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When Do Foliar Pyraclostrobin Fungicide Applications Produce Profitable Soybean Yield Responses?

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Abstract

From 2005 through 2009, 282 on-farm evaluation trials were conducted in soybean fields across Iowa to identify when a foliar application of pyraclostrobin produced profitable yield responses. Because of a delay in plant maturity, 218 trials exhibited a fungicide-induced "greening effect" documented using the late-season color infrared (CIR) digital aerial imagery of the soybean canopy. These 218 trials were approximately 35% more likely to produce profitable yield responses (65% vs 30%) than those without "the greening effect." In addition, greater yield responses were observed in trials that received more than 12 inches of cumulative March through May rainfall. Potentially, site-specific observations of spring rainfall could be used to identify fields that are or are not likely to produce above break-even yield responses, and therefore, help farmers avoid unnecessary foliar fungicide applications on soybean.

Introduction

Foliar fungicides are routinely used to manage soybean diseases in the southern United States. However, in the upper Midwest, fungicides were rarely used prior to 2004, when *Phakopsora pachyrhizi* Syd. & P. Syd. 1914, the causal organism of soybean rust, was first discovered in Louisiana (13). The agrichemical industry responded to the soybean rust threat by making available several foliar fungicides for soybean because soybean cultivars with resistance to soybean rust were not commercially available (11). At first (from 2005 through 2010), foliar fungicides were made available through emergency labels (Section 18) but then several of these fungicide chemistries received full labels (Section 3) for use on soybean. Many of the commonly used fungicides were strobilurin fungicides (FRAC CODE 11), where other fungicides commonly used on soybean included triazole fungicides (FRAC CODE 3) or pre-mixes of strobilurin and triazole fungicides (10).

Prior to 2004, fungicides were used sparingly in soybean production in Iowa. Even though the threat of soybean rust has not been realized to date, the use of foliar fungicides in soybean production has increased considerably within the state. Reasons for this include higher market grain prices and the need for better management of existing foliar diseases such as 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) (10). Because of relatively high soybean prices in recent years, soybean yield responses required to produce positive economic returns to foliar fungicide applications have been minimal (1).

Research on applications of strobilurin fungicides on various field crops has suggested that there are benefits beyond disease management (3), which may come from affecting various metabolic pathways (6). The potential fungicidal effect on these pathways may lead to various outcomes, including increased drought tolerance and induced systemic resistance to disease. Therefore, foliar fungicide applications are often promoted for their potential nonfungicidal physiological effects or improved "plant health" (4). The overall idea is that the application of a strobilurin fungicide will protect the plant from harmful foliar diseases and potential stress, both possibly resulting in greater yields.

In Iowa, a study conducted at three locations with four soybean cultivars in 2005 and 2006 found no significant yield response to foliar pyraclostrobin when applied at reproductive soybean growth stages such as R1, R3, and R5 (14). However, recent studies in Iowa found positive yield responses in the presence of foliar diseases and suggested a greater probability of profitable return from strobilurin than triazole applications (1).

The objective of this study was to use field-scale on-farm evaluation trials conducted by farmers across Iowa from 2005 through 2009 using precision agriculture technologies to study foliar pyraclostrobin applications on soybean and identify when these applications produce profitable yield responses.

Farmers Conducted On-Farm Evaluation Trials to Measure Soybean Yield Response to Fungicide Applications

Two hundred eighty-two on-farm evaluation strip trials were conducted by farmers across Iowa from 2005 through 2009 (Fig. 1). Each trial had two treatments that included pyraclostrobin fungicide-treated and non-treated strips alternated three to 14 times (Fig. 2). In most trials, fungicide treatments were made using typical ground spraying equipment; however, aerial applications were made in 14 trials. Depending on the width of the application equipment, trials covered from 15 to 30 acres within typical 60 to 80-acre soybean production fields. Pyraclostrobin was applied at a rate of 6 oz/acre with non-ionic surfactant at 0.25% v/v for ground and with crop oil concentrate for aerial applications. The amount of water used ranged from 10 to 20 gal/acre for ground applications and 3 to 5 gal/acre for aerial applications. A single soybean variety was planted in each trial and all other management practices were the same. Soybean varieties planted ranged in maturity from late MG1.7 to early MG3.5 across the state.

Applications were made from growth stages R1 (flowering) to R3 (podset) (2), with more than 60% of the trials receiving a pyraclostrobin application at growth stage R3. Locations of fungicide strips were recorded with on-board GPS systems in all 14 trials that received aerial fungicide applications and in approximately 90% of the trials that received ground fungicide applications. In the remaining 10% of the trials, farmers flagged the strips during fungicide applications and recorded GPS coordinates of each strip later during the growing season.

Treatments were alternated within each trial to help farmers accommodate treatment applications, allow researchers to verify treatment locations and conduct analysis of yield responses observed at both field and within-field (spatial observations) levels. All discussions in this article are focused only on field-level mean yield responses. More information about the purpose, methodology, and statistical analysis of observations collected in similar on-farm evaluation trials can be found in previous studies published by Kyveryga and Blackmer (7) and Kyveryga et al. (9).

Color-infrared (CIR) digital aerial images, composed of the near-infrared (NIR), red, and green spectral bands of the soybean canopy taken in each field in mid or late August (R6, R7, and R8 growth stages) were used to verify treatment locations, identify possible application errors, and other potential management problems within fields (Fig. 2). Specific characteristics and methods for collecting and processing digital aerial imagery used in this study were identical to those published by Kyveryga et al. (8).

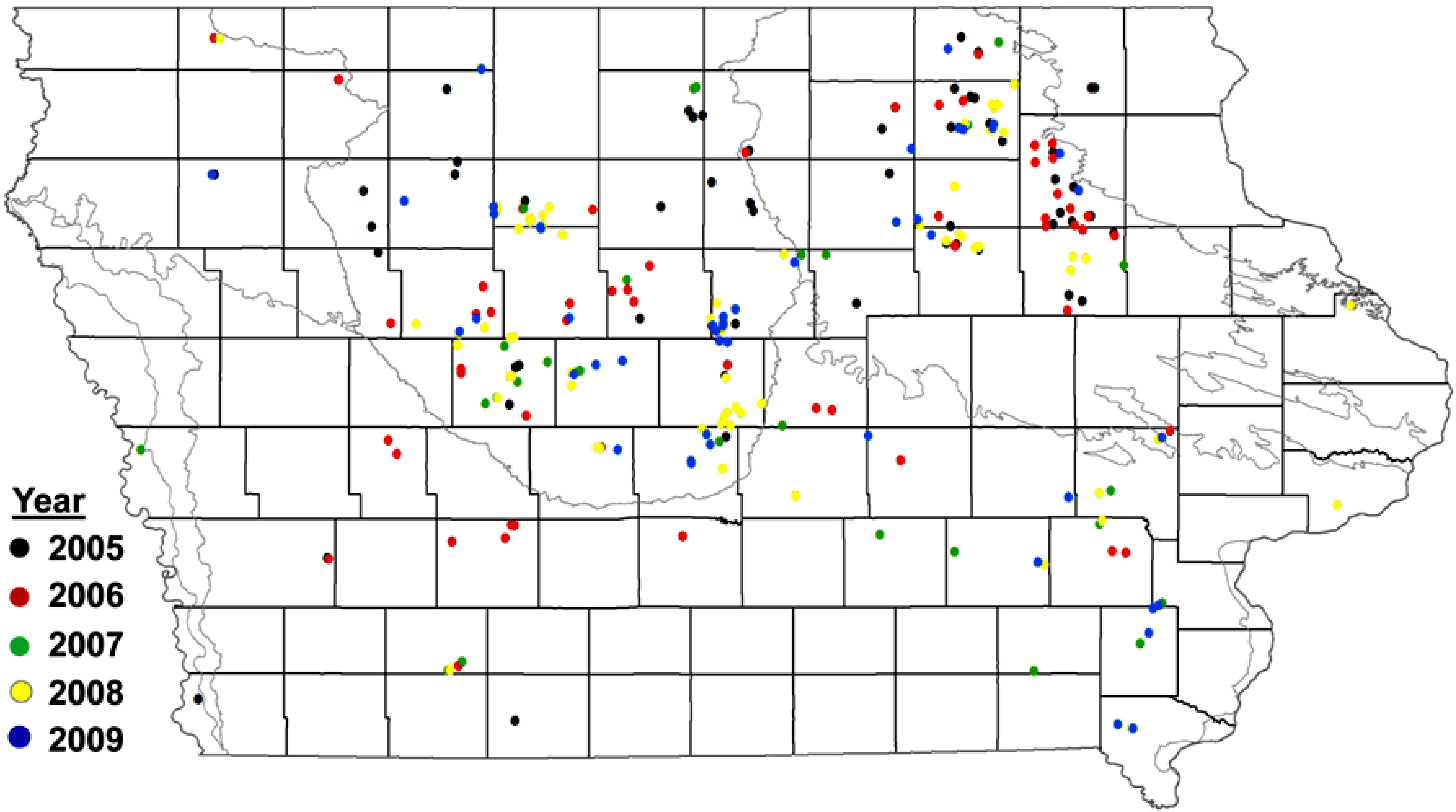

Fig. 1. Locations of 282 on-farm evaluation trials conducted between 2005 and 2006 across Iowa to identify factors that affected yield response of soybean to foliar pyraclostrobin applications.

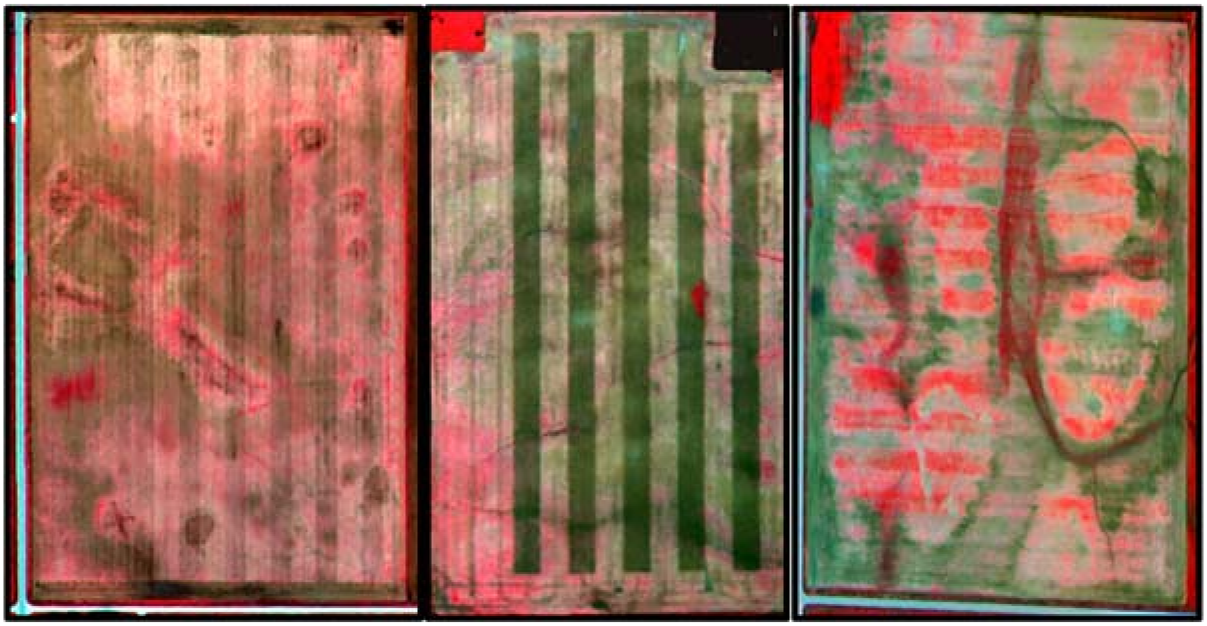

Fig. 2. These late-season color-infrared (CIR) images show three common examples of "the greening effect" of the soybean canopy from pyraclostrobin applications within three on-farm evaluation trials conducted in 2008 and 2009. The darker red color on the imagery indicates more vigorous soybean plants with greater biomass and/or greater chlorophyll content in fungicide-treated strips than in non-treated strips.

Color-infrared images show a range (from dark red to light green) in plant biomass, leaf area, and leaf chlorophyll content. Unlike color images, CIR images show the NIR reflectance of the soybean canopy by assigning the NIR band a red color. The dark red color of the soybean canopy on CIR imagery indicates growing plants with greater biomass, leaf chlorophyll content and larger leaf area. The light red, light or dark green colors on imagery indicate less vigorous soybean plants or plants that are either injured, diseased, or closer to physiological maturity than other plants within a field. The CIR imagery showed the so-called "greening effect" from pyraclostrobin applications in approximately 80% of the trials (Fig. 2). In these trials, strips receiving pyraclostrobin had much darker red color than non-treated strips.

Researchers studied the CIR imagery of each trial to determine whether soybean plants had already changed leaf color from green to yellow (approximately growth stage R6) or had started dropping leaves or had become completely defoliated (i.e., late R7 or R8 growth stage) at the time the imagery was taken. Soybean yields were measured by yield monitors equipped with GPS. Spatial yield observations were cleaned for potential outliers by removing yield observations located around flooded areas, waterways, terraces, or buffer strips. Yield responses to pyraclostrobin were estimated as mean yield differences between fungicide-treated and non-treated strips for each trial. Effects of field-level factors (e.g., crop stage, monthly average rainfall, cumulative spring or summer rainfall) on trial-level yield responses were tested using mixed linear models ($P < 0.1$), with trial location and year specified as random, and all other factors specified as fixed effects (R Development Core Team, 2009). Monthly rainfall estimates for trial locations were obtained by overlaying trial boundaries with 4-km radar interpolated rainfall grids downloaded from the Iowa Environmental Mesonet (5).

Magnitude and Frequency of Soybean Yield Response to Fungicide

Across all trials in each year, the average soybean yield response to fungicide ranged from 1.7 to 3.7 bu/acre (Table 1). Across all trials during five years, the average yield response was 2.4 bu/acre. This is slightly greater than a profitable (break-even) yield response of approximately 2 bu/acre. The break-even yield response was estimated using five-year average soybean market price of $9/bu and the cost of fungicide applications (assuming farmers used their own application equipment) of $18/acre. Using the estimated break-even yield response, approximately 55% of the trials had a profitable yield response across five years, with 41% of trials having a profitable yield response in 2005; 65%, in 2006 and 2007; 59%, in 2008; and 45% of trials in 2009 (Table 1).

Table 1. Soybean yield response to applications of the fungicide pyraclostrobin in 282 on-farm evaluation trials conducted across Iowa from 2005 through 2009.

Year	**No. of trials**	**Avg.**[ab] **soybean yield of untreated strips** (bu/acre)	**Avg. (median) yield response to fungicide** (bu/acre)	**% of trials w/ yield response greater than a break-even of 2 bu/acre**[c] (%)
2009	49	54.2	2.0 (1.7)[ab]	45
2008	77	53.3	2.7 (2.3)	59
2007	36	57.9	3.7 (2.5)	65
2006	61	56.4	2.2 (2.2)	65
2005	59	60.9	1.7 (1.7)	41
Pooled avg.		56.5	2.4	55

[ab] Statistically significant yield difference (*P* = 0.1) between treated and non-treated strips in each year and across all five years.

[c] Assuming an average soybean price of $9/bu and a fungicide application cost of $18/acre.

Field-average yield responses were approximately 0.5 to 2 bu/acre greater in relatively wet years (2007 and 2008) compared to the relatively dry years, such as 2005 and 2006 (Table 1). Average monthly spring and summer rainfall for trial locations in 2007 and 2008 were above the 30-year monthly statewide averages (Fig. 3). Average rainfall for trial locations in 2006 was below the long-term average during May, June, and July. The average yield response in 2009, a year with approximately normal monthly rainfall across the state, was 2 bu/acre, with the same median yield response of 1.7 bu/acre observed in a relatively dry 2005.

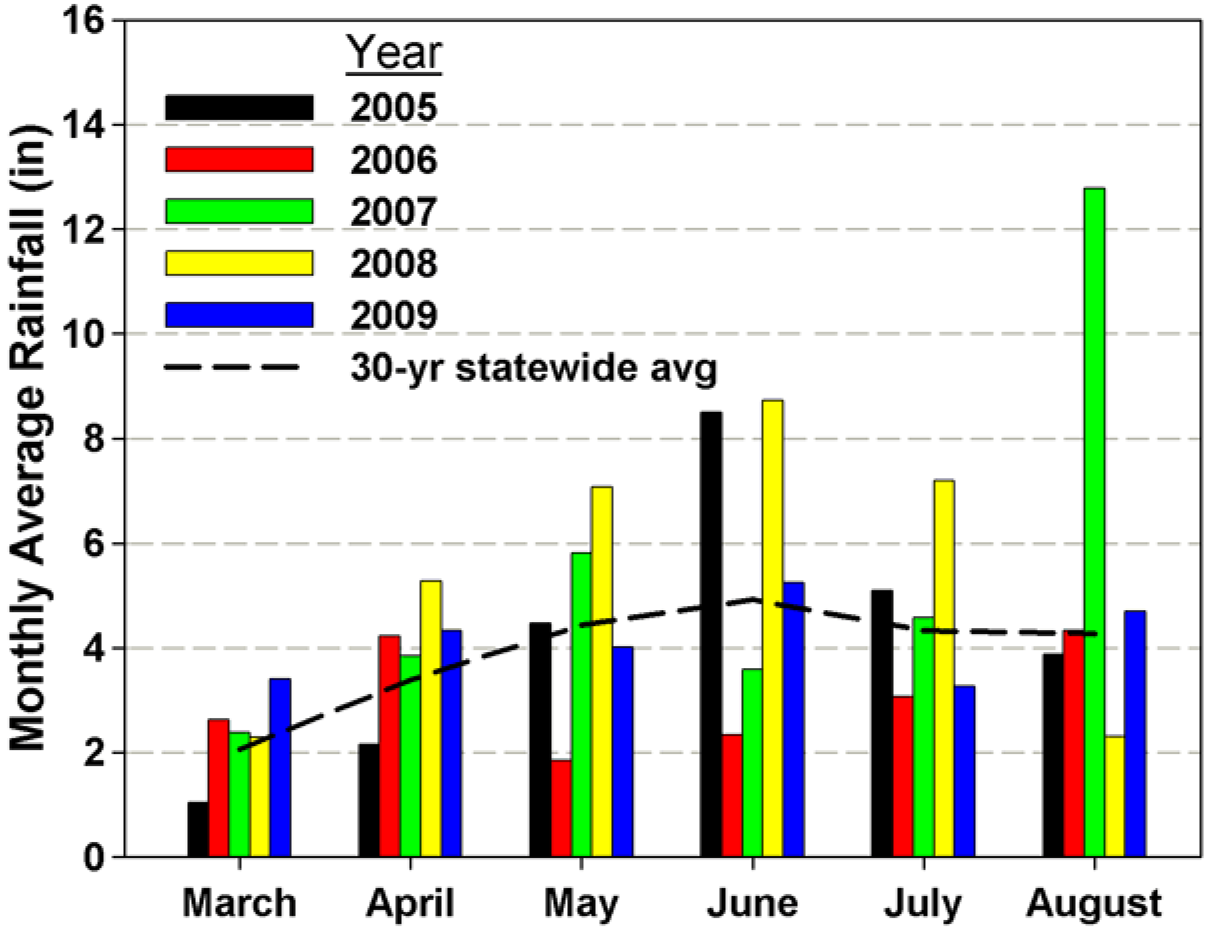

Fig. 3. Average site-specific rainfall for on-farm evaluation trials conducted in each year of the study and 30-year average monthly rainfall across Iowa.

A greater frequency of fungal foliar diseases would be expected in relatively wet years, especially with above-normal summer rainfall. While disease observations were not made in any of these trials, overall disease pressure was low (farmers' *personal observations*). Furthermore, disease ratings made in Iowa State University studies showed low levels of foliar diseases (< 3%) in the upper canopy in most counties across the state during 2005 and 2006 (12) and at five agronomy research farms during 2008 and 2009 (1).

Field-Level Factors Affecting Soybean Yield Response to Fungicide

Across all trials, average field-level yield responses to fungicide treatments tended to be greater with increasing spring (cumulative from March through May) rainfall (Fig. 4). This is a surprising observation because other field-level factors, including monthly average rainfall during the growing season, cumulative summer rainfall, soybean growth stage during application or soybean yield of non-treated strips, had no significant effect on yield response across all years. Variation in yield response also increased with the increasing amount of spring rainfall (Fig. 4). Additional analyses showed that approximately 35% of the trials had a profitable yield response in the lowest and 65% in the two highest categories of cumulative spring rainfall as presented in Fig. 4. Also, the majority of trials with above-normal spring rainfall (>12 inches) were located in the southern and northeastern portions of the state during the five years (Fig. 1). A possible explanation for the greater yield response with above normal spring rainfall could be that soybean plants with poorly developed root systems during wet springs were more likely to respond to foliar strobilurin applications

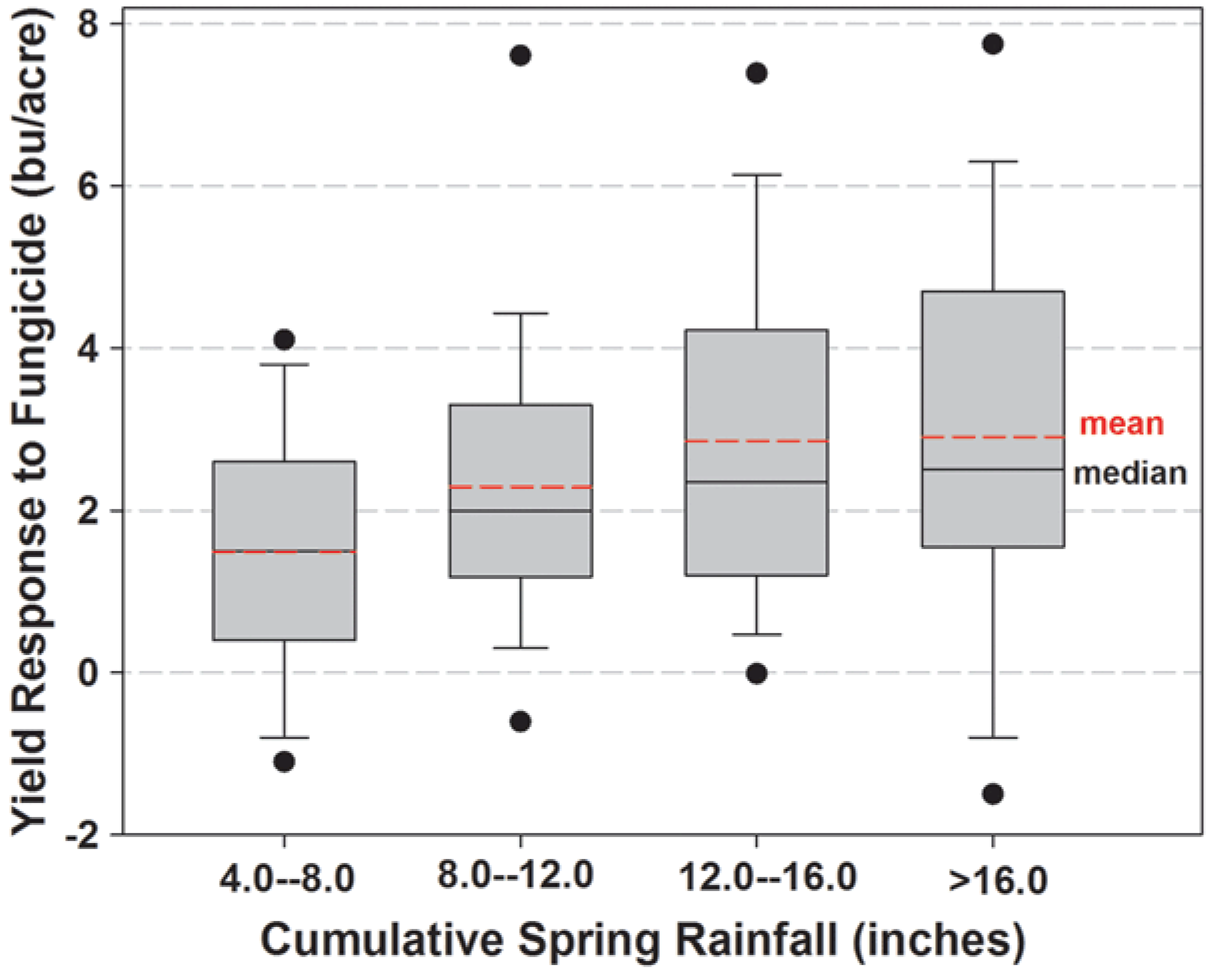

Fig. 4. Soybean yield response to applications of pyraclostrobin for four categories of cumulative spring (from March through May) rainfall observed in 282 on-farm evaluations trials conducted between 2005 and 2009. Wisker caps of the box plots show 5th and 95th percentiles.

Trials with Visual "Greening Effects" had Greater Probability of Profitable Yield Response

Two hundred eighteen trials showed the "greening effect" in the late-season digital aerial imagery of the soybean canopy (Fig. 2), where strips treated with pyraclostrobin had red (or darker red) color on the imagery, indicating greater soybean biomass and/or greater plant chlorophyll content compared to the non-treated strips. Classifying all trials into two categories based on visual differences between the two treatments showed that trials with fungicide-induced visual strips had an approximately 65% probability of profitable yield response compared with 30% of that in trials without visual strips (Fig. 5).

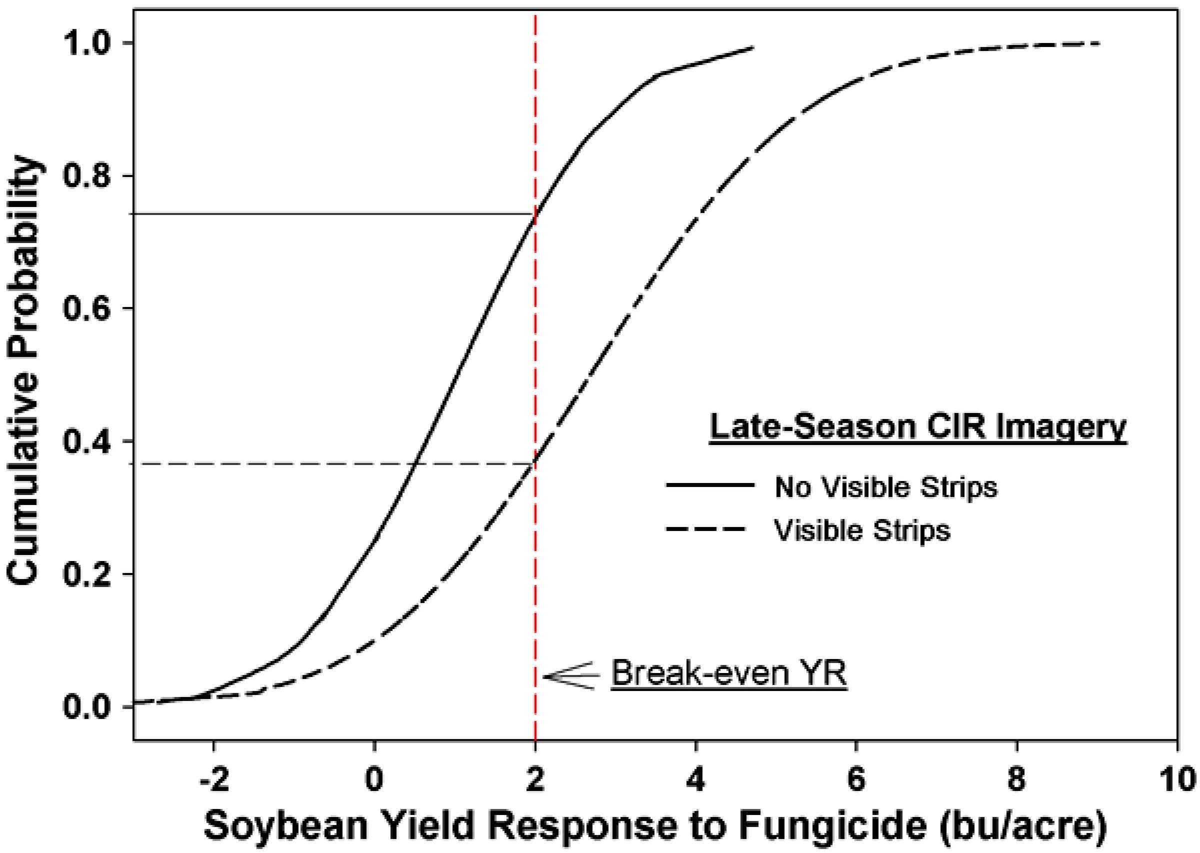

Fig. 5. Cumulative probability distributions of field-level yield response (YR) to pyraclostrobin applications in 218 trials with and in 48 trials without visible fungicide strips exhibiting the "greening effect" as observed on the late-season color-infrared (CIR) digital aerial imagery of the soybean canopy. Cumulative distribution curves indicate a probability of yield response at a specific value and below. For example, there was approximately 35% probability of a yield response at and below the break-even (2 bu/acre) for trials showing the fungicide-induced "greening effect." Probability of profitable yield response can be estimated as the distance from 1 on the Y axis to the intersection of each curve with the break-even yield response line.

The greater yield response in fields showing visible strips could be explained by a delay in senescence within the fungicide-treated strips. Delaying senescence is one of the non-specific physiological effects of using pyraclostrobin on crops that do not show symptoms of foliar fungal diseases (6). It is speculated that the delayed soybean senescence may help to extend grain filling period and increase the supply of dry matter to soybean seeds. It is difficult, however, to estimate the exact number of days the soybean senescence was delayed because the imagery was taken at different times and soybean plants in some fields may have already senesced before the imagery was collected. However, a two-fold increase in the probability of economic yield response in the visible strips was significant because the two cumulative probability curves of yield response in Figure 5 do not intersect

A quantitative analysis of the digital aerial imagery showed that the fungicide-treated strips had digital reflectance values for the NIR spectrum of approximately 25% greater than that for the non-treated strips, indicating larger soybean biomass or leaf area from the fungicide applications (data not shown). In addition, field-level differences in reflectance values between the treated and non-treated strips positively correlated ($r = 0.46$) to field-average yield response observations across all trials in 2007 and ($r = 0.48$) in 2008, but not in other years.

Indirectly, the fungicide-induced "greening effect" can be inferred by measuring grain moisture and combine speed during the harvest. The grain moisture was consistently greater and combine speed was consistently slower in the fungicide-treated strips than in non-treated strips (data not presented). However, differences in grain moisture (about 0.1%) and combine speed (about

0.1 mph) were relatively small. Additional calculations indicated that this average decrease in combine speed would add approximately 6 min of additional time to harvest a typical soybean field of approximately 70 acre with a 30-foot combine header. Therefore, the "greening effect" does not substantially change the cost and time associated with harvesting fungicide-treated fields.

The percentage of trials showing visual treatment effects, based on the CIR imagery in each category of the spring rainfall (Fig. 4), was almost the same, approximately 80% (*data not presented*). Only the highest category of the spring rainfall (>16 inches) had a slightly greater percentage of trials (approximately 90%) showing the visual fungicide effects. Therefore, the spring rainfall could not be solely used to explain the frequency of visual differences on the late-season CIR imagery. However, the average yield responses for the trials with detectable visible strips and with spring rainfall >12 inches were approximately at the break-even yield response of 2 bu/acre (Fig. 6). The average yield responses for the trials with non-visible strips and with spring rainfall < 12 inches were less than 1 bu/acre. These observations suggest that the effects of spring rainfall and the observed greening of the soybean canopy on yield response were independent and both these factors could be used to explain variation in yield response. In addition, across all trials, this study suggests no economic benefits from fungicide applications in fields with below normal spring (Fig. 4) or summer rainfall across five years (*data not presented*), dismissing the potential non-specific fungicidal effects in below normal rainfall conditions.

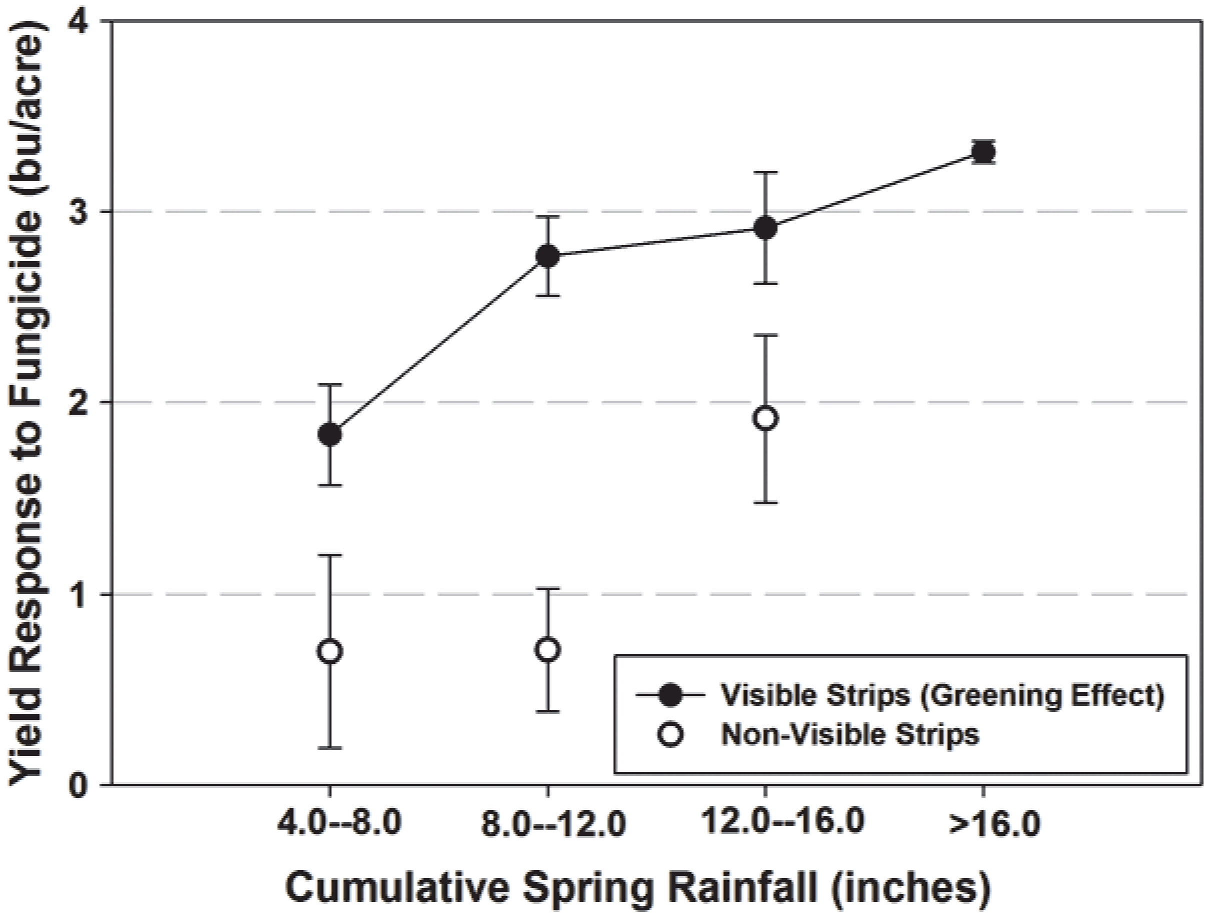

Fig. 6. Average soybean yield response to pyraclostrobin applications for categories of trials based on cumulative spring rainfall and visual differences between fungicide-treated (the greening effect") and non-treated strips as observed by the late-season CIR digital imagery of the soybean canopy. Means are shown with 90% confidence intervals. The graph shows results of 282 on-farm trials conducted between 2005 and 2009. Data for the highest category of spring rainfall (>16 inches) had only three observations for trials without visual differences and not shown on the graph.

If the relationship between yield response to pyraclostrobin and spring rainfall are consistent across a wide range of conditions, we can use long-term rainfall data shown in Figure 3 to estimate the historical frequencies of above-normal spring rainfall to predict the odds of profitable yield response to fungicide applications in different regions of Iowa. For example, northeastern Iowa, on average, receives more than 12 inches of spring rainfall 1 in 2 years, while central Iowa receives this amount of spring rainfall 1 in 3 years. The frequency of foliar fungal diseases (e.g., frogeye brown spot, soybean rust) in the upper canopy is relatively low. Predicting when these diseases limit yield is difficult, as many factors such as variety, in-season weather, and crop management practices will influence the frequency. In general, these diseases rarely cause yield losses in Iowa.

The ability to predict where pyraclostrobin applications can produce a profitable yield response in soybean without foliar fungal disease is important for managing potential resistance to fungicide products. Unlike the fungicide-induced "greening effect," which can only be observed toward the end of the growing season, observations of spring rainfall may help identify potentially responsive fields, allowing farmers to make more reliable decisions about whether or not to consider in-season foliar fungicide applications.

While we cannot identify with high certainty the main causes of increased yield responses in fields with above-normal spring rainfall, this finding can be used to design additional controlled studies in many locations across the state. These studies may shed light on why soybean plants are more likely to respond to fungicide after relatively wet springs and identify the average time of delaying soybean senescence in fungicide-treated strips. Additional studies are currently underway to identify whether spatial factors (e.g., field topography, soil moisture, soil drainage class) affect yield response variability at field and within-field levels. Even though the observed increases in plant greenness increased the likelihood of a positive yield response, caution should be taken. The increased use of a single fungicide class in blanket foliar applications could result in an increased risk of fungi developing resistance (10).

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