Renewable Agriculture and Food Systems: 27(4); 295–304 doi:10.1017/S1742170511000561

Insecticide use and crop selection in regions with high GM adoption rates

Scott W. Fausti[1]*, Tia Michelle McDonald[2], Jonathan G. Lundgren[3], Jing Li[4],
Ariel Ruth Keating[5] and Mike Catangui[6]

[1]Department of Economics, South Dakota State University, Box 504, 104 Scobey Hall, Brookings,
SD 57007-0895, USA.
[2]Purdue University, West Lafayette, IN 47907, USA.
[3]USDA-ARS, North Central Agricultural Research Laboratory, Brookings, SD 57006, USA.
[4]Department of Economics, University of Miami Ohio, OH, USA.
[5]DeBruce Grain Inc., 1700 East Front Street, Fremont, NE 68025, USA.
[6]47153 S. Clubhouse Road Sioux Falls, SD 57108, USA.
*Corresponding author: Scott.Fausti@sdstate.edu

Accepted 14 November 2011; First published online 19 December 2011 **Research Paper**

Abstract

South Dakota has been a leading adopter of genetically modified organism (GM) crops since their introduction in 1996. In 2009, South Dakota shared the top adoption rate with Iowa for the percentage of acres planted with Bt corn. However; South Dakota has also recently experienced a significant increase in the proportion of acres treated with insecticide. The empirical evidence presented suggests that corn, hay and sunflower production in South Dakota have experienced an intensification of insecticide use in 2007 relative to past US Census of Agriculture reporting years. This study links the proportion of acres planted for a specific crop to the proportion of total acres treated with insecticide at the county level. This approach provides insight on how changing cropping patterns in South Dakota have influenced insecticide use. Empirical results indicate that the upper-bound estimate for insecticide usage on non-Bt corn acreage increased from 38% in 2002 to all non-Bt corn acres planted in 2007. The implication of this result is that in 2007 South Dakota producers were likely treating a percentage of their Bt corn acres with insecticide. Changing cropping patterns in South Dakota are also compared to that in other states in the US Corn Belt region. It appears that the South Dakota experience is not unique and is part of a broader trend.

Key words: insecticides, genetically modified organism, targeted insect pests, crop production, pest management practices

Introduction

South Dakota lies in the northern corn belt of the United States and agricultural production is a main driver of South Dakota's economy. In 2008, agriculture accounted for close to 10% of South Dakota's $37 billion economy[1]. The agricultural industry in the state has undergone a myriad of changes that are related to the rapid adoption of biotechnology and an increased demand for corn driven by the rapid expansion in corn-based ethanol production in South Dakota[2]. These two factors have contributed to a change in the crop rotation profile over the last 30 years, shifting from a profile with a large proportion of wheat, barley and oats toward one that is dominated by corn and soybeans. In 2010, South Dakota was ranked: (a) seventh in corn production, (b) eighth in soybean production, (c) second in sunflower production and (d) fourth in hay production in the United States[3].

South Dakota has adopted genetically modified (GM) varieties faster than any other state (see Fig. 1)[4]. The rapid adoption of GM crops in South Dakota over the past 15 years suggests that a change in pest management practices should have occurred during this period. One of the predicted benefits of the adoption of GM crops is a decline in insecticide use due to the ability of insecticidal GM crops to kill specific target insects.

In South Dakota, corn acres planted with Bt or stacked gene varieties increased from 37% in 2000 to 71% in 2009[5]. In 2009, South Dakota shared the top adoption rate with Iowa for Bt and stacked gene varieties. Even though South Dakota is the highest adopter of this type of technology, there has been an increase in the number of acres and the proportion of acres planted that have been treated with

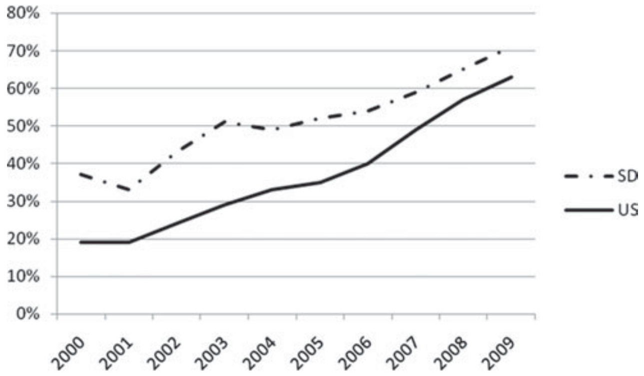

Figure 1. Adoption of insect-resistant and stacked GM varieties for South Dakota and the US (data collected from USDA-ERS website[4]).

insecticide over the past two decades. This positive trend has been gradual from 1978 to 2002, but in 2007 the increase was significantly above the trend. In 2002, South Dakota producers treated a total of 1.3 million acres with insecticides; by 2007 total acres treated had reached 3.1 million acres[6]. At the county level, this reflects an average increase in acres treated as a percentage of acres planted from 7.1% in 2002 to 20% in 2007. This trend is not consistent with the predicted inverse relationship between GM adoption rates and insecticide usage.

The objectives of this paper are to: (1) investigate the increase in South Dakota acres treated with insecticide; (2) establish whether there is a link between the type of crop planted and acres treated with insecticide; (3) analyze the relationship between Bt corn adoption rates and corn insecticide usage in South Dakota; and (4) consider the larger implications of the study with respect to insecticide use in other states or regions with high GM corn adoption rates.

Literature Review

Analysis of chemical usage, specifically insecticides, is complex given the number of factors that influence usage, including advances in seed varieties, introduction of new chemical compounds and fluctuating pest infestation levels.

Recent studies have focused on various trends in pesticide use. For example, as new ground is broken for growing a crop there is a tendency for pesticide use to increase. The literature indicates that this occurred in the early 1980s. Osteen and Livingston[7] reported that there was an increase in planted acres and also an increase in pesticide application rates. The literature also discusses a recent trend toward mono-cropping or reduced use of rotations to meet market demands. This trend is in contrast to integrated pest management practices that reduce insect pest populations, and monocultures may even intensify pest pressure[8]. Indeed, biodiversity and species evenness are both critical aspects of agroecosystems' natural ability to resist pest pressure, and this ability is reduced or eliminated by monoculture cropping practices[9,10]. Insecticide use is thus necessary to control the resulting increasing pest populations in monocultures.

The presence of damaging insect pests is an important determinant of insecticide use. Intuitively one can assume that insect pest infestation levels are closely related to the amount of insecticide applied. That is to say, *ceteris paribus*, the more insects that are present the more a producer will spray. These infestation levels, however, can fluctuate from year to year, are often difficult to predict and can spread rapidly. Previous studies indicate that the inability to predict pest infestations can lead producers to spray insecticide prophylactically[11,12].

Insect pest infestation data have been used in previous studies to investigate the issue of producers making a simultaneous decision of insecticide use and GM adoption[13,14]. Perceived pest pressure likely affects whether a producer adopts GM seed and also how much they spray. By omitting pest pressure data there is likely a correlation between the error term and the dependent variable. Two-stage regressions are often used to model this type of decision-making process.

The most common empirical methodology used to investigate insecticide usage on agricultural crops is to evaluate changes in total pounds of insecticide applied[14–17]. In the literature, however, an evaluation of chemical usage (such as 'volume applied') ignores important chemical attributes like strength and application practices[7]. As a result, problems arise when trying to assess changes in insecticide application rates over time.

One alternative method that accounts for changing chemical attributes is a hedonic pricing model. A hedonic pricing model can provide a proxy for changes in chemical potency and breadth[14]. Another alternative empirical method proposed by Alston et al.[18] estimates chemical usage by multiplying the total acreage by the percentage treated for corn rootworm specifically. We have adopted a similar approach in this study. Our empirical methodology focuses on estimating the changes in chemical usage as a percentage of crop acres treated with insecticides in South Dakota.

There is a general consensus in the literature that total pesticide (herbicide plus insecticide) usage (total pounds applied) has increased due to increased GM acreage planted[19], largely driven by increased glyphosate usage associated with glyphosate-tolerant GM crops. The general consensus is GM adoption has decreased insecticide per acre usage on US corn acreage planted over the past decade[20]. However, Benbrook[19] argues that only a small proportion of corn acres were treated with insecticides prior to the introduction of Bt varieties. Therefore, the reduction in per acre insecticide usage associated with Bt adoption may be overestimated in the recent literature.

These findings reported by Benbrook suggest that the observed increase in acres treated with insecticide in South Dakota may indicate a reversal in the downward trend for insecticide usage by producers in states with high GM adoption rates. This trend reversal may be reinforced by unintended consequences associated with very high Bt adoption rates. For example, the introduction of Bt corn has allowed US producers to practice mono-cropping or reduced use of rotations to increase corn production. Insect populations facing greater exposure to a single environmental barrier may genetically adapt, thus reducing the effectiveness of the GM trait. Meihls et al.[21] reports western corn rootworm has the ability to adapt to Bt toxins if refuge acre policy recommendations are not followed, and Bt-resistant corn rootworms were recently discovered in Iowa cornfields[22]. Our goal is to make a contribution to the GM/pesticide debate by providing insight on increased insecticide usage in a state having a high GM adoption rate targeting corn insect pests.

Methodological Issues

Corn, soybean, hay and sunflowers are important crops for South Dakota agriculture and each has significant pest problems. Corn has several pests that cause crop damage every year, including the European corn borer (*Ostrinia nubilalis*) and the western and northern corn rootworms (*Diabrotica virgifera* and *D. barberi*, respectively). Soybeans in South Dakota have recently (2001) been invaded by the soybean aphid (*Aphis glycines* Matsamura) which is present in all soybean-producing regions of South Dakota (J.G. Lundgren, pers. comm., November 13, 2009). In South Dakota, 46 counties produced soybean in 2007. Additional information on soybean aphid infestation levels at the county level can be found at http://www.ncipmc.org/index.cfm. In 2002, the soybean aphid was present in 20 of 66 counties (30%) in South Dakota counties[23]. By 2007, the soybean aphid had spread to 46 counties in South Dakota (≈ 70%). Alfalfa weevil (*Hypera postica*) affects alfalfa and is present in every county in South Dakota[24]. Sunflowers, because they are a native species and harbor an endemic insect fauna, face a substantial pest threat from 15 different insects[25]. Infestations can be highly variable even within a single sunflower field. Over time these pests have undoubtedly affected insecticide use. As this study does not directly link GM adoption to insecticide use, the inclusion of pest infestation data is not critical. However, we included a proxy variable for soybean aphid infestation at the county level in 2007. This proxy is potentially important because the scope of infestation and insecticide-use responses have changed dramatically over the timeframe of this study.

To estimate the effect of multiple explanatory variables on insecticide use for all counties in South Dakota, a fixed-effect model was employed. A fixed-effect model is often used on non-experimental data, where a scientific control group is not available or possible, treating each observation as its own control[26]. This model also accounts for time-invariant unobserved effects that are not captured with available data[27].

A typical ordinary least-squares (OLS) model often suffers from omitted variable bias. In the case of insecticide usage, the omitted variable is frequently the magnitude of the pest population. In South Dakota there are limited data on this particular issue, making it challenging to describe the relationship between insecticide use and other variables. Using the fixed-effect model we can assume there are two types of unobserved effects, those that vary over time and those that are constant, denoted as U_{it} and a_i, respectively[27]. The unobserved effect, a_i, accounts for unobserved effects that do not change over time (i.e., latitude, longitude, soil type and cultural norms). The time-varying error term U_{it} is subject to many assumptions that require some discussion. Examples include precipitation and technology adoption.

Accounting for pest populations is of particular importance. Some pest populations are unpredictable and can vary greatly from year to year. Also, pest communities have experienced dramatic change over the past 30 years. To account for the potential effect of soybean aphid pest populations at the county level we include a variable that identifies soybean aphid infestation presence in South Dakota in 2007. Other changes in pest populations are contained within the time-varying error term. We also make the assumption that pest populations are not correlated with crop choice as we believe there are other factors that have greater influence on crop selection, including market demands and prices as well as protective measures if pest infestations occur. If correlation between crop proportion and pest population does exist it would violate several of the assumptions necessary to ensure unbiased estimation[27]. Furthermore, we are not interested in how market factors are affecting cropping patterns. We consider this an issue for future research. Given the econometric caveats, our goal is to investigate how changes in cropping patterns may have affected the proportion of crop acreage applied with insecticide. Of special interest is corn acreage treated with insecticide because it is the only major crop in South Dakota that has a GM solution for insect pests.

Data

Data from several sources were used in this project. Data were collected from the National Agriculture Statistics Service (NASS) as well as the US Census of Agriculture. Data regarding total acres planted and crop-specific acres planted at the county level were retrieved from NASS's Quick 'Stats All States Data-Crops'[28]. The census data on chemical usage were collected from 'Agriculture Chemicals Used, specifically: sprays, dusts,

Table 1. Variables used in panel regression.

Variable name	Definition	Source/Description
%Treated	Dependent variable—percentage of total planted acres treated with insecticide	USDA Agriculture Census; 1978, 1982, 1987, 1992, 1997, 2002, 2007
YR07	Dummy variable for 2007	
Corn	Percentage of total acres planted with corn	USDA NASS
Soybean	Percentage of total acres planted with soybeans	USDA NASS
Sunflower	Percentage of total acres planted with sunflowers	USDA NASS
Hay	Percentage of total acres planted with hay	USDA NASS/ includes alfalfa
Aphid	Dummy variable for presence of soybean aphid in a county in a given year	Field survey by various extension educators (SDSU extension)
Intercept	Constant term	

Table 2. County-level summary statistics: percentage of acres planted: $N = 462$.

Variable description	Mean	Standard deviation	Min.	Max.
%Treated	0.099	0.095	0	0.89
YR07	0.14	0.35	0	1.0
%Corn	0.22	0.16	0	0.64
%Soybean	0.12	0.15	0	0.51
%Sunflower	0.02	0.04	0	0.23
%Hay	0.28	0.19	0.035	1.9
%Aphid	0.14	0.35	0	1.0

granules, fumigants, etc. to control insects on hay and other crops'. The census reports all acres treated at the county level, but does not report crop-specific acres treated. The empirical hurdle we overcome is the lack of data on which crops are being treated, and by extension providing insight on why there has been an increase in acres treated as a proportion of acres planted at the county level. Soybean aphid infestation information by county is provided by the Plant Science Department at South Dakota State University and the Agricultural Research Service Station in Brookings South Dakota.

Empirical Model

The data set contains observations for each county over the past seven Census reporting periods (1978–2007). A fixed-effect modeling approach was selected to analyze the constructed panel data set. The data are a balanced panel, meaning that there are no missing observations for any counties over the observed years. Given the econometric issues discussed earlier, we used a 'cluster robust standard error' approach to account for both the intra-cluster correlation and between-cluster heteroscedasticity. Intra-cluster correlation can be caused by unobserved omitted variables (e.g., insect populations: see equation 21–13 in Cameron and Trivedi[29] for more details). A complete listing of the variables used in the model, and their definitions, is located in Table 1. Summary statistics for the variables are provided in Table 2.

The analysis uses South Dakota county-level data on acres planted with corn, soybean, sunflower and hay. In aggregate, these four crops accounted for 77% of all acres planted in 2007. The empirical analysis employs two regression models. The first regression model (Eqn 1) used all the crop variables as well as two dummy variables: (a) shift variable for 2007 and (b) a dummy variable to account for county-level aphid infestation in 2007. The second regression model (Eqn 2) includes interaction terms to capture the influence of each crop variable on insecticide usage in 2007.

The decision to include only the 2007 dummy variables (i.e., year, aphid) to capture changes in insecticide use over time is based on data indicating that insecticide use in South Dakota remained fairly stable from 1978 to 2002, with 8–10% of county-level planted acres being treated with insecticides. In 2007, South Dakota counties experienced an increase in acres treated with insecticides, on average; roughly 20% of the planted acres were treated with insecticides. This increase is depicted in Figure 2.

$$\begin{aligned} Y_{1it} = {} & \delta_1 + \delta_2 \mathrm{YR07}_{2it} + \delta_3 \mathrm{Aphid}_{3it} + \beta_1 \mathrm{Corn}_{1it} \\ & + \beta_2 \mathrm{Soybean}_{2it} + \beta_3 \mathrm{Sunflower}_{3it} \\ & + \beta_4 \mathrm{Hay}_{4it} + a_i + U_i t \end{aligned} \tag{1}$$

$$\begin{aligned} Y_{2it} = {} & \delta_1 + \beta_1 \mathrm{Corn}_{1it} + \beta_2 \mathrm{Soybean}_{2it} \\ & + \beta_3 \mathrm{Sunflower}_{3it} + \beta_4 \mathrm{Hay}_{4it} + \beta_5 \mathrm{Corn}^{*}07_{5i} \\ & + \beta_6 \mathrm{Soybean}^{*}07_{6i} + \beta_7 \mathrm{Sunflower}^{*}07_{7i} \\ & + \beta_8 \mathrm{Hay}^{*}07_{8i} + \alpha_i + U_{it}, \\ & \text{for } i \text{ county in year } t. \end{aligned} \tag{2}$$

The dependent variable in both regressions is a county-level variable and is defined as: $Y_{it} \equiv$ total acres treated with insecticide$_{it}$/total acres planted$_{it}$. By using the proportion of acres treated with insecticide as the dependent variable, instead of a weighted measurement of pesticides applied, we can avoid the problem of aggregating across a heterogeneous group of pesticides[30].

The outliers within the data identified in Figures 2 and 3 are worth discussion. Figure 2 shows the level and year of outlier occurrence, whereas Figure 3 provides

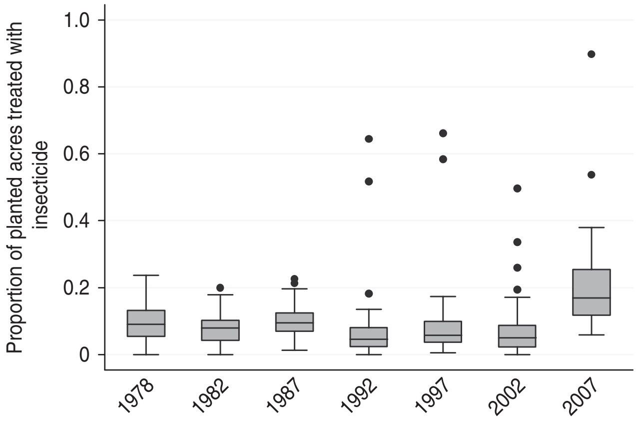

Figure 2. Proportion of planted acres treated with insecticide by county in South Dakota.

the geographical location of outlier counties where an unusually high percentage of acres treated with insecticides occurred. The outliers tend to form a cluster in the southeast region of the state, which is also a large corn and soybean production area. One 2007 outlier, Shannon county in western South Dakota, represents a county with very few planted acres, thus easily achieving a high percentage of their acres treated with insecticides. Using a robust model accounts for the outliers and therefore these observations were left in the data[31].

The crop variables are defined as a percentage of county-level total acres planted that are devoted to each specific crop for a specific county. County-level crop production patterns from 1978 to 2007 are provided in Figure 4. A change in a crop's acreage share at the county level is hypothesized to influence insecticide usage at the county level. Corn has recently experienced a large increase in acres planted at the county level, increasing from 23.5% in 2002 to 28.5% of total acres planted in 2007. Soybean acres planted have also dramatically increased over the span of the study, increasing from just 2.4% in 1978 to 21% in 2002 before dropping to 18% in 2007. Hay acres harvested and planted (1978–2007) ranged between 25 and 30% of acres planted at the county level. A majority of the hay acres harvested are located in western South Dakota. From 1978 to 2007, the proportion of acres planted with sunflowers was variable, ranging from 0.5 to 4% of county-level total acres planted.

The rapid expansion of the soybean aphid from 20 counties in 2001 to 46 counties in 2007 (all soybean-producing counties in South Dakota) has resulted in it becoming targeted as a major pest. To capture the aphid effect on insecticide usage a binary variable is included, set to one for counties when the soybean aphid is present in 2007 and zero otherwise. This variable is a proxy for aphid pest populations and it is hypothesized that the presence of the soybean aphid affected insecticide usage in South Dakota.

Results

Tables 3 and 4 provide coefficient and goodness-of-fit statistics for the two estimated models. The Hausman Test indicated that a fixed-effect approach is the appropriate choice for both models. The regression estimates for the first model indicate that corn, hay and aphid coefficients are statistically significant and are positively related to the proportion of acres treated with insecticide. The soybean and sunflower coefficients are not statistically significant. The estimated model has a global F statistic of 24.16, an R^2 of 0.35, and a correlation between model residuals and regressors of: $(u_i, Xb) = -0.3790$.

The initial fixed-effect model estimates indicated that the soybean parameter estimate was significant at the 1% level. However, when the model was adjusted for intra-cluster correlation the parameter estimate became statistically insignificant. This also occurred in the second regression, where the soybean parameter estimate was statistically significant at the 1% level prior to the regression procedure being adjusted for intra-cluster correlation. Therefore, we believe that our parameter estimates are valid but are insignificant due to multicollinearity between the aphid, corn and soybean variables.

Table 3 indicates, *ceteris paribus*, that a 1% increase in corn acres planted will result in an estimated 0.24% increase in total acres treated in a county. The average proportion of county corn acres planted has increased from about 20% in the 1980s and 1990s to 28.5% in 2007. This suggests as corn acreage increases relative to alternative crops, insecticide usage increases. During this period South Dakota producers increased their planting of insect-resistant GM corn acres from 33% in 2000 to 59% in 2007, respectively (Fig. 1). The literature suggests that the relationship between GM corn and insecticide usage should be inversely related. That does not appear to be the case in South Dakota. These empirical findings may be reflecting the prophylactic application of neonicotinoid seed treatments[32] that often accompany GM trait packages in corn seed purchases. Or the increased usage of insecticide on corn acres planted may be due to producers abandoning traditional crop rotation practices, or breaking native ground to create additional crop land.

The statistically significant and positive coefficient for hay is also interesting. The hay coefficient implies that, holding the effects of the other variables constant, a 1% increase in the proportion of hay acres planted would result in a 0.27% increase in the proportion of acres treated. This may be the result of pest damage. Alfalfa, a subset of the hay variable, faces a significant pest threat from the alfalfa weevil. The alfalfa weevil has been present in South Dakota since 1973 and causes economic damage in many western South Dakota counties, where a large proportion of South Dakota alfalfa acres are planted[24].

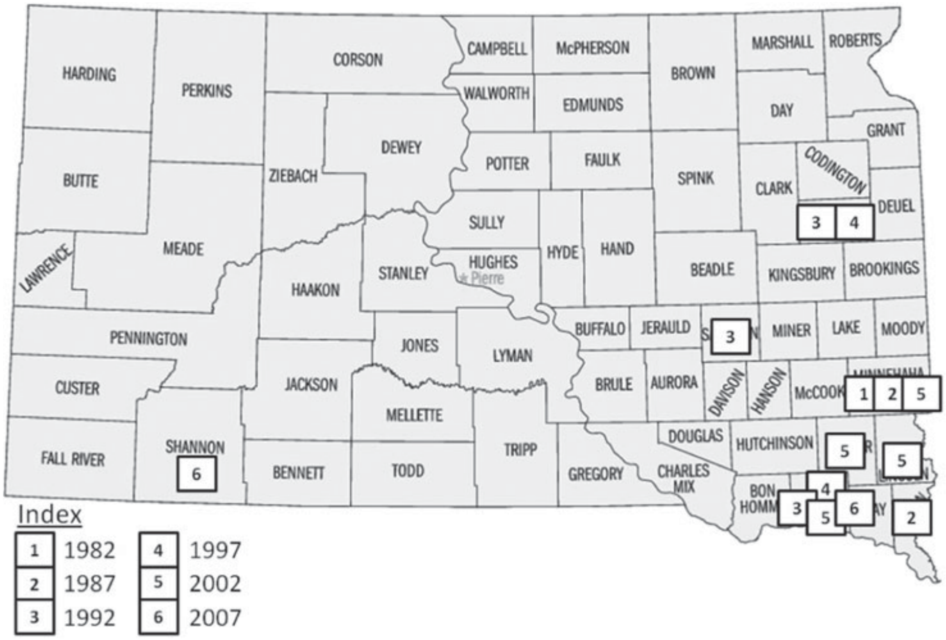

Figure 3. Map of South Dakota county outliers by year.

The soybean coefficient is statistically insignificant at the 10% level. As expected, the corn and soybean variables are highly correlated. The estimated correlation coefficient is 0.80. The aphid variable is also highly correlated with corn and soybeans, 0.40 and 0.45, respectively. Alternative estimation methods to deal with this high level of multi-collinearity were ineffective. Multi-collinearity inflates the standard errors but the coefficient estimates retain efficiency. The soybean coefficient is consistent with expected behavior. The only major insect pest threat to soybeans in South Dakota is the soybean aphid. Therefore, a negative soybean coefficient and a statistically significant positive aphid coefficient are consistent with the expected relationship between these variables and the dependent variable, i.e., the proportion of planted acres treated with insecticide.

The soybean aphid coefficient estimate is statistically significant at the 5% level. In 2007, *ceteris paribus*, it is estimated that counties with aphid infestation had 5.8% more acres treated with insecticide than counties without aphid infestations.

In Table 3, the 2007 year-dummy variable was statistically significant and positive. The regression coefficient indicates the estimated increase in total acres treated in 2007 is 6.1% higher than for the other census years in the study. This result corresponds to the noticeable increase in acres treated as shown in Figure 2. This statistically significant result prompted additional analysis that resulted in the inclusion of the 2007 interaction terms that are present in the second regression.

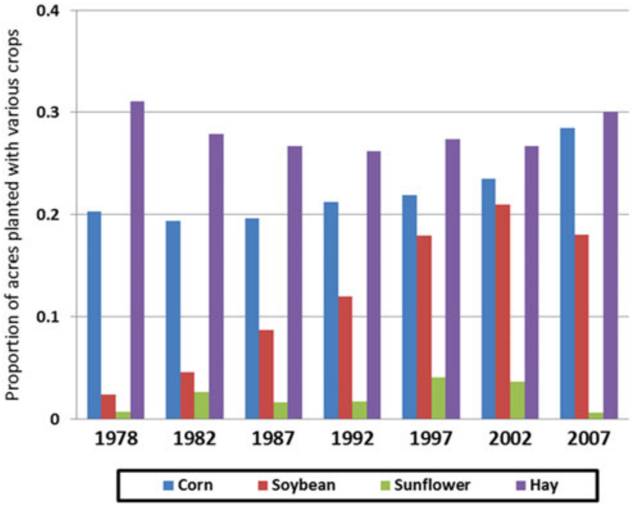

Figure 4. County-level crop acres planted in South Dakota.

The second regression and the inclusion of 2007 interaction terms is an attempt to gain insight on why acres treated increased in 2007. The interaction terms capture the change in the slope relationship between the percentage of acres treated and the proportion of acres planted for a specific crop for the year 2007. If the regression coefficient for an interaction term is statistically significant and positive, then the implication is that insecticide usage has intensified for that specific crop. The second regression model is statistically significant, with an F statistic of 51.27, an R^2 value of 0.36 and a correlation between model residuals and regressors of: $(u_i, Xb) = -0.2436$. The results for the second regression

Table 3. Results from first panel regression.

OBS = 462 **No. of Groups = 66** **OBS per group = 7**	**R^2: Within = 0.35** **Between = 0.02** **Overall = 0.10**	**$F(6, 65) = 24.16$** **Prob > F = 0.00** **Corr (U_i, Xb) = −0.379** **RHO = 0.54 (intra-class corr)**			
		Robust standard		**95% CI**	
Variable	**Coefficient**	**error**	***t*-statistic**[1]	**Lower**	**Upper**
Yr07	0.0612	0.0178	3.43***	0.025	0.097
Corn	0.239	0.080	2.99***	0.079	0.400
Soybean	−0.094	0.067	−1.39[2]	−0.230	0.041
Sunflower	0.0588	0.065	0.91	−0.070	0.188
Hay	0.271	0.093	2.92***	0.085	0.456
Aphid07	0.058	0.0269	2.17**	0.004	0.112
Intercept	−0.033	0.0314	−1.07	−0.096	0.029

[1] ***Significant at 1% level; **Significant at 5% level; *Significant at 10% level.

[2] The soybean coefficient has a P-value of 0.168.

Table 4. Results from panel regression analysis with interaction terms.

OBS = 462 **No. of Groups = 66** **OBS per group = 7**	**R^2: Within = 0.36** **Between = 0.00** **Overall = 0.16**	**$F(8, 65) = 51.27$** **Prob > F = 0.00** **Corr (U_i, Xb) = −0.243** **RHO = 0.49 (intra-class corr)**			
		Robust standard		**95% CI**	
Variable	**Coefficient**	**error**	***t*-statistic**[1]	**Lower**	**Upper**
Corn	0.2212	0.0862	2.57***	0.049	0.393
Soybean	−0.0974	0.0701	−1.39	−0.23	0.042
Sunflower	−0.0129	0.0602	−0.21	−0.13	0.107
Hay	0.2000	0.0880	2.27**	0.024	0.375
Corn*07	0.2309	0.1082	2.13**	0.014	0.447
Soybean*07	0.0231	0.1360	0.17	−0.25	0.295
Sunflower*07	0.4311	0.1242	3.47***	0.183	0.679
Hay*07	0.1054	0.0320	3.29***	0.041	0.169
Intercept	−0.008	0.0305	−0.27	−0.07	0.052

[1] ***Significant at 1% level; **Significant at 5% level; *Significant at 10% level.

are reported in Table 4. The 2007 dummy variables were dropped from the second model due to multi-collinearity issues.

The coefficient estimates for the crop variables were consistent with the first regression while the interaction terms lend some insight on the increase in insecticide use in 2007. The 2007 interaction variables for corn, sunflower and hay are significant and positive, implying an intensification of insecticide usage. The soybean and soybean interaction terms are statistically insignificant. The soybean parameter estimate was statistically significant at the 1% level prior to the regression procedure being adjusted for intra-cluster correlation.

Bt Corn and Insecticide Usage in South Dakota Counties

The regression estimates (Table 4) indicate that there is a statistical relationship between the proportion of corn acres planted and the proportion of acres treated. Holding all other variables constant the prediction equation is

$$E(Y_{2\,\mathrm{corn}}) = 0.2212^{*}\mathrm{Corn} + 0.2309^{*}\mathrm{Corn}^{*}07. \qquad (3)$$

Equation 3 includes the corn*2007 interaction term. For all Census years except for 2007, the effect of the proportion of corn acres related to the proportion of acres treated with insecticide is given by the first term only. Thus, a 1% increase in acres planted with corn results in a

0.22% increase in the proportion of acres treated, *ceteris paribus*.

In 2002, on average for South Dakota counties, the proportion of corn acres to total acres planted is estimated at 0.2347. By substituting the average proportion of corn acres planted for 2002 into Equation 3, the predicted overall contribution of corn acres planted to the proportion of acres treated is estimated to be 0.0518 (0.2211*0.2347). The summary statistics for 2002 indicate that, on average, 7.1% of planted acres were treated with insecticide. Corn acres planted in 2002, on average, accounted for 73% (0.0518/0.071) of total acres treated and 24.6% (0.0518/0.2347) of corn acres planted in 2002 were treated with insecticide. In 2002, 43% of corn acres planted were Bt or stacked gene corn acres (state average). Therefore, Bt corn accounted for 0.1001 of the 0.2347 share of corn acres (0.43*0.2347) to total acres planted. Thus, the proportion of non-Bt corn acres planted accounted for 0.1346 of total acres planted. Assume Bt corn acres were not treated with insecticide (this assumption is made to in order to determine the upper bound of non-Bt corn acres treated). The implication is that in 2002, 38.5% (0.0518/0.1346) of non-Bt corn acres planted in South Dakota were treated with insecticide. It should be noted that the above estimates are based on the assumption that the percentage of acres planted with Bt seed at the state level is consistent with Bt plantings at the county level. County-level data on Bt usage is not available.

In 2007, on average for South Dakota counties, the proportion of corn acres to total acres planted is estimated at 0.284. The total effect of corn acres planted in 2007 on acres treated is determined by both coefficients in Equation 3. At the county level, the predicted contribution of the proportion of corn acres planted to the proportion of acres treated with insecticide is estimated to be 0.128, i.e. (0.2211*0.284 + 0.231*0.284). The estimated predicted value of acres treated associated with acres of corn planted in 2007 indicates that approximately 12.8% of the total acres planted were treated corn acres.

The summary statistics for 2007 indicate that on average, 20.1% of total (all crops) planted acres were treated with insecticide. Corn acres planted in 2007, on average, accounted for 63.8% (0.128/0.201) of acres treated. Furthermore, it is estimated that 45% (0.128/0.284) of corn acres planted in 2007 were treated with insecticide, a substantial increase relative to 2002 (24.6%). Given that 59% of corn acres planted in South Dakota contained Bt, our estimate for corn acres treated suggests that some Bt acres were treated in 2007.

These back of the envelope findings are surprising on a number of levels. First, GM corn acreage share and insecticide corn acreage coverage both increased. Secondly, in 2007, on average at the county level, corn accounted for 28.4% of total acres planted. Bt corn account for 59% of corn acres planted. Therefore, Bt corn accounted for 16.75% of total acres planted (0.59*0.284). If we assume Bt corn acres were not treated with insecticide, then non-Bt corn acres accounted for 11.65% of total acres planted. The implication is that in 2007 109.87% of non-Bt corn acres planted in South Dakota was treated with insecticide (0.128/0.1165). We regard this estimate as an upper-bound for non-Bt acres treated and it suggests that South Dakota producers treated some Bt acres with insecticide in 2007.

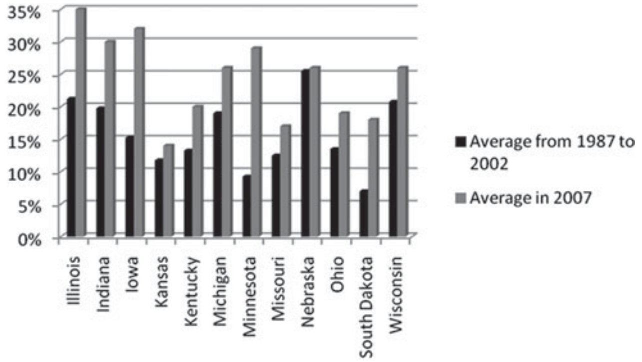

Figure 5. Proportion of acres treated with insecticide for mid-west states.

This proportion is exceedingly high given: (1) that in 2002 it is estimated that 38.5% of non-Bt corn acres were treated acres; (2) traditional insect pest management patterns prior to GM introduction; and (3) the USDA refuge acreage requirement for producers who use Bt seed. Our estimate of a very large increase in corn acres treated raises some interesting questions. Has the change in cropping or seed marketing patterns forced producers to rely more heavily on chemical control? Is it the result of producers moving away from traditional rotation control methods used in the past to suppress insect pests? Are producers treating Bt corn acres in a manner they treat non-Bt acres? Additional research needs to be conducted on this issue.

Next, the coefficient estimates for the interaction terms found in Table 4 provide additional empirical evidence of increased acreage treated with insecticide being linked to changing cropping patterns. The corn interaction term coefficient estimate indicates that the slope relationship between corn acres planted and total acres treated with insecticide increased dramatically in 2007 from 0.2212 during the 1978–2002 period to 0.4521 in 2007 (0.2212 + 0.2309). This steepening of the slope indicates an increase in the marginal contribution of corn acres planted to total acres treated in 2007, relative to previous census years.

Overall, the empirical evidence suggests that corn, hay and sunflower production in South Dakota have experienced a recent intensification of insecticide use in 2007 relative to past Census reporting years. Empirical evidence indicates that the presence of the soybean aphid in South Dakota did contribute to increase the acres treated in 2007.

Broader Implications of the South Dakota Case Study

One question raised by the findings reported in this case study is whether the 2007 increase in acres treated with insecticide in South Dakota was an isolated phenomenon or whether other mid-western states experienced a similar increase. Figure 5 shows the proportion of acres treated with insecticide from 1987 to 2007. Of the 13 states that were looked at, Illinois, Indiana, Iowa, Minnesota and Kentucky seem to have experienced a marked increase in the proportion of acres treated in 2007. It is worth noting that while there appears to be a large and sudden increase, because of the limited nature of the data, it is unclear as to whether this increase was in fact gradual for the years in between 2002 and 2007.

For some states, like Illinois, the increase in the proportion of acres treated began in 1992. Other states, including Iowa, Minnesota, South Dakota, Indiana, Kentucky, had relatively low, though variable, proportions of their cropland treated with insecticides until the increase in 2007. The differences between states could be the result of varying or spreading pest populations, but more likely this is the result of a national paradigm shift in insecticide use in spite of the widespread adoption of Bt.

The 13 states listed in Figure 5 make up the Midwest region of the United States and are intensive crop-producing states. These states will provide the basis for further analysis at the county level and could provide greater insight into the reasons for the 2007 increase in the proportion of acres planted being treated with insecticide.

Conclusion

The empirical evidence gleaned from this South Dakota case study indicates that corn, hay and sunflower production in South Dakota has experienced a recent intensification of insecticide use. Furthermore, we have provided an empirical linkage to the increase in acres treated with insecticide in South Dakota to the intensification of insecticide use for specific crops. USDA data on acres treated with insecticide for other Midwestern states suggest that these states have experienced a similar recent increase in acres treated as is the case for South Dakota. The specter of a pattern of intensification of insecticide usage for crops coinciding with an intensification of GM crop production suggests additional research is needed.

Empirical evidence indicates that corn acres planted has a major impact on the proportion of acres treated with insecticide in South Dakota. This is partially due to corn being a major South Dakota crop. It is interesting that as GM adoption rose in South Dakota, so did the proportion of acres treated. There are a number of plausible explanations for this positive correlation. Producers may be treating more acres as an insurance policy against unnamed insect pests that are not targeted by Bt corn. The chemicals and products applied to crops today to protect against this and other non-target pests are often broad-spectrum products which will protect against a variety of potential threats, but also pose potential environmental harm to beneficial species[33].

Exogenous shocks affecting the market demand for corn may be affecting traditional crop rotation patterns, which have been a common cultural method for pest management practices. Producers may now be relying on insecticides (planting GM seed and seed and foliar applications) more heavily than traditional crop rotation to control pests, thus increasing the acres being treated.

As a final note, our study suggests that additional research is needed on the relationship between GM adoption rates and insecticide usage. Our analysis suggests that regions with high GM adoption rates may be experiencing unexpected insect pest issues not predicted in the previous literature.

Acknowledgements. The authors are appreciative of the anonymous reviewer comments. Any remaining errors are the sole responsibility of the authors. The authors gratefully acknowledge partial funding by USDANIFA, South Dakota Agricultural Experiment Station, and the South Dakota CUC. Mention of trade names or commercial products is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the USDA.

References

1 United States Bureau of Economic Analysis. 2009. Gross domestic product by state. Available at Web site: http://www.bea.gov/regional/gsp/ (accessed November 19, 2009).

2 Qasmi, B.A., Hamda, Y., and Fausti, S.W. 2009. Impacts of Dramatic Increase in Corn Based Ethanol Production on Grain Production and Marketing Patterns in South Dakota. South Dakota State University, Department of Economics, Brookings, SD. Available at Web site: http://purl.umn.edu/113045 (accessed August 15, 2012).

3 National Agriculture Statistics Service. 2011. South Dakota agriculture 2011. Available at Web site: http://www.nass.usda.gov/Statistics_by_State/South_Dakota/Publications/Annual_Statistical_Bulletin/2011/toc11.asp (accessed June 9, 2011).

4 Economic Research Service. Adoption of genetically engineered crops in the US. Available at Web site: http://www.ers.usda002Egov/data/biotechcrops/ (accessed May 14, 2010).

5 Economic Research Service. 2009. Supplemental Tables. ERS.GM.pdf. Available at Web site: http://www.organic-center.org/reportfiles/SupplementalTablesv2.pdf (accessed June 4, 2010).

6 National Agriculture Statistics Service. 2007. Agriculture census. Available at Web site: http://www.agcensus.usda.gov.

7 Osteen, C. and Livingston, M. 2000. Pest management practices. Agricultural Resources and Environmental Indicators 4:3.

8 Lewis, W.J., van Lenteren, J.C., Phatak, S.C., and Tumilnson, J.H. III. 1997. A total system approach to

sustainable pest management. Proceedings of the National Academy of Sciences of the United States of America 94:12243–12248.

9 Crowder, D.W., Northfield, T.D., Strand, M.R., and Snyder, W.E. 2010. Organic agriculture promotes evenness and natural pest control. Nature 466:109–112.

10 Lundgren, J.G. and Fergen, J.K. 2011. Enhancing predation of a subterranean insect pest: A conservation benefit of winter vegetation in agroecosystems. Applied Soil Ecology 51:9–16.

11 Lazarus, W.F. and Swanson, E.R. 1983. Insecticide use and crop rotation under risk: Rootworm control in corn. American Journal of Agricultural Economics 65:738–747.

12 Foster, R.E., Tollefson, J.J., Nyrop, J.P., and Hein, G.L. 1986. Value of adult corn rootworm (Coleoptera: Chrysomelidae) population estimates in pest management decision making. Journal of Economic Entomology 79:303–310.

13 Fernandez-Cornejo, J. and Li, J. 2005. The impacts of adopting genetically engineered crops in the USA: The case of Bt corn. In Paper presented at American Agricultural Economics Association Annual Meeting, Rhode Island, July 24–27.

14 Vialou, A., Nebring, R., Fernandez-Cornejo, J., and Grube, A. 2008. Impact of GM crop adoption on quality-adjusted pesticide use in corn and soybeans: A full picture. In Paper presented at the American Agricultural Economics Association Annual Meeting, Orlando, FL, July 27–29.

15 Dill, G.M., CaJacob, C.A., and Padgette, S.R. 2008. Glyphosate-resistant crops: Adoption, use and future considerations. Pesticide Management Science 64:326–331.

16 Fitt, G.P. 2008. Have Bt crops led to changes in insecticide use patterns and impacted IPM? In J. Romeis, A.M. Shelton and G.G. Kennedy (eds). Integration of Insect-Resistant Genetically Modified Crops within IPM Programs. Progress in Biological Control, Vol. 5. Springer Science and Business Media, Dordrecht, The Netherlands. p. 303–328.

17 Fernandez-Cornejo, J. and McBride, W. 2002. Adoption of bioengineered crops. Agricultural Economic Report 810. http://www.ers.usda.gov/publications/aer810/ (accessed December 8, 2011).

18 Alston, J.M., Hyde, J., Marra, M.C., and Mitchell, P.D. 2002. An ex ante analysis of the benefits from the adoption of corn rootworm resistant transgenic corn technology. AgBioForum (3):article 1.

19 Benbrook, C. 2009. Impacts of genetically engineered crops on pesticide use in the United States: The first thirteen years. The Organic Center at www.organic-center.org (accessed December 8, 2011).

20 Fernandez-Cornejo, J. and Caswell, M. 2006. The first decade of genetically engineered crops in the United States. ERS-Economic Information Bulletin 11 (April). Available at Web site: http://www.ers.usda.gov/publications/eib11/eib11.pdf. (downloaded July, 2011).

21 Meihls, L.N., Higdon, M.L., Siegfried, B.D., Miller, N.J., Sappington, T.W., Ellersieck, M.R., Spencer, T.A., and Hibbard, B.E. 2008. Increased survival of western corn rootworm on transgenic corn within three generations of on-plant greenhouse selection. Proceedings of the National Academy of Sciences of the United States of America 105:19177–19182.

22 Gassmann, A.J., Petzold-Maxwell, J.L., Keweshan, R.S., and Dunbar, M.W. 2011. Field-evolved resistance to Bt maize by western corn rootworm. PLoS One 6:e22629.

23 Catangui, M. 2002. Soybean aphid in South Dakota. South Dakota State University Cooperative Extension Service Fact Sheet 914. December. Available at Web site: http://pubstorage.sdstate.edu/AgBio_Publications/articles/FS914.pdf (accessed July, 2010).

24 Catangui, M. 2001. Evaluation of control practices in South Dakota alfalfa weevil. South Dakota State University Cooperative Extension Service Fact Sheet 011. December.

25 Knodel, J.J., Charlet, L.D., and Gavloski, J. 2010. Integrated pest management of sunflower insect Pests in the Northern Great Plains. North Dakota State University Extension Service, E1457. February. Available at Web site: http://www.ag.ndsu.edu/pubs/plantsci/pests/e1457.pdf (accessed June 8, 2010).

26 Allison, P.D. 2006. Fixed effects regression methods in SAS. In Paper presented at the SUGI Proceedings, San Francisco, California, March 26–29.

27 Wooldridge, J.M. 2000. Introductory Econometrics: A Modern Approach. South-Western College Publishing, USA.

28 National Agriculture Statistics Service. 2010. Quick Stats U.S. & All States Data – Crops. Available at Web site: http://www.nass.usda.gov/QuickStats/Create_Federal_All.jsp (accessed June 9, 2010).

29 Cameron, A.C. and Trivedi, P.K. 2003. Microeconometrics: Methods and Applications. Cambridge University Press, New York.

30 Burrows, T.M. 1983. Pesticide demand and integrated pest management: A limited dependent variable analysis. American Journal of Agricultural Economics 65:806–810.

31 Bramati, M.C. and Croux, C. 2007. Robust estimators for the fixed effects panel data model. Econometrics Journal 10:521–540.

32 Elbert, A., Haas, M., Springer, B., Thielert, W., and Nauen, R. 2008. Applied aspects of neonicotinoid uses in crop protection. Pest Management Science 64:1099–1105.

33 Seagraves, M.P. and Lundgren, J.G. 2012. Effects of neonicotinoid seed treatments on soybean aphid and its natural enemies. Journal of Pest Science (in press).