Soybean Association On-Farm Network® were collected from on-line reports (www.isafarmnet.com). Small plot research data were collected from various trials conducted at ISU research farms across Iowa (Figure 1, Appendix A). Many of the data accessed were from trials conducted by the authors (2,23). Other data was received from managers at ISU research farms. Yield responses were calculated as the difference between a fungicide treatment and an appropriate control. In most cases, this was the difference between a fungicide alone and the untreated control. Some yield responses were the difference between a fungicide and insecticide tank mix and the insecticide alone. It was common in the small plot studies for multiple yield responses to be derived from a single trial since multiple products were evaluated.

Statistical analysis. Analysis of variance of the yield response was completed using a mixed model (PROC MIXED) in SAS (SAS Institute, Cary NC). The fixed effect was plot size and the random effect was variety. Each data set was analyzed by year. Differences in means were detected using LSMEANS ($P < 0.05$). A 'matched' data set was also analyzed in an attempt to limit bias. This data set only included observations from the land area within 80.6 km of Nashua, IA where the ISU Northeast Research Farm is located and the majority of observations of small plot research originate.

Results

The number of observations for each data set in this study can be found in Table 1. In 2008 and 2009, pyraclostrobin was the focus of many more research than premix fungicides. In 2010, there was a sharp decline in the number of observations available and we are only reporting those that used pyraclostrobin. The reduction in data points was due to ISA On-Farm Network® doing less soybean fungicide research and from small plot research at ISU being scaled back (Table 1). There were no observations of premix fungicides being used in on-farm research in Iowa in 2010.

There were no detectable differences of yield response between on-farm and small plot data found in our analysis during each year. Means of the yield responses for each on-farm and small plot data set can be found in Table 1. For each year, the standard errors of the mean estimates were similar between on-farm and small plot research for each year and were generally lower than what was found in the premix fungicides.

Matched analysis. Due to the uncontrolled nature of observational analyses we filtered out a subset of "matched" data. Over 80% of the data used from small plot research derived from a single research farm in Floyd County in the northeastern area of Iowa. To help eliminate this bias and increase precision of the analysis we used data only from on-farm research that was conducted within a 80.6 km radius of Nashua, IA.

We were unable to detect differences of yield responses of pyraclostrobin between on-farm and small plot research trials in all years. In 2010, n=4 and 5 in on-farm and small plot research, respectively, and the standard error was much higher for both types of research plots in this year relative to the standard errors found in the previous years of the study (Table 2).

Discussion

This is the first attempt at detecting and explaining differences between small plot and on-farm research results. On-farm and small plot fungicide research that we have analyzed has come to the same conclusions. While results may differ between individual studies and observations when compared to each other, differences are not necessarily due to plot size. Environmental conditions (weather, aphid populations, etc.) that may affect the effectiveness of a fungicide should be considered to explain differences that may exist.

From the pyraclostrobin data set, we are confident that the small plot and on-farm fungicide trials are coming to the same conclusions. Differences were not detected during any of the analyses even as we eliminated potential bias of variety and location. Had differences been detected during any of the analyses we would have used factors such as variety, location, application timing, disease severity, and other available data to help better understand such differences. However, doing so may have been difficult since many on-farm trials do not have sufficient agronomic data collected such as disease severity.

Varieties used in fungicide trials can have a large impact on yield responses of fungicides (1,5). Small plot researchers often plant varieties that are susceptible to the diseases they are studying, and this may inflate the usefulness of fungicides when compared to on-farm data. On-farm researchers usually choose varieties based on other factors, such as yield potential and resistance to diseases such as sudden death syndrome and soybean cyst nematode, which are not managed by foliar fungicides.

A weakness in many on-farm fungicide protocols is the lack of data collection outside of yield response. At a minimum foliar disease severity data should always be recorded in field fungicide trials as well as other data that might impact yield (e.g., soybean aphid pressure, SDS, etc.). Such data are very useful since they can be used to possibly explain yield responses. This is even more important because some strobilurin fungicides may affect plant physiology, which industry has coined “plant health” (12,18,26,35). Dorrance et al (2010) were able to collect disease and aphid assessment data in their on-farm research in Ohio. This data collected enabled the researchers to better explain how treatments affected yield responses at the various locations in the study.

Small plot trials are useful to evaluate experimental fungicides that require crop destruct prior to registration. Agrochemical companies often have universities research institutions test products that are nearing registration in order to collect third party data for registration. Small plot researchers can have access to products sooner than on-farm researchers. These evaluations enable university researchers to develop an understanding of how new fungicides perform under various environmental conditions and cultural practices, and in comparison to older products before they are marketed. Such data are valuable for recommendations on use of these new products in crop management strategies. It is more difficult and often uneconomical for on-farm researchers to test products during product development in fungicide trials due to the restrictions of fungicide use.

Methods of experimental design may vary between on-farm and small plot research, but the goals remain largely the same, to provide data on up-to-date evaluations of fungicides that help soybean growers in a region or state make better crop management decisions. When differences between research methods occur, investigation and explanation are warranted. Differences seen between on-farm and small plot data on a superficial level should not be seen as flaws between the types of research. Rather, identifying the sources of variation should be attempted but that can only be done with the proper collection of agronomic data. Ideally, disease data should accompany any fungicide trial, regardless of plot size. Numerous factors influence the efficacy of fungicides including timing, variety, and environmental factors (14,24,32). Within each growing season there are unique growing conditions present and many may affect yield responses from fungicides. The increased use of fungicide on soybean is part of a national trend in all of agriculture. The sales of fungicides were estimated in the United States to be over $1.3 billion (13) in 2007 compared to approximately $860 million in 2000 (19). To best understand the role of fungicides in soybean production research must continue, but size of plots do not affect the validity of these research trials.

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Table 1. Yield response of foliar fungicides from small-plot or on-farm fungicide trials across Iowa in 2008, 2009, and 2010.

Fungicide	**Year**	**Plot size[z]**	**Number of observations**	**Mean yield response (kg ha^{-1})[y]**	**Standard error**
Pyraclostrobin	2008	On-farm	92	193	20
		Small plot	37	185	32
	2009	On-farm	49	133	25
		Small plot	73	141	21
	2010	On-farm	9	266	73
		Small plot	9	295	78

[z]On-farm research conducted by Iowa Soybean Association On-Farm Network® and Iowa State University faculty and staff; small plot research was conducted by Iowa State University faculty and staff.
[y]Mean yield response estimates followed by the same letter are not significantly different within on-farm and small plot pairs for each year.

Table 2. Matched data set of on-farm and small plot fungicide research within 80 kilometers of ISU Northeastern Research Farm in Nashua, IA in 2008, 2009 and 2010.

Fungicide	**Year**	**Plot size**[z]	**Number of observations**	**Mean yield response (kg ha^{-1})**[y]	**Standard error**
Pyraclostrobin	2008	On-farm	27	172A	35
		Small Plot	29	173A	35
	2009	On-farm	10	102A	50
		Small Plot	57	86A	28
	2010	On-farm	4	253A	97
		Small Plot	5	169A	114

[z]On-farm research conducted by Iowa Soybean Association On-Farm Network® and Iowa State University faculty and staff; small plot research was conducted by Iowa State University faculty and staff.
[y]Mean yield response estimates followed by the same letter are not significantly different within on-farm and small plot pairs for each year.

CHAPTER 5.

SUMMARY

General Conclusions

Fungicides used in this study were generally effective in reducing disease severity when compared to untreated controls, however, there was not always a corresponding yield response, particularly when disease severity was low or remained in the lower canopy. Furthermore, adding a fungicide to an insecticide application did not always result in an added yield response. Probabilities of making a return investment on fungicides were greatest in instances where disease severity was high. We conclude that fungicides, in order to maximize effectiveness, should only be applied in the presence of foliar disease.

While foliar fungicide applications reduced anthracnose stem blight severity, there was no associated yield response. Late-season symptoms of anthracnose stem blight in the absence of early-season symptoms of anthracnose are not good indicators of a fungicide's ability to protect yield. Late-season symptoms of anthracnose stem blight should not be considered a major threat to soybean yields in Iowa and should not be considered in current crop management strategies. However, like other diseases endemic to Iowa, anthracnose stem blight should be monitored and if early-season symptoms develop then the use of fungicides to control the disease may be warranted.

We are confident that small plot research is still a viable method for field fungicide trials in Iowa and offers valuable information to growers on how fungicides should be used. Fungicide trials need to be continued as new products begin to enter the market and as fungicide resistance monitoring continues in soybean pathosystems. The continuation of assessing small plot and on-farm data is recommended as new products are evaluated in both types of trials.

Future Research

In order to keep up with new fungicide uses and products, fungicide trials need to continue to explore the best methods of using fungicides in the context of complete crop management. If soybean grain prices remain high or continue to rise more growers may decide to spray, regardless of disease. As fungicides are used more often in Iowa exploration into the baseline sensitivities of fungal pathogens to fungicides should be completed on a regular basis.

An economic threshold for foliar disease severity is not available. Diseases like Septoria brown spot and frogeye leaf spot are both capable of reducing yield in Iowa. Further research is needed to determine what levels are required for these diseases to cause yield damage. Furthermore, there is room for improvement for the disease severity rating method for Septoria brown spot. The inclusion of defoliated nodes in the severity assessment may offer further indication of the severity of Septoria brown spot in the field. Examining how a severity assessment including defoliation relates to yield may be warranted. The impact Cercospora leaf blight on soybean yield in Iowa is unknown. The biology of the pathogen *Cercospora kikuchii* is not well studied and the knowledge gap should be closed in order to make better recommendations in controlling this disease.

APPENDIX

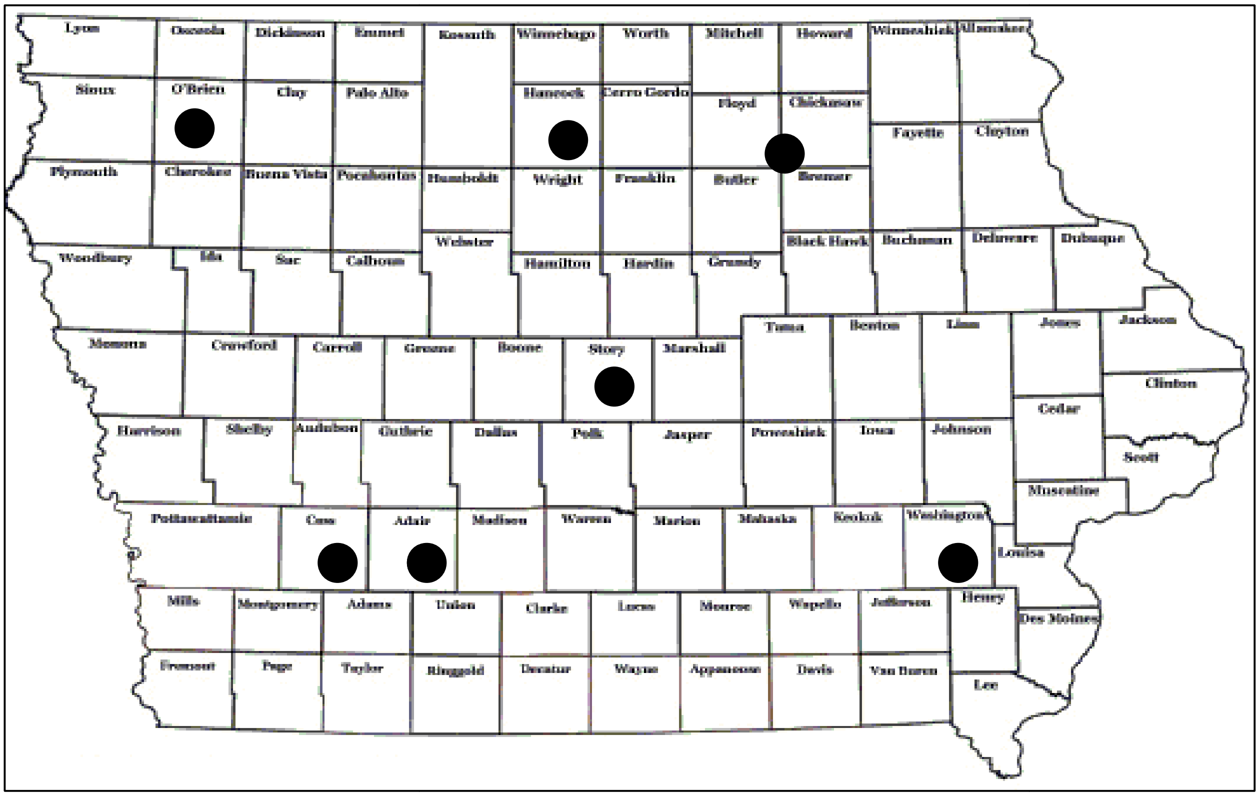

Figure 1. Map of Iowa showing research farm locations used in the fungicide-insecticide study that was done from 2008 to 2010.

Table 1. 30-year weather averages for locations near fungicide-insecticide trials.

Location	May			June			July			August			September		
	T_{high}[a]	T_{low}	Rain (mm)	T_{high}	T_{low}	Rain (mm)	T_{high}	T_{low}	Rain (mm)	T_{high}	T_{low}	Rain (mm)	T_{high}	T_{low}	Rain (mm)
Cass Co.	22.8	8.9	124	28.1	14.4	149	29.9	16.8	124	28.8	15.3	97	25.2	9.8	88
Floyd Co.	21.1	9.2	116	26.2	14.5	134	28.1	16.7	122	26.8	15.5	105	22.8	10.4	82
Hancock Co.	20.5	8.4	103	26.0	14.4	137	27.7	16.6	115	26.3	15.2	98	22.5	9.8	77
O'Brien Co.	21.6	8.7	98	26.8	14.3	124	28.3	16.4	95	26.9	14.9	112	23.1	9.9	83
Story Co.	22.8	10.1	122	27.5	15.5	126	29.1	17.6	123	28.1	16.4	122	24.9	11.6	83
Washington Co.	22.5	9.6	116	27.6	15.1	119	29.8	17.2	109	28.8	16.1	106	24.9	10.6	91

Table 2. Average high and low temperature and total rainfall from May to September at each research site from 2008-2010.

Location	May			June			July			August			September		
	T_{high}[z]	T_{low}	Rain (mm)	T_{high}	T_{low}	Rain (mm)	T_{high}	T_{low}	Rain (mm)	T_{high}	T_{low}	Rain (mm)	T_{high}	T_{low}	Rain (mm)
2008															
Cass Co.	21.5	8.7	173	27.0	15.6	307	28.8	18.3	92	28.0	15.8	31	23.4	11.8	106
Floyd Co.	20.0	7.1	109	25.6	14.7	233	28.4	16.9	168	26.8	14.2	14	23.3	11.0	61
Hancock Co.	20.7	7.2	155	25.8	14.4	194	28.3	16.5	81	26.5	13.7	27	23.2	10.3	58
O'Brien Co.	19.8	7.2	142	25.8	13.9	123	28.1	16.6	54	26.7	13.7	33	23.0	9.5	81
Washington	21.7	8.6	137	27.9	15.9	144	28.5	17.2	94	27.5	14.6	80	23.5	11.2	191
2009															
Adair Co.	22.5	10.4	52	26.4	15.8	155	25.9	15.4	105	25.7	15.4	214	24.1	11.4	14
Floyd Co.	20.7	8.9	131	25.3	14.3	84	24.6	13.7	88	24.7	14.1	93	23.7	10.7	50
O'Brien Co.	21.4	7.9	40	24.6	13.1	65	25.0	12.6	105	24.9	12.7	43	23.9	10.0	29
Story Co.	21.7	9.7	96	26.5	15.7	50	25.9	15.0	2	25.2	15.3	4	24.0	12.1	1
Washington	22.5	9.6	129	26.7	15.6	196	25.7	14.3	114	25.7	14.7	218	24.1	10.5	30
2010															
Floyd Co.	21.8	9.6	67	26.1	15.2	203	28.1	17.8	166	29.1	17.4	70	23.0	10.3	39
O'Brien Co.	21.3	7.5	29	25.9	14.3	288	28.1	16.8	224	28.3	16.9	128	22.7	10.2	94
Story Co.	21.9	10.3	84	27.1	16.3	282	28.7	18.9	129	29.5	18.5	336	23.7	11.8	110

[z]Average high and low temperature in degrees Celsius.

Table 3. Analysis of variance (ANOVA) for main effects of year, location, treatment, and their interactions on Septoria brown spot severity and yield from data collected from fungicide-insecticide trials conducted across Iowa in 2008, 2009 and 2010.

Source	**DF**	**F**	**P > F**
Septoria brown spot			
Treatment	39	8.9	<0.0001
Rep	5	8.8	<0.0001
Year	2	35.6	<0.0001
Location	6	35.5	<0.0001
Treatment*Location	140	1.5	0.0002
Treatment*Year	24	4.3	<0.0001
Yield			
Treatment	39	4.3	0.0007
Rep	5	16.1	<0.0001
Year	2	233.0	<0.0001
Location	6	188.2	<0.0001
Treatment*Location	140	4.3	<0.0001
Treatment*Year	24	8.7	<0.0001

Table 4. Analysis of variance (ANOVA) by year for main effects location, treatment, and their interactions on Septoria brown spot severity (SBS) and yield from data collected from fungicide-insecticide trials conducted across Iowa in 2008, 2009 and 2010.

	2008			**2009**			**2010**		
Source	**DF**	**F**	**P>F**	**DF**	**F**	**P>F**	**DF**	**F**	**P>F**
SBS Severity									
Treatment	14	10.6	<0.0001	25	5.2	<0.0001	32	3.6	<0.0001
Rep	5	4.4	0.0006	5	10.6	<0.0001	5	2.9	0.0150
Location	4	29.5	<0.0001	4	42.1	<0.0001	2	0.7	0.5189
Treatment*Location	56	1.4	0.0536	100	1.0	0.3895	13	1.3	0.2433
Yield									
Treatment	14	18.7	<0.0001	25	4.2	<0.0001	32	13.6	<0.0001
Rep	5	9.5	<0.0001	5	3.0	0.0112	5	8.5	<0.0001
Location	4	344.7	<0.0001	4	136.6	<0.0001	2	211.8	<0.0001
Treatment*Location	56	3.6	<0.0001	100	2.7	<0.0001	11	1.4	0.1842

Table 5. Analysis of variance (ANOVA) by year and location for main effects treatment, and rep on Septoria brown spot severity (SBS) and yield from data collected from fungicide insecticide trials conducted across Iowa in 2008, 2009 and 2010.

		2008			**2009**			**2010**		
Source		**DF**	**F**	**P>F**	**DF**	**F**	**P>F**	**DF**	**F**	**P>F**
SBS severity										
Adair Co.	Treatment	---	---	---	25	1.2	0.2622	---	---	---
	Rep	---	---	---	5	51.6	<0.0001	---	---	---
Cass Co.	Treatment	14	1.6	0.0952	---	---	---	---	---	---
	Rep	4	1.1	0.3462	---	---	---	---	---	---
Floyd Co.	Treatment	14	6.7	<0.0001	25	5.3	<0.0001	7	1.7	0.1427
	Rep	4	3.9	0.0060	5	17.8	<0.0001	5	0.6	0.7326
Hancock Co.	Treatment	14	5.7	<0.0001	---	---	---	---	---	---
	Rep	5	4.0	0.0029	---	---	---	---	---	---
O'Brien Co.	Treatment	14	2.1	0.0200	25	4.3	<0.0001	7	2.8	0.0166
	Rep	4	7.4	<0.0001	5	3.9	0.0027	5	1.5	0.2094
Story Co.	Treatment	---	---	---	25	2.3	0.0018	31	3.2	<0.0001
	Rep	---	---	---	4	10.7	<0.0001	5	3.1	0.0111
Washington Co.	Treatment	14	1.2	0.2982	25	1.6	0.0604	---	---	---
	Rep	2	4.0	0.0280	5	42.8	<0.0001	---	---	---

Table 5. (continued)

		2008			2009			2010		
Source		**DF**	**F**	**P>F**	**DF**	**F**	**P>F**	**DF**	**F**	**P>F**
Yield (kg ha^{-1})										
Adair Co.	Treatment	---	---	---	25	3.7	<0.0001	---	---	---
	Rep	---	---	---	5	7.5	<0.0001	---	---	---
Cass Co.	Treatment	14	1.9	0.0449	---	---	---	---	---	---
	Rep	4	6.8	0.0001	---	---	---	---	---	---
Floyd Co.	Treatment	14	9.8	<0.0001	25	1.2	0.2399	7	1.7	0.1329
	Rep	4	4.7	0.0019	5	0.3	0.9388	5	2.8	0.0309
Hancock Co.	Treatment	14	2.8	0.0017	---	---	---	---	---	---
	Rep	5	4.4	0.0012	---	---	---	---	---	---
O'Brien Co.	Treatment	14	33.7	<0.0001	25	1.8	0.0227	7	3.3	0.0077
	Rep	4	16.8	<0.0001	5	0.9	0.5061	5	1.4	0.2398
Story Co.	Treatment	---	---	---	25	13.3	<0.0001	30	3.8	<0.0001
	Rep	---	---	---	4	4.1	0.0040	5	18.7	<0.0001
Washington Co.	Treatment	14	4.1	<0.0001	25	1.5	0.0657	---	---	---
	Rep	5	3.1	0.0132	5	14.0	<0.0001	---	---	---

Table 6. Cercospora leaf blight severity (%) in the upper canopy of soybean plots treated with various pesticides applied at growth stage R1 or R3 at five locations across Iowa in 2008.

	Cass Co.		Floyd Co.		Hancock Co.		O'Brien Co.		Washington Co.	
Treatment	**R1**[y]	**R3**[y]	**R1**	**R3**	**R1**	**R3**	**R1**	**R3**	**R1**	**R3**
PIC	2.8	6.9	1.9	1.9	0.6	1.2	2.9	4.4	7.2	10.9
PYR	6.5	9.7	4.6	2.6	0.4	0.9	5.0	4.8	8.3	11.8
FLU	13.1	17.3	1.9	2.3	1.6	1.0	7.0	5.2	4.2	9.1
TRI + PRO	11.8	8.2	5.3	4.9	1.0	0.4	6.6	6.3	16.6	5.2
ESF	5.6	5.1	3.1	2.3	1.6	0.6	0.8	0.8	17.4	3.5
IMI	8.9	9.5	1.8	2.1	0.0	0.7	2.6	1.3	11.1	9.1
FLU + ESF	18.8	9.2	3.0	4.0	0.6	0.5	2.1	2.5	12.4	13.5
TRI +PRO + IMI	17.7	11.4	3.6	2.2	1.5	0.6	1.8	1.1	20.0	10.5
IPM	5.6		3.4		1.4		3.4		15.7	
CON	12.3		8.2		1.7		8.2		2.3	
$LSD_{(0.05)}$[x]	9.7		3.5		NS		NS		NS	

[z]Cercospora leaf blight severity is a mean from10 visually assessed leaflets in the lower canopy of each plot at R5 to R6.
[y]PIC=picoxystrobin (Approach®, Du Pont Crop Protection, Wilmington, DE), PYR=pyraclostrobin (Headline®, BASF Crop Protection, Beaumont, TX), FLU=flusilazole (Punch®, Du Pont Crop Protection, Wilmington, DE), TRI +PRO = trifloxystrobin + prothioconazole (Stratego® YLD, Bayer CropScience, Research Triangle Park, NC), ESF=esfenvalerate (Asana®, Du Pont Crop Protection, Wilmington, DE), IMI=imidicloprid (Leverage®, Bayer CropScience, Research Triangle Park, NC), IPM=integrated pest management (only sprayed aphids exceed economic threshold), CON=untreated control.
[x]Growth stage R1 is the beginning of flowering; growth stage R3 is the beginning of pod set.

[w]Least significant difference between means within columns under the same location heading when alpha =0.05.

Table 7. Frogeye leaf spot severity (%)[z] in the upper canopy of soybean plots treated with various pesticides applied at growth stage R1 or R3 at five locations across Iowa in 2008.

	Cass Co.		Floyd Co.		Hancock Co.		O'Brien Co.		Washington Co.	
Treatment[y]	**R1[x]**	**R3[x]**	**R1**	**R3**	**R1**	**R3**	**R1**	**R3**	**R1**	**R3**
PIC	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PYR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
FLU	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TRI + PRO	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ESF	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
IMI	0.0	0.6	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0
FLU + ESF	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TRI +PRO + IMI	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
IPM	0.0		0.0		0.0		0.1		0.0	
CON	0.0		0.0		0.0		0.0		0.0	
$LSD_{(0.05)}$[w]	NS		NS		NS		NS		NS	

[z]Frogeye leaf spot severity is a mean from10 visually assessed leaflets in the lower canopy of each plot at R5 to R6.
[y]PIC=picoxystrobin (Approach®, Du Pont Crop Protection, Wilmington, DE), PYR=pyraclostrobin (Headline®, BASF Crop Protection, Beaumont, TX), FLU=flusilazole (Punch®, Du Pont Crop Protection, Wilmington, DE), TRI +PRO = trifloxystrobin + prothioconazole (Stratego® YLD, Bayer CropScience, Research Triangle Park, NC), ESF=esfenvalerate (Asana®, Du Pont Crop Protection, Wilmington, DE), IMI=imidicloprid (Leverage®, Bayer CropScience, Research Triangle Park, NC), IPM=integrated pest management (only sprayed aphids exceed economic threshold), CON=untreated control.
[x]Growth stage R1 is the beginning of flowering; growth stage R3 is the beginning of pod set.

[w]Least significant difference between means within columns under the same location heading when alpha =0.05.

Table 8. Cercospora leaf blight (%)[z] in the upper canopy of soybean plots treated with various pesticides applied at growth stage R1 or R3 at five locations across Iowa in 2009.

	Adair Co.		Floyd Co.		O'Brien Co.		Story Co.		Washington Co.	
Treatment[y]	**R1**[x]	**R3**[x]	**R1**	**R3**	**R1**	**R3**	**R1**	**R3**	**R1**	**R3**
PIC	12.1	6.8	1.4	1.2	0.7	0.5	0.4	0.4	16.7	23.2
PYR	8.8	8.2	1.6	1.8	0.2	0.4	0.4	0.3	23.0	27.4
TET	4.1	7.3	2.5	1.4	0.3	0.5	0.6	1.0	20.4	15.8
TRI + PRO	10.5	7.4	1.8	1.0	0.6	0.3	0.6	0.9	18.7	26.7
PEN	9.4	6.9	1.7	2.0	0.4	0.4	0.4	0.5	15.4	17.8
CLO	8.7	13.3	0.9	2.5	0.5	0.3	0.6	0.4	23.9	22.7
ESF	7.0	9.9	2.2	1.9	0.4	0.4	1.0	0.6	21.9	20.0
IMI	8.2	5.9	1.0	1.0	0.6	0.4	0.9	0.6	24.8	17.0
PIC + ESF	5.9	12.7	0.7	1.2	0.4	0.3	0.2	0.4	16.2	20.5
PYR + ESF	---	7.8	---	0.9	---	0.4	---	0.2	---	23.2
TET + CLO	10.0	13.6	1.3	1.3	0.3	0.3	1.1	0.5	26.7	21.9
TRI + PRO + IMI	8.9	12.6	1.1	1.9	0.3	0.4	0.6	0.2	24.6	32.1
PEN + ESF	6.0	8.0	1.4	1.1	0.3	0.3	0.6	0.2	18.4	28.4
IPM	4.6		1.7		0.4		0.5		22.1	
CON	4.5		2.0		0.5		0.4		22.4	
$LSD_{(0.05)}$[w]	NS		NS		NS		NS		NS	

[z]Cercospora leaf blight is visually estimated as percent diseased area of 10 leaflets in each plot at R5-R6.
[y]PIC=picoxystrobin (Approach®, Du Pont Crop Protection, Wilmington, DE), PYR=pyraclostrobin (Headline®, BASF Crop Protection, Beaumont, TX), TET=tetraconazole (Domark®, Valent, Walnut Creek, CA), TRI +PRO = trifloxystrobin + prothioconazole (Stratego® YLD, Bayer CropScience, Research Triangle Park, NC), PEN=penthiopyrad (Vertisan®, Du Pont, Wilmington, DE), CLO=clothianidin (Belay®, Valent, Walnut Creek, CA), ESF=esfenvalerate (Asana®, Du Pont Crop Protection, Wilmington, DE), IMI=imidicloprid (Leverage®, Bayer CropScience, Research Triangle Park, NC), IPM=integrated pest management (only sprayed aphids exceed economic threshold), CON=untreated control.
[x]Growth stage R1 is the beginning of flowering; growth stage R3 is the beginning of pod set.
[w]Least significant difference between means within the same column when alpha = 0.05.

Table 9. Frogeye leaf spot severity (%) in the upper canopy of soybean plots treated with various pesticides applied at growth stage R1 or R3 at five locations across Iowa in 2009.

	Adair Co.		**Floyd Co.**		**O'Brien Co.**		**Story Co.**		**Washington Co.**	
Treatment	**R1**[y]	**R3**[x]	**R1**	**R3**	**R1**	**R3**	**R1**	**R3**	**R1**	**R3**
PIC	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.3
PYR	0.1	0.2	0.0	0.0	0.1	0.0	0.1	0.0	0.0	0.1
TET	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.2
TRI + PRO	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.1	0.0
PEN	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CLO	0.2	0.0	0.1	0.0	0.1	0.0	0.0	0.0	0.0	0.0
ESF	0.4	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2
IMI	0.7	0.3	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.1
PIC + ESF	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PYR + ESF	---	0.2	---	0.0	---	0.0	---	0.1	---	0.0
TET + CLO	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TRI + PRO + IMI	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0
PEN + ESF	0.3	0.3	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0
IPM	0.2		0.0		0.0		0.0		0.0	
CON	0.0		0.0		0.0		0.0		0.0	
$LSD_{(0.05)}$[w]	NS		NS		NS		NS		NS	

[z]Frogeye leaf spot severity is visually estimated as percent diseased area of 10 leaflets in each plot at R5-R6.
[y]PIC=picoxystrobin (Approach®, Du Pont Crop Protection, Wilmington, DE), PYR=pyraclostrobin (Headline®, BASF Crop Protection, Beaumont, TX), TET=tetraconazole (Domark®, Valent, Walnut Creek, CA), TRI +PRO = trifloxystrobin + prothioconazole (Stratego® YLD, Bayer CropScience, Research Triangle Park, NC), PEN=penthiopyrad (Vertisan®, Du Pont, Wilmington, DE), CLO=clothianidin (Belay®, Valent, Walnut Creek, CA), ESF=esfenvalerate (Asana®, Du Pont Crop Protection, Wilmington, DE), IMI=imidicloprid (Leverage®, Bayer CropScience, Research Triangle Park, NC), IPM=integrated pest management (only sprayed aphids exceed economic threshold), CON=untreated control.
[x]Growth stage R1 is the beginning of flowering; growth stage R3 is the beginning of pod set.
[w]Least significant difference between means within the same column when alpha = 0.05.

Table 10. Cercospora leaf blight (%)[z] in the upper canopy of soybean plots treated with various pesticides applied at growth stage R1 or R3 at five locations across Iowa in 2010.

	Floyd Co.		**O'Brien Co.**		**Story Co.**	
Treatment[y]	**R1[x]**	**R3[x]**	**R1**	**R3**	**R1**	**R3**
PIC	---	---	---	---	1.9	2.8
PYR	---	---	---	---	2.5	2.5
TET	---	---	---	---	2.9	2.7
TRI + PRO	3.5	2.6	3.3	4.5	1.7	1.9
PEN	---	---	---	---	2.9	4.4
CLO	---	---	---	---	5.1	5.0
ESF	---	---	---	---	3.2	2.6
IMI	2.9	2.2	3.2	3.8	2.3	5.1
PIC + ESF	---	---	---	---	2.3	1.5
TET + CLO	---	---	---	---	1.5	2.5
TRI + PRO + IMI	2.8	3.0	3.2	3.5	2.6	2.2
PEN + ESF	---	---	---	--	2.3	4.3
IPM	2.7		3.7		1.7	
CON	3.0		1.3		3.7	
$LSD_{(0.05)}$[w]	NS		NS			

[z]Cercospora leaf blight severity is visually estimated as percent diseased area of 10 leaflets in each plot between R5 and R6.
[y]PIC=picoxystrobin (Approach®, Du Pont Crop Protection, Wilmington, DE), PYR=pyraclostrobin (Headline®, BASF Crop Protection, Beaumont, TX), TET=tetraconazole (Domark®, Valent, Walnut Creek, CA), TRI +PRO = trifloxystrobin + prothioconazole (Stratego® YLD, Bayer CropScience, Research Triangle Park, NC), PEN=penthiopyrad (Vertisan®, Du Pont, Wilmington, DE), CLO=clothianidin (Belay®, Valent, Walnut Creek, CA), ESF=esfenvalerate (Asana®, Du Pont Crop Protection, Wilmington, DE), IMI=imidicloprid (Leverage®, Bayer CropScience, Research Triangle Park, NC), IPM=integrated pest management (only sprayed aphids exceed economic threshold), CON=untreated control.
[x]Growth stage R1 is the beginning of flowering; growth stage R3 is the beginning of pod set.
[w]Least significant difference between means under the same location when alpha = 0.05.

Table 11. Frogeye leaf spot severity (%)[z] in the upper canopy of soybean plots treated with various pesticides applied at growth stage R1 or R3 at five locations across Iowa in 2010.

	Floyd Co.		O'Brien Co.		Story Co.	
Treatment[y]	**R1**[x]	**R3**[x]	**R1**	**R3**	**R1**	**R3**
PIC	---	---	---	---	0.7	1.0
PYR	---	---	---	---	1.2	0.9
TET	---	---	---	---	0.9	1.0
TRI + PRO	4.8	4.5	0.6	0.3	0.4	0.3
PEN	---	---	---	---	0.4	0.5
CLO	---	---	---	---	0.5	1.0
ESF	---	---	---	---	1.2	0.6
IMI	7.8	2.3	0.8	0.9	1.1	1.4
PIC + ESF	---	---	---	---	0.6	0.5
TET + CLO	---	---	---	---	1.2	0.9
TRI + PRO + IMI	5.7	7.2	0.8	0.4	0.8	0.6
PEN + ESF	---	---	---	--	0.6	0.3
IPM	8.3		0.6		0.7	
CON	6.9		0.7		1.1	
$LSD_{(0.05)}$[w]	NS		0.3		0.7	

[z]Frogeye leaf spot severity is visually estimated as percent diseased area of 10 leaflets in each plot between R5 and R6.
[y]PIC=picoxystrobin (Approach®, Du Pont Crop Protection, Wilmington, DE), PYR=pyraclostrobin (Headline®, BASF Crop Protection, Beaumont, TX), TET=tetraconazole (Domark®, Valent, Walnut Creek, CA), TRI +PRO = trifloxystrobin + prothioconazole (Stratego® YLD, Bayer CropScience, Research Triangle Park, NC), PEN=penthiopyrad (Vertisan®, Du Pont, Wilmington, DE), CLO=clothianidin (Belay®, Valent, Walnut Creek, CA), ESF=esfenvalerate (Asana®, Du Pont Crop Protection, Wilmington, DE), IMI=imidicloprid (Leverage®, Bayer CropScience, Research Triangle Park, NC), IPM=integrated pest management (only sprayed aphids exceed economic threshold), CON=untreated control.
[x]Growth stage R1 is the beginning of flowering; growth stage R3 is the beginning of pod set.
[w]Least significant difference between means under the same location when alpha = 0.05.

Table 12. Moisture, protein, and oil from seed quality analysis 2008.

	Seed composition (%)[z]							
	Cass Co.		Floyd Co.		O'Brien Co.		Washington	
Treatment[y]	**R1[x]**	**R3[x]**	**R1**	**R3**	**R1**	**R3**	**R1**	**R3**
Moisture								
PIC	10.2	9.1	11.5	10.2	8.6	8.7	8.8	8.4
PYR	9.0	9.4	10.3	10.4	8.7	8.3	8.4	8.7
FLU	9.9	9.7	11.1	10.4	8.6	8.8	8.5	8.2
TRI + PRO	9.1	9.5	11.0	11.0	7.8	8.6	8.0	9.0
ESF	10.1	9.0	11.2	11.1	8.1	8.4	7.8	8.4
IMI	9.0	9.1	10.6	11.5	8.2	8.4	8.0	8.8
FLU + ESF	9.6	9.1	10.9	10.7	8.1	8.3	8.7	8.0
TRI +PRO + IMI	9.4	9.8	10.5	10.8	8.7	8.2	8.4	8.9
IPM	9.4		10.3		8.0		8.6	
CON	9.7		10.5		8.9		8.7	
$LSD_{(0.05)}$[w]	NS		NS		NS		NS	

[z]Seed composition was determined by use of near-infrared spectroscopy.
[y]PIC=picoxystrobin (Approach®, Du Pont Crop Protection, Wilmington, DE), PYR=pyraclostrobin (Headline®, BASF Crop Protection, Beaumont, TX), FLU=flusilazole (Punch®, Du Pont Crop Protection, Wilmington, DE), TRI +PRO = trifloxystrobin + prothioconazole (Stratego® YLD, Bayer CropScience, Research Triangle Park, NC), ESF=esfenvalerate (Asana®, Du Pont Crop Protection, Wilmington, DE), IMI=imidicloprid (Leverage®, Bayer CropScience, Research Triangle Park, NC), IPM=integrated pest management (only sprayed aphids exceed economic threshold), CON=untreated control.
[x]Growth stage R1 is the beginning of flowering; growth stage R3 is the beginning of pod set.
[w]Least significant difference between means within columns under the same location heading when alpha =0.05.

Table 12. (continued)

	Seed composition (%)[z]							
	Cass Co.		Floyd Co.		O'Brien Co.		Washington	
Treatment[y]	R1[x]	R3[x]	R1	R3	R1	R3	R1	R3
Protein								
PIC	34.9	34.3	34.7	34.5	33.9	34.0	35.2	34.5
PYR	34.3	34.9	34.6	34.0	34.1	33.8	35.0	34.5
FLU	34.9	34.7	35.0	35.0	34.1	33.8	35.1	35.2
TRI + PRO	34.9	34.3	35.5	34.2	34.2	34.1	35.1	34.2
ESF	35.3	34.1	34.5	34.5	33.7	33.4	35.2	34.8
IMI	34.8	34.2	34.3	33.9	33.6	33.5	35.4	35.3
FLU + ESF	35.0	34.2	34.7	34.5	33.2	33.5	35.2	34.6
TRI +PRO + IMI	34.8	34.1	34.5	33.9	33.7	33.5	34.9	34.4
IPM	35.0		34.8		33.3		35.6	
CON	35.3		35.0		33.7		35.4	
$LSD_{(0.05)}$[w]	NS		0.7		0.5		0.6	
Oil								
PIC	18.3	18.5	19.3	19.4			18.1	18.2
PYR	18.6	18.1	19.1	19.3	19.0	19.1	18.1	18.4
FLU	18.1	18.1	19.1	19.3	19.0	19.2	18.0	18.1
TRI + PRO	18.3	18.5	19.1	19.7	19.0	19.1	18.0	18.4
ESF	18.2	18.6	19.5	19.4	19.0	19.1	18.1	18.1
IMI	18.3	18.4	19.2	19.7	19.0	19.1	17.9	18.0
FLU + ESF	18.2	18.6	19.4	19.4	19.1	19.1	18.1	18.3
TRI +PRO + IMI	18.3	18.8	19.5	19.3	19.1	19.1	18.0	18.4
IPM	18.3		19.2		19.0		17.9	
CON	17.9		19.2		19.2		17.9	
$LSD_{(0.05)}$[w]	0.5		0.3		NS		0.2	

Table 13. Moisture, protein, and oil from seed quality analysis in 2009.

	Seed composition (%)[z]									
	Adair Co.		Floyd Co.		O'Brien Co.		Story Co.		Washington Co.	
Treatment[y]	**R1**[x]	**R3**[x]	**R1**	**R3**	**R1**	**R3**	**R1**	**R3**	**R1**	**R3**
Moisture										
PIC	7.9	8.2	6.4	6.5	10.0	9.3	6.7	6.5	6.1	6.4
PYR	8.9	8.2	6.2	6.2	8.5	10.6	6.6	6.6	6.1	6.4
TET	7.4	7.6	6.3	6.5	9.9	7.9	6.6	6.5	6.4	6.2
TRI + PRO	8.5	9.4	6.4	6.4	9.2	10.2	6.5	6.5	6.6	6.3
PEN	7.9	8.3	6.5	6.6	9.3	9.5	6.4	6.6	6.3	6.3
CLO	8.1	7.8	6.5	6.5	8.8	9.7	6.8	6.5	6.3	6.4
ESF	8.6	8.6	6.6	6.4	10.0	8.9	6.4	6.4	6.4	6.4
IMI	8.6	7.8	6.4	6.3	11.1	9.4	6.4	6.9	6.4	6.5

[z]Seed composition was determined by use of near-infrared spectroscopy.
[y]PIC=picoxystrobin (Approach®, Du Pont Crop Protection, Wilmington, DE), PYR=pyraclostrobin (Headline®, BASF Crop Protection, Beaumont, TX), TET=tetraconazole (Domark®, Valent, Walnut Creek, CA), TRI +PRO = trifloxystrobin + prothioconazole (Stratego® YLD, Bayer CropScience, Research Triangle Park, NC), PEN=penthiopyrad (Vertisan®, Du Pont, Wilmington, DE), CLO=clothianidin (Belay®, Valent, Walnut Creek, CA), ESF=esfenvalerate (Asana®, Du Pont Crop Protection, Wilmington, DE), IMI=imidicloprid (Leverage®, Bayer CropScience, Research Triangle Park, NC), IPM=integrated pest management (only sprayed aphids exceed economic threshold), CON=untreated control.
[x]Growth stage R1 is the beginning of flowering; growth stage R3 is the beginning of pod set.
[w]Least significant difference between means within the same column when alpha = 0.05.

Table 13. (continued)

	Seed composition (%)[z]									
	Adair Co.		**Floyd Co.**		**O'Brien Co.**		**Story Co.**		**Washington Co.**	
Treatment[y]	**R1[x]**	**R3[x]**	**R1**	**R3**	**R1**	**R3**	**R1**	**R3**	**R1**	**R3**
PIC + ESF	8.0	8.3	7.9	8.2	9.1	8.9	6.5	6.5	6.3	6.3
PYR + ESF	---	8.2	---	8.2	---	10.0	6.6	6.7	---	6.3
TET + CLO	7.4	7.6	7.9	8.2	10.6	10.2	6.6		6.5	6.3
TRI + PRO + IMI	8.7	8.0	6.3	6.4	9.6	8.9	6.4	6.5	6.4	6.6
PEN + ESF	8.0	8.3	7.9	8.3	7.7	8.8	6.5	6.5	6.3	6.3
IPM	8.2		8.2		9.9		6.5		6.3	
CON	8.8		8.8		8.8		6.6		6.4	
$LSD_{(0.05)}$[w]	NS		0.2		NS		NS		NS	
Protein										
PIC	36.2	36.1	36.2	36.1	35.1	35.3	34.9	34.8	35.2	35.3
PYR	36.1	36.0	36.1	36.0	34.9	34.4	34.9	34.4	35.6	29.6
TET	36.4	36.2	36.4	36.2	34.7	35.0	35.0	35.3	35.5	35.2
TRI + PRO	36.4	36.2	36.4	36.2	35.1	34.9	34.3	34.8	35.2	28.3
PEN	36.1	36.0	36.1	36.0	35.2	35.1	35.0	34.7	35.2	34.9

Table 13. (continued)

	Seed composition (%)[z]									
	Adair Co.		**Floyd Co.**		**O'Brien Co.**		**Story Co.**		**Washington Co.**	
Treatment[y]	**R1[x]**	**R3[x]**	**R1**	**R3**	**R1**	**R3**	**R1**	**R3**	**R1**	**R3**
CLO	36.3	36.3	36.3	36.3	35.2	34.4	34.8	35.0	35.5	35.4
ESF	36.0	36.2	36.0	36.2	34.9	34.8	35.0	34.1	35.3	35.5
IMI	36.1	36.0	36.1	36.0	34.3	34.6	34.6	34.3	34.9	35.6
PIC + ESF	36.2	36.1	36.2	36.2	34.9	34.7	34.8	34.4	34.9	35.4
PYR + ESF	---	36.1	---	36.1	---	34.0	---	33.8	---	35.3
TET + CLO	36.2	36.4	36.2	36.4	34.6	34.4	34.5	35.0	35.8	35.5
TRI + PRO + IMI	36.0	36.0	36.0	36.0	35.0	35.6	34.0	34.1	35.0	25.3
PEN + ESF	36.0	35.8	36.1	36.0	35.1	34.3	34.0	34.2	35.4	35.1
IPM	36.3		36.3		35.0		34.0		35.2	
CON	36.5		36.5		35.1		34.4		30.8	
$LSD_{(0.05)}$[w]	0.3		0.5		0.5		0.7		5.7	
Oil										
PIC	17.2	17.4	17.2	17.4	18.7	18.5	19.1	19.2	17.6	17.6
PYR	17.4	17.2	17.4	17.2	18.8	19.0	19.0	19.2	17.4	18.0
TET	17.2	17.2	17.2	17.2	18.9	19.7	18.9	18.8	17.6	17.7
TRI + PRO	17.2	17.4	17.2	17.4	18.6	18.7	19.4	19.0	17.7	17.3
PEN	17.3	17.3	17.3	17.3	18.6	18.6	18.9	19.1	17.6	17.8

Table 13. (continued)

	Seed composition (%)[z]									
	Adair Co.		Floyd Co.		O'Brien Co.		Story Co.		Washington Co.	
Treatment[y]	**R1**[x]	**R3**[x]	**R1**	**R3**	**R1**	**R3**	**R1**	**R3**	**R1**	**R3**
CLO	17.3	17.3	17.3	17.3	18.6	19.0	19.2	19.0	17.6	17.5
ESF	17.4	17.3	17.4	17.3	18.8	18.9	19.1	19.6	17.6	17.5
IMI	17.4	17.2	17.4	17.2	19.0	18.9	19.2	19.4	17.8	17.6
PIC + ESF	17.3	17.3	17.3	17.3	18.8	19.0	19.0	19.5	17.8	17.6
PYR + ESF	---	17.3	---	17.3	---	19.3	---	19.5	---	17.6
TET + CLO	17.3	17.2	17.3	17.2	18.9	19.0	19.5	18.9	17.4	17.6
TRI + PRO + IMI	17.4	17.2	17.4	17.2	18.7	19.0	19.6	19.4	17.7	17.8
PEN + ESF	17.3	17.5	17.3	17.5	18.6	18.6	19.6	19.4	17.6	17.6
IPM	17.2		17.2		18.9		19.8		17.7	
CON	17.2		17.2		18.6		19.3		17.4	
$LSD_{(0.05)}$[w]	NS		0.3		0.3		0.4		NS	

Table 14. Analysis of variance (ANOVA) by year and location for main effects treatment and rep anthracnose stem blight (ASB) severity and yield from data collected from fungicide-insecticide trials conducted across Iowa in 2008, 2009, and 2010.

		2008			2009			2010		
Source		**Df**	**F**	**P**	**Df**	**F**	**P**	**Df**	**F**	**P**
ASB										
Adair Co.	Trt	---	---	---	4	10.29	0.0002	---	---	---
	Rep	---	---	---	5	0.99	0.4524	---	---	---
Cass Co.	Trt	4	7.01	0.0038	---	---	---	---	---	---
	Rep	4	0.79	0.5529	---	---	---	---	---	---
Floyd Co.	Trt	4	6.76	0.0026	4	5.30	0.0059	2	3.64	0.0751
	Rep	4	0.38	0.8165	5	0.50	0.7731	5	0.59	0.7104
Hancock Co.	Trt	---	---	---	---	---	---	---	---	---
	Rep	---	---	---	---	---	---	---	---	---
O'Brien Co.	Trt	4	10.22	0.0008	4	6.69	0.0038	2	1.33	0.3183
	Rep	4	0.89	0.4999	5	1.11	0.4022	5	1.19	0.3929
Story Co.	Trt	---	---	---	4	2.58	0.0830	4	1.55	0.2253
	Rep	---	---	---	4	0.84	0.5223	5	1.37	0.2761
Washington Co.	Trt	4	4.25	0.0135	4	3.14	0.0419	---	---	---
	Rep	5	0.74	0.6031	5	1.00	0.4454	---	---	---

Table 14. (continued)

		2008			2009			2010		
Source		**Df**	**F**	**P**	**Df**	**F**	**P**	**Df**	**F**	**P**
Yield (kg ha^{-1})										
Adair Co.	Trt	---	---	---	4	1.47	0.2476	---	---	---
	Rep	---	---	---	5	2.59	0.0583	---	---	---
Cass Co.	Trt	4	0.64	0.6400	---	---	---	---	---	---
	Rep	4	1.95	0.1511	---	---	---	---	---	---
Floyd Co.	Trt	4	1.78	0.1827	4	0.31	0.8658	2	0.61	0.5606
	Rep	4	3.62	0.0277	5	0.98	0.4541	5	0.40	0.8306
Hancock Co.	Trt	---	---	---	---	---	---	---	---	---
	Rep	---	---	---	---	---	---	---	---	---
O'Brien Co.	Trt	4	4.60	0.0115	4	0.94	0.4602	2	1.64	0.2413
	Rep	4	9.64	0.0004	5	1.79	0.1603	5	1.23	0.3655
Story Co.	Trt	---	---	---	4	3.06	0.0473	4	3.61	0.0227
	Rep	---	---	---	4	0.65	0.6359	5	1.21	0.3426
Washington Co.	Trt	4	2.87	0.0498	4	0.26	0.9028	---	---	---
	Rep	5	0.91	0.4928	5	1.24	0.3290	---	---	---