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A Two-Stage Approach for Estimating the Value of Damage Control with Fungicide in Soybean Production

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A Two-Stage Approach for Estimating the Value of Damage Control with Fungicide in Soybean Production

Abstract

Little is known about the profitability of treating soybean infected with frogeye leaf spot (FLS) with a foliar fungicide. We determine the economic effect of total water applied, growing degree days, and foliar fungicide treatment on FLS severity and yield of soybean MG III, IV, and V with a two-stage severity/treatment outcome model. Data were collected from an 11-year soybean fungicide experiment in Tennessee under high, natural disease pressure. The marginal value product and the breakeven price of soybean for applying a foliar fungicide to treat FLS were estimated for each MG. Applying foliar fungicide reduced FLS severity and increased yields for each MG. The results suggest a profit-maximizing producer would apply a foliar fungicide each year to manage FLS.

Keywords: Damage Abatement; Frogeye Leaf Spot; Fungicide; Soybean Two-Stage Regression

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Introduction

Soybean (*Glycine max* L.) production in the United States has expanded over the last decade to cover 86.2 million acres harvested, producing a total of 3.9 billion bushels valued at over $40 billion in 2012 (United States Department of Agriculture National Statistical Service (USDA NASS), 2014). This is approximately a 250% increase in soybean cash receipts since 2000 (USDA Economic Research Service (ERS), 2015). This expansion in soybean production has occurred across the United States, but especially in the north-central plains and the southeastern states. Soybean acres have increased in Kentucky, Louisiana, Mississippi, and Tennessee by over 500,000 acres per state since 2005, surpassing all other crops in cash receipts (USDA NASS, 2015). With this expansion in soybean production in the Southeast, an emerging challenge confronting producers is the management of the fungal pathogen called "frogeye leaf spot" (FLS) (Mian et al., 2008) (*Cercospora sojina* Hara.).

FLS is primarily a foliar disease but can infect the stems, pods, and seeds of soybean (Westphal, Abney, and Shaner, 2006). Grey lesions with a purple or red-brown margin are formed on the foliage that reduces the green area, thereby decreasing the leaf photosynthetic capability. This causes premature defoliation and yield loss (Mian et al., 2008). Severity levels of FLS are rated as a percentage of the leaf area affected by FLS (Sinclair, 1982), the higher the percentage of the leaf area that is covered with FLS, the less area available for photosynthesis, reducing yield (Mian et al., 2008). Depending on the severity of FLS, yield loss has been reported up to 60% of the treated yield potential (Akem and Dashiell, 1994; Dashiell and Akem, 1991; Laviolette et al., 1970; Bernaux, 1979; Ma, 1994; Mian et al., 1998).

The warm, wet, and humid climate of the southeast United States is ideal for FLS to overwinter in diseased crop residue, which is thought to be responsible for the initiation and

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development of FLS outbreaks in the Southern United States (Phillips, 1999; Mengistu et al., 2014; Mian et al., 2008; Walker et al., 1994). In Tennessee, approximately 75% of all crop acres are commonly planted without using tillage (USDA NASS, 2015), referred to as no-till, to control soil erosion and provide other agronomic and economic benefits (Toliver et al., 2012). However, no-till production systems could be exacerbating FLS dispersal (Mengistu et al., 2014). The interaction between climate and no-till production results in FLS outbreaks being more frequent in the southeast than other areas of soybean production (Mengistu et al., 2014; Mian et al., 2008; Walker et al., 1994), making FLS one of the most economically damaging diseases in the region (Newman, 2013). Recent reports, however, suggest that the severity and prevalence of FLS in northern states such as Ohio, Wisconsin, and Iowa have increased in recent years, (Cruz and Dorrance, 2009; Dorrrance et al.; 2010; Wrather and Koenning, 2006; Yang, Uphoff, and Sanogo, 2001).

FLS pressure can be reduced by early planting (Akem and Dashiell, 1994), using cultivars with FLS resistance (Mian et al., 1998), rotating crops (Mwase and Kapooria, 2000), and planting seeds treated with fungicide (Poag et al., 2005). A producer could adopt management practices to lower the probability of a FLS outbreak in a given year, but these practices cannot guarantee a FLS or other foliar disease outbreaks will not occur. Thus, a foliar fungicide application might be necessary in addition to using other preventative measures. Foliar fungicide spray is not capable of reducing or eliminating FLS infections already present on plants, but the purpose of spraying is to protect uninfected growth to reduce further yield loss (Akem and Dashiell, 1994; Dashiell and Akem, 1991).

Reduction in further yield loss from applying foliar fungicide has varied across climate and production system (Akem and Dashiell, 1994; Dashiell and Akem, 1991; Mengistu et al.,

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2014; Mwase and Kapooria, 2000). For example, soybean yields that were non-treated with a foliar fungicide were 5% to 66% lower than soybean yields treated with a foliar fungicide in Nigeria (Akem and Dashiell, 1994; Dashiell and Akem, 1991). In Zambia, soybean yields increased 31% to 37% when a fungicide was applied to control FLS (Mwase and Kapooria, 2000). In the United States, treating soybean for FLS increased yields from zero to 37% across several locations in the southern states (Mian et al., 1998). Recently, in Tennessee, non-treated soybean yields were 17% lower than treated soybean (Mengitsu et al., 2014). These studies provide evidence that foliar fungicide application during the growing season can improve soybean yield by preventing further FLS infection.

However, the profitability of using foliar fungicide to manage FLS mid-growing season has never been evaluated in Tennessee or the southeast United States. A challenge many producers in the southeast and across the United States are confronted with is determining if the revenue gains from avoiding yield loss with a foliar fungicide application (marginal value product) is greater than the cost of applying the foliar fungicide (marginal factor cost). Studies have measured threshold fungus levels where an application of foliar fungicide is profitable, but this methodology does not provide accurate estimates of the marginal value product of damage abatement inputs (Norwood and Marra, 2003). Furthermore, FLS severity and other diseases can vary within a field, making it hard to know the overall FLS severity in a field and if the threshold level has been exceeded. Thus, a producer might be better off applying a recommended rate of foliar fungicide annually based on plant maturity and cultivar disease resistance rather than applying foliar fungicide based on severity levels of FLS. This practice may especially be important in the warmer climate of the southeast United States and Tennessee where no-till production systems are common (Mengistu et al., 2014).

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The objective of this study was to determine the effect of total water applied (rainfall plus irrigation), growing degree days, and foliar fungicide treatment on FLS severity and yield of soybean maturity groups (MG) III, IV, and V with a two-stage severity/treatment outcome model. Field level soybean yields and FLS severity data were collected from an 11-year soybean cultivar-fungicide experiment in Tennessee. Using regression estimates, the marginal value product of foliar fungicide and the breakeven price of soybean for applying a foliar fungicide to treat FLS was calculated for each MG. Results from this study could provide insight into the profitability of treating FLS with foliar fungicide.

Conceptual Framework

In agricultural production, some inputs such as pesticides, insecticides, and fungicides are not yield increasing inputs (such as fertilizer and irrigation) but are applied to manage or control damage to limit yield loss (Lichtenberg and Zilberman, 1986). Lichtenberg and Zilberman (1986) demonstrated when a damage abatement input (such as pesticides, insecticides, and fungicides) is treated as a yield increasing input in a production function, the marginal productivity of the damage abatement input will be overestimated. They specified a framework that analyzed these types of inputs with a damage abatement function concurrently with a crop production function. Babcock, Lichtenberg, and Zilberman (1992) empirically tested Lichtenberg and Zilberman's (1986) theoretical model by estimating yield (i.e., production function) and pest pressure (damage abatement function) as a simultaneous system of equations and compared the results to a yield function that incorporated the damage abatement inputs into the production function. They found the marginal value product of the pesticide was more accurately estimated following Lichtenberg and Zilberman's (1986) framework. Additional studies extended

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Lichtenberg and Zilberman's (1986) model to other damage abatement inputs (Carrasco-Tauber and Moffitt, 1992; Elbakidze, Lu, and Eigenbrode, 2011; Kuosmanen, Pemsl, and Wesseler, 2006; Lansink and Carpentier, 2001; Lichtenberg and Zilberman, 1986; Norwood and Marra, 2003; Qaim and De Janvry, 2005; Saha, Shumway, and Havenner, 1997).

Many of the studies adapted Lichtenberg and Zilberman's (1986) study by using a different functional form for the production and/or damage abatement function as well as unique estimation procedures. For example, Saha, Shumway, and Havenner (1997) included interactions between yield increasing inputs and damage abatement inputs, and Lansink and Carpentier (2001) showed that using a quadratic functional form for the production and damage abatement function was appropriate for their dataset. Norwood and Marra (2003) concluded that the marginal value product of pesticides had downward bias if pest pressure (or disease severity) was not explicitly included in their unique production function. Elbakidze, Lu, and Eigenbrode (2011) presented how weather variables can affect both yield and pest outbreak using a simultaneous equation model. They concluded that favorable weather variables for yield could also increase the impact of pest outbreak, thus, yield damage depended on the magnitude of the weather effects on pest outbreak. They noted the importance of including weather variables in both the production function and damage abatement function.

Building on previous research, we model a producer's decision to apply foliar fungicide on an annual basis while simultaneously considering FLS severity. The vast majority of the previous research has developed damage abatement functions for pesticides and insecticides. Models for foliar fungicide are less common. In this study, soybean yield (bu/acre), y, was defined as a function of total water (irrigation, I, plus rainfall, R), growing degree days, G, and the damage function for FLS severity D, where D is the percent leaf area covered by FLS (

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$0 \le D \le 1$). The damage abatement was defined as a function of total water, growing degree days, and foliar fungicide treatment *F*. We assume a producer maximizes profits by choosing to apply a foliar application of fungicide to soybean, which is expressed as

(1) $\max_F E(\pi_F) = py(R + I, G, D(F, R + I, G)) - wF$,

where $E(\pi_F)$ is the expected net return in $/acre; *p* is the price of soybean in $/bu; and *w* is the total cost of foliar fungicide application, which includes the fungicide cost and machinery cost to make the application in $/acre. A producer would choose to apply foliar fungicide if the marginal value product from foliar fungicide was greater than the marginal factor cost of foliar fungicide, otherwise the producer would not apply foliar fungicide. Therefore, the first order condition with respect to fungicide *F* determines if the producer would or would not apply foliar fungicide. Furthermore, the total cost of the foliar fungicide treatment can be divided by the estimated yield gain from the foliar fungicide treatment (i.e., marginal physical product) to find the breakeven price of soybean a producer would need in order to pay for the treatment cost.

Data

Soybean yield data for MG III, IV, and V were obtained from the cultivar trials conducted at the University of Tennessee Milan Research and Education Center located in Milan, TN (35°56′ N, 88°43′ W) from 2003 to 2013. The experiment was conducted on predominantly Grenada silt loam soil, which is well suited for soybean production in Tennessee. In May, soybean plots were planted on 30-inch row spacing using a no-till drill. Each plot consisted of four 25-foot long rows. Seed depth was half an inch to one inch and eight seeds were planted per foot. Phosphorus and Potassium were applied based on University of Tennessee soil-test recommendations. All other production inputs, such as weed and pest control, were applied following the University of

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Tennessee's recommended management practices. Table 1 shows the average rainfall and average growing degree days over the time of the experiment at Milan, Tennessee.

<< Insert Table 1 Approximately Here >>

Irrigation was uniformly applied to the irrigated plots using a Valley linear irrigation system (Valmont Irrigation, Valley, NE). The irrigation rates were based on the Management of Irrigation System in Tennessee (MOIST) soil moisture management system program, which is an online irrigation scheduler available for corn producers in Tennessee (Leib, 2013). The data indicate that 2007 and 2012 were drought years, requiring early season irrigation, and 2009 was an abundant-rainfall year, reducing the total amount of supplemental irrigation compared to other years. Average irrigation totals applied by month are presented in Table 2.

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The foliar fungicide experimental design was a randomized complete block with four replications. In each of the plots, two of the four rows were treated with a foliar fungicide application at the R3 growth stage (beginning pod), which typically occurred sometime in July, and the other two rows were not treated. Ratings of FLS severity were taken on both the treated and non-treated rows at the R5 growth stage (beginning seed). Ratings were based on the area infected by the disease in each year, which could range between zero and 100% (Sinclair, 1982). Soybean were harvested at maturity, which was from October through November, and yields for soybean were gathered in each year for the treated and non-treated rows. Table 3 shows the average yields and FLS severity for non-treated and treated soybean by maturity and year.

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The cost of applying foliar fungicide to soybean and machinery cost are from the University of Tennessee Enterprise Budgets (2015) for soybean. The cost of fungicide was

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estimated to be $17.40/acre in 2015, and the machinery cost (ownership and operation) for a 90 foot boom sprayer to apply the fungicide was $9.75/acre in 2015. The machinery cost was estimated based on a representative soybean farm in Tennessee (University of Tennessee Enterprise Budgets, 2015). We conducted a sensitivity analysis of the breakeven price of soybean by selecting a low, average, and high total cost of applying a foliar fungicide application. The low, average, and high were $25/acre, $30/acre, and $35/acre, respectively. Soybean prices were gathered from 2003 to 2013 (USDA NASS, 2015) and adjusted into 2013 dollars using the seasonally adjusted annual Gross Domestic Product Implicit Price Deflator (Federal Reserve Bank, 2013). The expected real price of soybean in 2013 dollars was $14.05/bu (USDA NASS, 2015).

It is worth noting that most of the previous research has adapted damage abatement functions based on data constraints and unique aspects of the damage abatement input (Elbakidze, Lu, and Eigenbrode, 2011). Aggregate county or state level survey data for quantity of a damage abatement input applied and the number of applications were commonly used in the aforementioned literature to estimate damage abatement. Thus, accurate in-field measurements of disease or pest pressure were rarely presented. This presents challenges in benchmarking the impact of a damage abatement input when there are limited number of non-treated observation (or a control treatment), and severity measurements are aggregated for county-level or state-level. Field -level data has been suggested to be more appropriate to estimate the marginal physical product and marginal value product of a damage abatement input (Elbakidze, Lu, and Eigenbrode, 2011; Norwood and Marra, 2003), making this dataset a unique contribution to the literature.

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Econometric Methods

Time Trend and Heteroscedasticity

Failure to correct for deterministic time trends in yield data can bias the estimators of long-term yield datasets (Finger et al., 2013). We test and remove a time trend in the data since we have a longer term dataset. Soybean yields have increased linearly since the 1920s. This trend is attributable to genetic improvements and other agronomic and management factors (e.g., earlier planting, improved weed control, and improved harvesting equipment) (Rinker et al., 2014; Specht et al., 2014). Determining the persistence of a deterministic time trend involves regressing yield against time variables. However, the selection of the appropriate time trend structure is debated. A deterministic time trend is frequently estimated following a quadratic functional form. For each MG, yields are regressed on time as

$$(2) \qquad y_t = \gamma_0 + \gamma_1 t + \gamma_2 t^2 + e_t \ ,$$

where y_t is the soybean yield in bu/acre obtained in year t (t = 1,2,…,T); γ_0, γ_1, and γ_2 are coefficients; and e_t is the idiosyncratic disturbance. The null hypothesis was no time trend is present $\gamma_1 = \gamma_2 = 0$.

We estimate Eq. (2) with M-estimation using the default PROC ROBUSTREG procedure in SAS (SAS Institute Inc., 2003). Several studies have recently applied Huber's (1973) M-estimation method to reweight time trend crop yield models (Boyer et al., 2015; Finger, 2010, 2013; Woodard et al., 2011). If a time trend was significant in the mean and/or the variance, the time trend was removed by using the standardized residuals.

Once the time trend was removed, we tested the soybean yields for heteroscedasticity with respect to time and make necessary corrections. We tested for heteroscedasticity in soybean yield data with respect to time using the Lagrange multiplier test. If evidence of

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heteroscedasticity was found, weights to correct for heteroscedasticity were estimated using feasible generalized least squares. Once the time trend was removed and weights to correct for heteroscedasticity were developed, the two-stage severity/treatment outcome model was estimated.

Two-Stage Regression

Following previous models, a two-stage severity/treatment outcome model was estimated using Full Information Maximum Likelihood. Weather variables were estimated to follow a quadratic functional form in both the damage abatement function and yield function following Elbakidze, Lu, and Eigenbrode (2011). The first stage estimated the impact of total water, growing degree days, and fungicide treatment on the severity level of FLS following quadratic functional form. The second stage estimated the effects of total water, growing degree days, and severity of FLS on yield also following quadratic functional form. The model for each MG was defined as

(3) $$D_{ti} = \alpha_0 + \alpha_1(R_{ti} + I_{ti}) + \alpha_2(R_{ti} + I_{ti})^2 + \alpha_3 G_{ti} + \alpha_4 G_{ti}^2 + \alpha_5(R_{ti} + I_{ti})G_{ti} + \alpha_6 F_{ti} + \varepsilon_{ti},$$

(4) $$\hat{y}_{ti} = \beta_0 + \beta_1(R_{ti} + I_{ti}) + \beta_2(R_{ti} + I_{ti})^2 + \beta_3 G_{ti} + \beta_4 G_{ti}^2 + \beta_5(R_{ti} + I_{ti})G_{ti} + \beta_6 D_{ti} + e_{ti},$$

where D_{ti} $0 \le D_{ti} \le 1$ is the severity of FLS (as a percentage coverage on the leaf) for time period *t* and plot *i*; R_{ti} is the amount of rainfall (inch); I_{ti} is the amount of irrigation applied (inch); G_{ti} is the growing degree days; F_{ti} is an indicator variable equal to one when foliar fungicide was applied and zero otherwise; $\hat{y}_{ti}$ is the time-adjusted yield (bu/acre); $\alpha_0,\ldots,\alpha_6$ and $\beta_0,\ldots,\beta_6$ are coefficients; and ε_{ti} and e_{ti} are independent and identically distributed with mean zero and constant variance.

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We substitute equations (3) and (4) into equation (1) and take the derivative with respect to the foliar fungicide treatment to determine the marginal value product and marginal factor cost of applying foliar fungicide, which is expressed as

(5) $$\frac{\partial \pi}{\partial F} = p(\alpha_6 \times \beta_6) - w = 0 .$$

If marginal value product $p(\alpha_6 \times \beta_6)$ from one application of fungicide at the recommend rate exceeds the marginal factor cost *w*, the producer would apply foliar fungicide. Having more than one application rate of fungicide in the dataset would allow us to estimate the marginal value product for an additional unit of fungicide; however, these data were not generated due to the experimental design of the field trials. Therefore, the interpretation applies to marginal value product gained from the application of fungicide at the recommend rate. The producer chooses to apply or not apply a set rate of fungicide as a part of annual production practices.

Additionally, the expected difference in treated and non-treated soybean yields or the marginal physical product of foliar fungicide application ($\partial y / \partial F = \alpha_6 \times \beta_6$) was estimated along with the standard errors using the delta method (Greene, 2008; pg. 69). Thus, we test if the yield gains for applying foliar fungicide were different from zero. Finally, the breakeven price of soybean for applying a foliar fungicide was calculated for each MG. We divide the yield gains from applying foliar fungicide by the total cost of fungicide application, which includes the fungicide and custom application charge to find the soybean price, which is expressed as $p^{BE} = w/(\alpha_9 \times \beta_9)$ where p^{BE} is the breakeven soybean price ($/bu).

Equations (3) and (4) were estimated using the MODEL procedure in SAS (SAS Institute Inc., 2003). A potential limitation of the model described in equation (3) is the predicted values of FLS severity were not restricted to be bounded between zero and 100%. We attempted to

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solve a truncated two-stage regression model but the model did not converge. We investigated the degree of this potential limitation by evaluating the predicted values of FLS for each MG. For all three MGs, the predicted values for FLS severity were within the bounds of zero and 100%, the predicted values were within the physical limits.

Results

Time Trend and Heteroscedasticity

The null hypothesis of no deterministic time trend model was rejected at the 0.01 level for all soybean MGs (Table 4), indicating that soybean yields for all three MGs increased at a decreasing rate over the 11-year study period. Literature suggests that soybean yields increased linearly over time, but most of these studies include longer time datasets (Specht, Hume, and Kumudini, 1999; Rowntree et al., 2013; Specht et al., 2014). Heteroscedasticity with respect to time was found in the detrended yield data for all MGs and was corrected.

<< Insert Table 4 Approximately Here >>

Two-Stage Regression

Parameter estimates for the two-stage severity/treatment outcome model by MG are presented in Table 5. For MG III, yield and FLS severity were found to have a similar response to changes in total water and growing degree days, which is not unexpected since FLS outbreaks have been found to increase in years where weather conditions promote high soybean yields. However, yield and FLS severity for soybean in MG IV and V were found to have indirect responses to changes in total water and growing degree days. This indirect relationship between FLS severity and yield for soybean in MG IV and V were likely due to the required number of days in the

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field until harvest for each MG as well as the timing of the total water and growing degree days for each MG. For all MGs, FLS severity responded the same to a change in total water and growing degree days, increasing with an increase in growing degree days but decreasing with an increase in total water. However, for MG III, an increase in total water decreased yield and an increase in growing degree days increased yield while for MG IV and V, an increase in total water increased yield and an increase in growing degree days decreased yield. Soybean in MG IV and V need more days in the field until maturity than MG III, thus, may require more water to reach maturity and receives enough growing degree days to reach the yield potential than soybean in MG III. For all three MG, a foliar fungicide treatment was found to decrease FLS severity, and an increase in FLS severity resulted in a yield decrease ($P \leq 0.05$).

<< Insert Table 5 Approximately Here >>

The marginal physical products or expected difference in treated and non-treated soybean yields were significant at the 0.01 level (Table 6). Relative to yields that were non-treated with a foliar fungicide, treating soybean with one foliar fungicide application increased yields by 7 bu/acre (16%) for MG III, 5 bu/acre (10%) for MG IV, and 6 bu/acre (15%) for MG V (Table 6). The relative yield differences in treated and non-treated soybean found here were similar to results to Mengitsu et al. (2014), but not as high as the 37% increase reported by Mian et al. (1998) in several southern states. The highest expected yield was found for MG IV, followed by MG III with MG V having the lowest expected yields (Table 6). Yields in MG IV had the smallest marginal physical product from a fungicide application while MG III had the largest marginal physical product (Table 6).

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FLS severity decreased approximately 26% (from 37.13% to 10.08%) when soybean in MG III were treated with a foliar fungicide (Table 6). For MG IV, treating soybean decreased FLS severity about 22% (from 33.17% to 10.85%), and FLS severity decreased approximately 17% (from 31.01% to 14.37%) when a foliar fungicide was applied to soybean in MG V (Table 6). The expected FLS severity for each MG was similar to what was reported for Tennessee and the southeast (Mengitsu et al., 2014; Mian et al., 1998). MG III had the highest expected FLS severity for non-treated soybean, but also received the largest reduction in severity from a foliar fungicide application, which explains MG III having the highest marginal physical product. As MGs went from III to V, the expected reduction in FLS severity from a foliar fungicide application decreased. However, the FLS severity of non-treated soybean also decreased. MG III will likely need fewer days in the field until harvest than MGs IV and V if the same planting date occurred for both MG. Therefore, results suggest that the more days the soybean remain in the field the less effective a foliar fungicide is at reducing FLS severity.

Given the average price of soybean over the course of the experiment was $14.05/bu in 2013 dollars, the marginal value product (or the average increase in revenue) from applying the recommend foliar fungicide application rate was $99/bu, $67/bu, and $85/bu for MGs III, IV, and V, respectively. Assuming three costs of applying the foliar fungicide of $25/acre, $30/acre, and $35/acre, a profit-maximizing producer would select to apply a foliar fungicide as part of the annual production practices to manage FLS. The breakeven price of soybean, for applying a foliar fungicide, ranged from $3.50/bu to $8.37/bu for all MGs and costs of applying the foliar fungicide (Figure 1). The higher the marginal physical product of a foliar fungicide application the lower the breakeven price, thus, MG III had the lowest breakeven price and MG IV had the highest breakeven price (Figure 1). Since 1940, the real price of soybean (in 2013 dollars) in

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Tennessee has dropped below $8.50/bu less than 5% of the time (USDA NASS, 2015), suggesting that a the likelihood of a foliar fungicide application breakeven was about 95% since 1940.

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Conclusions

We determined the effect of total water applied, growing degree days, and foliar fungicide treatment on FLS severity and yield of soybean MG III, IV, and V. A two-stage severity/treatment outcome model was estimated using Full Information Maximum Likelihood. Frogeye leaf spot severity was estimated as function of total water, growing degree days, and fungicide treatment, and yield was estimated as a function of total water, growing degree days, and FLS severity. Data on FLS severity and yield were collected from an 11-year soybean cultivar-fungicide experiment in Tennessee. The marginal value product and the breakeven price of soybean for applying a foliar fungicide to treat FLS were calculated for each MG (III-V).

The paper builds on previous damage abatement literature to develop a conceptual and econometric framework for foliar fungicide application. We use long term, field-level data to estimate the impact of foliar fungicide on FLS severity, which is helpful in producing accurate marginal value product estimates. Furthermore, FLS is one of the primary challenges soybean producers in the Southeast have to manage; however, little is known about the effectiveness and profitability of foliar fungicide on soybean infected with FLS.

The results show that applying a foliar fungicide to soybean will reduce FLS severity and increased yields for each MG. The expected reduction in FLS severity from a foliar fungicide application was highest for MG III and lowest for MG IV. The marginal physical product or

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increase in yield of a foliar fungicide application was highest, on average, for MG III. Therefore, MG III had the highest marginal value product and the lowest breakeven price of soybean for applying a foliar fungicide. Results from this study will inform Tennessee and Southeast producers on the effectiveness and profitability of spraying soybean with a foliar fungicide to manage FLS.

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Table 1. Average rainfall and average growing degree days at Milan, Tennessee for May through September from 2003-2013.

Year	May	June	July	August	September	Total
			Precipitation (Inches)			
2003	10.93	3.13	2.34	4.49	3.39	24.28
2004	4.61	5.02	2.1	4.85	0.32	16.90
2005	0.59	5.08	5.31	8.09	3.76	22.83
2006	5.02	5.93	3.53	3.3	4.48	22.26
2007	2.30	4.40	2.16	1.27	7.26	17.39
2008	9.39	1.52	3.12	0.74	0.43	15.20
2009	9.05	2.22	7.91	2.23	4.72	26.13
2010	21.05	3.23	5.93	1.97	0.36	32.54
2011	11.24	6.80	1.42	1.14	10.21	30.81
2012	1.60	1.84	4.79	4.59	5.09	17.91
2013	9.75	5.43	6.95	2.09	5.89	30.92
Average	7.51	4.03	4.37	3.14	4.42	23.48
30-Year Average	6.29	4.43	4.30	2.87	4.03	21.92
			Average Growing Degree Days			
2003	18.7	21.8	28.8	28.6	13.5	108.5
2004	21.8	25.4	27.4	23.2	16.0	101.5
2005	15.3	25.2	28.6	29.9	17.0	110.5
2006	17.6	25.0	29.9	30.4	15.0	111.0
2007	21.1	26.6	27.9	35.3	21.0	120.0
2008	16.7	27.9	29.9	27.2	22.0	115.0
2009	18.2	28.8	26.3	26.1	17.0	105.5
2010	21.2	31.5	31.7	32.0	21.5	123.0
2011	17.5	29.5	32.2	29.5	24.0	131.5
2012	22.7	25.7	33.1	28.6	17.0	126.0
2013	17.1	26.8	26.1	26.6	21.5	109.5
Average	18.85	26.97	29.36	29.20	18.9	115.5
30-Year Average	17.91	25.63	28.89	28.17	20.63	121.22

Source: NOAA, Milan, TN weather station.
Growing degree day = [(High Temperature – Low Temperature)/2]-50.

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Table 2. Average irrigation applied to soybean experiment at Milan, Tennessee from 2003-2013.

Year	May	June	July	August	September	Total
			Irrigation (Inches)			
2003	-	1.00	2.17	2.87	-	6.04
2004	-	0.50	1.91	2.76	-	5.17
2005	1.01	1.52	1.64	1.64	-	5.81
2006	-	1.23	1.64	2.05	0.41	5.33
2007	2.23	2.05	4.10	3.28	-	11.66
2008	-	1.23	4.10	2.87	-	8.20
2009	-	1.23	1.64	1.23	0.82	4.92
2010	-	2.05	2.05	2.87	0.82	7.79
2011	-	1.23	2.69	2.87	-	7.79
2012	1.64	4.10	2.05	1.23	-	9.02
2013	-	1.23	0.82	0.82	-	2.87
Average	1.63	1.58	2.26	2.23	0.68	6.78

Source: MOIST (Leib, 2013).

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Table 3. Average soybean yield (in bu/acre) and frogeye leaf spot severity (%) that were non-treated and treated for frogeye leaf spot at Milan, Tennessee from 2003-2013 by maturity group.

	Non-treated Yields by Maturity Group			Treated Yields by Maturity Group		
Year	III	IV	V	III	IV	V
			Yield (bu/acre)			
2003	-	34.95	39.21	-	44.42	43.35
2004	-	46.75	22.24	-	54.43	29.38
2005	33.80	36.14	43.78	42.40	49.08	51.73
2006	45.42	53.10	52.61	53.14	62.83	59.85
2007	44.84	46.98	45.53	60.08	52.78	52.77
2008	47.21	56.68	40.12	49.91	60.16	42.93
2009	36.11	56.31	57.95	46.36	60.93	64.43
2010	53.06	47.18	-	57.56	57.80	-
2011	44.19	43.07	41.58	48.55	47.73	44.98
2012	42.55	52.92	40.76	43.23	53.84	48.35
2013	37.58	37.87	32.97	40.08	40.65	35.57
Average	42.65	47.68	41.62	49.69	52.59	47.36
			Frogeye Leaf Spot Severity (%)			
2003	-	69.72	46.31	-	16.11	11.97
2004	-	48.25	52.50	-	15.57	18.83
2005	72.29	68.24	37.64	14.38	12.04	15.28
2006	36.67	31.49	29.05	12.50	8.23	5.71
2007	40.00	30.00	30.93	13.33	9.41	6.67
2008	34.44	34.96	29.52	17.22	8.89	10.32
2009	13.33	17.59	17.90	4.81	5.37	7.46
2010	45.67	37.61	-	12.18	12.22	-
2011	17.85	38.97	33.50	5.00	12.21	18.00
2012	22.19	26.08	20.47	10.00	10.63	4.53
2013	9.63	14.53	29.91	2.94	8.66	27.06
Average	37.30	33.42	33.20	10.97	10.10	12.20

Note: Yields and Frogeye Leaf Spot Severity are averaged across replications.

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Table 4. Parameter estimates for the time trend regression for soybean yields (in bu/acre) at Milan, Tennessee from 2003-2013

Parameter Estimate	Maturity Group		
	III	IV	V
Intercept (γ_0)	19.347***	33.957***	29.431***
Time (γ_1)	9.402***	6.856***	7.426***
Time^2 (γ_2)	-0.700***	-0.561***	-0.618***
F-Test	<0.0001	<0.0001	<0.0001

***=significant at p=0.01.

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Table 5. Parameter estimates for the two-stage regression of soybean frogeye leaf spot severity and yield in Tennessee

Parameter	Maturity Group III		Maturity Group IV		Maturity Group V	
Estimate	Yield	Severity	Yield	Severity	Yield	Severity
Intercept (β_0, α_0)	-1,325.19***	-16.419***	423.952***	-2.0027	210.029***	-1.418
Severity (β_6)	-26.662***	-	-20.510***		-30.983***	
TW (β_1, α_1)	-6.605***	-0.1754***	1.061	-0.1716***	13.063***	-0.139***
TW ^{2} (β_2, α_2)	-0.0984***	-0.0015***	0.0679***	-0.0010***	-0.326***	0.069
GDD (β_3, α_3)	25.006***	0.335***	-6.480***	0.0853***	-6.179**	0.0615
GDD^2 (β_4, α_4)	-0.120***	-0.0017***	0.035***	-0.0006***	0.019***	-0.0004
GDD*TW (β_5, α_5)	0.110***	0.0023***	-0.051***	0.0020***	0.058***	0.0005
Treatment (α_6)		-0.2635***		-0.2233***		-0.1663***
R^2	0.1022	0.3880	0.1170	0.2387	0.2224	0.1768
Adjusted R^2	0.0930	0.3818	0.1152	0.2371	0.2187	0.1729
Log Likelihood	-1932		-10728		-4396	

***=significant at p=0.01; **=significant at p=0.05.

TW=total water (rainfall + irrigation) and GDD = growing degree days.

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Table 6. Predicted yield (bu/acre), frogeye leaf spot severity (%), and marginal physical product ($/acre) of treating soybean for frogeye leaf spot with a foliar fungicide in Tennessee

	Maturity Group		
Parameter Estimates	III	IV	V
Expected Treated Yield	49.92	52.48	47.05
Expected Non-treated Yield	42.86	47.70	40.97
Expected Yield Difference or Marginal Physical Product	7.06***	4.78***	6.08***
Expected FLS Severity of Treated Soybean	10.08%	10.85%	14.37%
Expected FLS Severity of Non-treated Soybean	37.13%	33.17%	31.01%
Expected FLS Severity Difference	26.33%	22.32%	16.64%

***=significant at p=0.01

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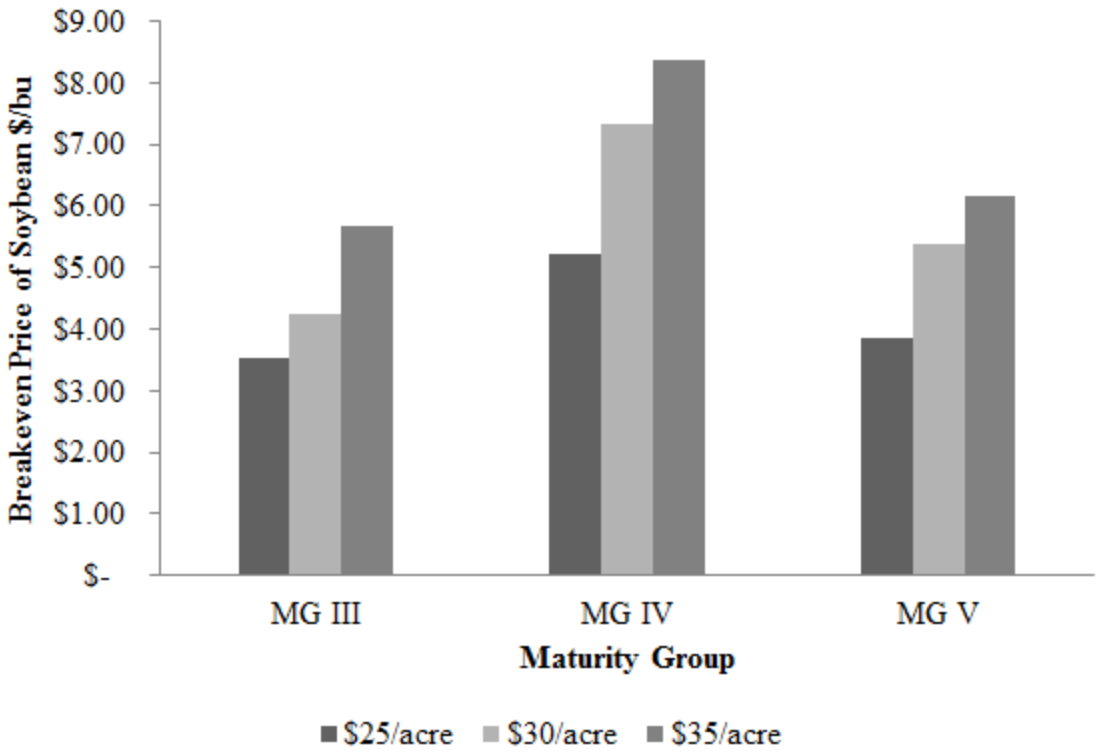

Figure 1. Breakeven price of soybean for applying a foliar fungicide at three different costs of application for each maturity group

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