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Insecticide Use and Crop Selection:

A South Dakota Case Study

by

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ABSTRACT

South Dakota has recently experienced a significant increase in the proportion of acres treated with insecticide. Unfortunately, data on insecticide usage by crop at the county level is not available. The following case study seeks to uncover the reasons for this increase by analyzing county-level data in South Dakota with a fixed effects panel regression. The study links the proportion of acres planted for a specific crop to the proportion of total acres treated with insecticide. This approach provides insight on how changing cropping patterns in South Dakota have influenced insecticide use.

Keywords: Insecticides; Genetically Modified Organism; Target pests

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Insecticide Use and Crop Selection:
A South Dakota Case Study

1. Abstract

South Dakota has recently experienced a significant increase in the proportion of acres treated with insecticide. Unfortunately, data on insecticide usage by crop at the county level is not available. The following case study seeks to uncover the reasons for this increase by analyzing county-level data in South Dakota with a fixed effects panel regression. The study links the proportion of acres planted for a specific crop to the proportion of total acres treated with insecticide. This approach provides insight on how changing cropping patterns in South Dakota have influenced insecticide use.

Keywords: Insecticides; Genetically Modified Organism; Target pests

2. 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 (Gross Domestic Product by State, US Bureau of Economic Analysis). The agricultural industry in the state has undergone a myriad of changes that are related to the rapid adoption of biotechnology and an increase in demand for corn-ethanol production. These two factors, along with prices and marketing opportunities, have contributed to a change in the crop rotation profile over the past 30 years, shifting from larger proportions of acres planted with wheat, barley and oats toward predominantly corn and soybeans.

South Dakota has adopted GM varieties faster than any other state (Adoption of Genetically Engineered Crops in the US, Economic Research Service: see Figure 1). The

rapid adoption of genetically modified (GM) crops in South Dakota over the last 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. For instance, in South Dakota, corn acres planted with Bt or stacked gene varieties increased from 37% in 2000 to 71% in 2009 (Supplemental Tables, Economic Research Service). In 2009, South Dakota shared the top adoption rate with Iowa for Bt / 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 insecticide over the past two decades. This positive trend has been gradual from 1978 to 2002, but in 2007 the increase is significantly above 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 (Agriculture Census, National Agriculture Statistics Service). This reflects an increase in acres treated as a percentage of acres planted from 8% in 2002 to 20% in 2007.

The objectives of this paper are to 1) gain insight on why there has been an increase in insecticide application usage and intensity and 2) establish whether there is a link between the type of crop planted and acres treated with insecticide and 3) consider the larger implications of the study with respect to insecticide use in other states.

3. 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. As new ground is broken for growing crops pesticide use likely increases. This occurred in the early 1980s when, overall, there was an increase in planted acres and also an increase in pesticide application rates (Osteen 2000, 6). More recent movements toward mono-cropping or reduced use of rotations to meet market demands is contradictory to fundamental pest management practices to reduce pest damage and has intensified pest populations (Lewis et al 1997, 12246).

The presence of damaging pests is an important determinant of insecticide use. Intuitively one can assume that pest infestation levels are closely related to the amount of insecticide applied. That is to say, ceterus paribus, the more insects that are present the more a producer will spray. These infestation levels, though, can fluctuate from year to year and are often difficult to predict and can spread rapidly. Studies have shown that variability in pest infestations can lead producers to spray insecticide prophylactically (Lazarus and Swanson 1983, 738).

For many studies the inclusion of pest infestation data helps to address the simultaneous decision of insecticide use and GM adoption (Cornejo and Li, 2005, 1; Vialou et al 2008, 4). Pest pressure likely impacts 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.

Corn, soybean, hay and sunflowers are important for South Dakota agriculture and each have significant pest pressures. Corn has several pests that cause crop damage every year including the European Corn Borer (*Ostrinia nubilalis*) and the Western Corn

Rootworm (*Diabrotica virgifera*). Soybeans have a recently burgeoning pest problem. Beginning around 2001, the soybean aphid (*Aphis glycines Matsamura*) started to spread and now is present throughout all of the soybean producing regions of the state[1]. In 2002 the soybean aphid was present in 30% of South Dakota counties and by 2007 the soybean aphid had reached nearly 70% of counties or all soybean producing counties (Catangui, 2005). Alfalfa weevil (*Hypera postica*) affects alfalfa and is present in every county in South Dakota. Sunflowers, because they are native species, face a substantial pest threat from 15 different insects (Knodel 2010, 1). These infestations can be highly variable even within a single field (2). Over time these pests have undoubtedly affected insecticide use. Because this study does not directly link GM adoption to insecticide use, the inclusion of pest infestation data is not critical. However, we were able to include a proxy variable for soybean aphid infestation, important because the level of infestation has changed dramatically over the time-frame of this study.

This case study evaluates the changes in chemical usage as a percentage of crop acres treated with insecticides in South Dakota. An evaluation of acres treated is a different approach to most literature reviewed, as most evaluate changes in a total pounds of insecticide applied (Dill et al 2008, 326; Fitt 2008, 315; Fernandez-Cornejo and McBride 2002, 26; Vialou et al 2008, 3). Recent studies have acknowledged that an evaluation of chemical usage as volume applied ignores important chemical attributes like strength and application practices (Osteen 2000, 4). As a result, problems arise when trying to assess changes in insecticide application rates over time.

To account for changing chemical attributes a hedonic pricing model can be utilized providing a proxy for changes in chemical potency and breadth (Vialou et al 2008, 3). Other

[1] J.G. Lundgren, personal communication, November 13, 2009.

studies, like Alston J. et al, have questioned the validity of using a pounds measure (2002, 72). They estimated chemical usage by multiplying the total acreage by the percentage treated for corn rootworm specifically (Alston et al 2002, 72). We have adopted a similar approach in this study

4. Methodology

To estimate the effect of multiple variables on insecticide use for all counties in South Dakota, a fixed effects 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 (Allison 2006, 1). This model also accounts for time-invariant unobserved effects that are not captured with available data (Wooldridge 2000, 461).

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 is limited data on this particular issue, making it challenging to describe the relationship between insecticide use and other variables. Using the fixed-effects 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 (Wooldridge 2000, 461). The unobserved effect, a_i, accounts for unobserved effects that do not change over time (ie latitude, longitude, soil type, 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. Pest populations are often unpredictable and can vary greatly from year to year. Some pest populations have experienced dramatic change over the past 30 years. We assume that changes in pest

populations are partially accounted for by including a variable that tracks the spread of soybean aphid across South Dakota. Other changes in pest populations are contained within the time-varying error term. We are also making 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 (Wooldridge 2000, 507-8).

5. Data

Data from several data sources was used in this project. Data was collected from the National Agriculture Statistics Service (NASS) as well as the Census of Agriculture. Data regarding total acres planted was retrieved from NASS's *Quick Stats All States Data-Crops*. The Census data used is *Agriculture Chemicals Used*, specifically: *sprays, dusts, granules, fumigants, etc. to control insects on hay and other crops*. The Census reports all acres treated at the county level, not crop specific. Thus a challenging factor for this research and one of our objectives, investigating which crops are being treated and by extension, exploring the main causes of the increase in acres treated.

The analysis included variables that represented acres planted with corn, soybean, sunflower and hay which, combined, accounted for 77% of all acres planted in 2007. Two regressions were employed with the analysis. The first regression (Equation 1) used all the crop variables as well as a dummy variable for 2007 and a dummy aphid variable. The second regression (Equation 2) included interaction terms for all variables interacted with the

2007 dummy variable to try to capture the influence each variable had on insecticide usage in 2007.

The decision to include only the 2007 dummy variable to capture changes in insecticide use over time is because insecticide use in South Dakota remained fairly stable from 1978 to 2002, with eight to ten percent of planted acres being treated with insecticides. In 2007, South Dakota experienced an increase in acres treated with insecticides, with nearly twenty percent of the planted acres treated with insecticides; this increase is documented in Figure 2.

$$Y_{1it} = \delta_1 + \delta_2 YR07_{2it} + \delta_3 Aphid_{3it} + \beta_1 Corn_{1it} + \beta_2 Soybean_{2it} + \beta_3 Sunflower_{3it} + \beta_4 Hay_{4it} + a_i + U_{it} \quad (1)$$

$$Y_{2it} = \delta_1 + \beta_1 Corn_{1it} + \beta_2 Soybean_{2it} + \beta_3 Sunflower_{3it} + \beta_4 Hay_{4it} + \beta_5 Corn*07_{5i} + \beta_6 Soybean*07_{6i} + \beta_7 Sunflower*07_{7i} + \beta_8 Hay*07_{8i} + \alpha_i + U_{it} \quad (2)$$

for *i* county in year *t* .

The dependent variable in both regressions is a proportional variable and is defined in Equation 3. 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 (Burrows 1983, 808).

$$Y_{it} \equiv \text{total acres treated with insecticide}_{it} / \text{total acres planted}_{it} \quad (3)$$

The outliers within the data identified in Figure 2 and Figure 3 are worth discussion. Figure 2 shows the level and year of outlier occurrence whereas Figure 3 provides 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 (Bramati and Croux 2007, 535).

A 2007 year dummy variable was included to focus on the changes in acres treated in 2007. Variables were also included to show the effect of changes in land planted with various crops to include: corn, soybeans, sunflowers and hay. Harvested acres were used for the hay variable since hay is a perennial. The hay variable includes all hay crops, including alfalfa, grass silage, haylage and hay crops cut and fed green as described by the Census of Agriculture. The crop variables are represented as a percentage of total acres planted that are devoted to each specific crop for the specific county. These crop proportions and how they have changed over the years of the study are shown in Figure 4. The crop variables are meant to make inferences about the effect different crops contribute to insecticide use. Corn has recently experienced a large increase in acres planted and in 2007 accounted for nearly 33 percent of total acres planted. Soybean acres planted have also dramatically increased over the span of the study, increasing from just three percent in 1978 to 25 percent in 2002 before dropping to 22 percent in 2007. Hay acres have declined slightly but remain an important crop accounting for 20% of acres planted. Most of these acres are in western South Dakota.

From 1978 to 2007 the proportion of acres planted with sunflowers was variable, ranging from 1% to 5% of total acres planted. Data for these variables was collected from the National Agriculture Statistics Service.

The introduction and rapid expansion of the soybean aphid 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, displaying a one for counties where the soybean aphid is present and a zero when it is not was constructed. The data was collected by South Dakota State University Entomology Extension who conducted yearly field surveys to determine the presence of soybean aphid in a given county (Catangui, 2005). The soybean aphid was not present in South Dakota prior to 2001. Because of other data limitations we are restricted to census years, thus from 1978 to 1997 we report zero counties with the soybean aphid. In 2002 twenty counties had experienced a noticeable level of soybean infestation. In 2007 the soybean aphid had already spread to 46 out of 66 counties. This variable is a proxy for aphid pest populations and is meant to explain important pest changes in South Dakota.

The complete data set is a panel that has observations for each county over the past seven Census years. The data is a balanced panel, meaning there are no missing observations for any counties over the observed years. A complete listing of the variables used in the model, and their definitions, is located in Table 1.

6. Results

Because the data showed relative stability in the dependent variable (acres treated with insecticide) up to 2007, only one dummy variable was included to show the difference between 2007 and all other years. The first model also includes the four crop variables and the aphid variable. The results of this regression are displayed in Table 2. Results from the

Hausman Test were significant so the following results are fixed effects estimation. The overall model was also significant, with an R^2 of 0.35 and an F statistic of 21.32.

Every variable was significantly related to the proportion of acres treated with insecticide except the sunflower variable. Corn and Hay are both positive and significant. Previous studies that have looked at the relationship between GM corn and insecticide usage have reported mixed results. Our results indicate, ceterus paribus, that a 1% increase in corn acres planted will result in 0.26% increase in total acres treated. Given that average proportion of corn acres planted range from 21% to 33% and a very high proportion of those corn acres are Bt and stacked gene varieties, the marginal increase in the proportion of acres treated appears to be very high. This result may be reflecting prophylactic spraying, as discussed by Lazarus and Swanson (1983), on the part of producers.

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 0.22% 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 (Catangui, M. 2000).

Soybean is the last significant crop variable. This is the only crop variable with a significant and negative coefficient. Anecdotally, producers say that they are much more likely to spray their soybeans than their corn, most likely due to the substantial pest threat from the aphid beginning in 2001. Also, currently there is not a GM insecticide resistant

soybean variety option for producers as there is for corn. Because of this, the results of the soybean variable must be considered jointly with the aphid dummy variable. A significant and positive aphid variable suggests that when an aphid is present in a county, acres treated with insecticide increases by 3.25%. The soybean variable alone suggests that a 1% increase in the proportion of soybeans acres planted in a county would result in a reduction in the proportion of acres treated by 0.12%. Likely, the aphid variable is controlling for many of the effects of the pest so when the proportion of soybean acres increases, holding the effects of the aphid constant, there is a decrease in the proportion of acres treated with insecticide. If a GMO soybean variety is developed that targets the soybean aphid, then one would expect a significant drop in the usage of insecticides on soybean acres.

Lastly, as expected, the 2007 year-dummy variable was significant and positive corresponding to the noticeable increase in acres treated as shown in Figure 1. This highly significant result prompted additional analysis that resulted in the inclusion of the 2007 interaction terms that are present in the second regression. The regression coefficient indicates the estimated increase in total acres treated in 2007 is 8.2% higher than for the other census years in the study. This estimate is very consistent with the actual data.

The second regression and the inclusion of 2007 interaction terms is an attempt to dissect the causes of that increase in 2007, one of our main objectives with this study. 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 highly significant, with an F statistic of 26.43 and an R^2 value of 0.364. Three key variables are missing from this regression, i.e., the 2007 dummy variable, the aphid variable and an aphid 2007 interaction term. When the 2007 dummy variable is included it is not significant. We conclude the information contributed by this variable is captured by the addition of the 2007 interaction terms. The aphid and the aphid 2007 interaction term were not included in the regression due to high levels of correlation with the corn*07 interaction term (0.77 and 0.95 respectively).

The overall 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 interaction term is insignificant. A careful discussion of each interaction term and the contribution of each crop is presented below.

The results of the regression 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 empirically estimated relationship can be described as:

$$Y_2 = 0.2168*Corn + 0.2546*Corn*07 \qquad (4)$$

What this equation indicates is that when the 2007 dummy variable equals 0, the second term in eq. 4 is then equal to 0 and the effect of the proportion of corn acres is related to the proportion of acres treated with insecticide via the first term in the equation. That is to say that for all years in the study, a 1% increase in acres planted with corn results in a 0.22% increase in the proportion of acres treated, ceteris paribus. For all years the average proportion of acres planted with corn is 0.22. By substituting into Equation 4 the average proportion of corn acres planted for all years, the overall contribution of corn to the

proportion of acres treated is estimated to be 0.0477 (0.2168*0.22). Thus, for all years in the study, it is estimated that on average, 4.8% of acres treated are a result of the proportion of corn acres planted.

In 2007, the regression results indicate that the proportion of corn acres planted had a much larger impact. Now, looking at Equation 4 again, the second term becomes very important. In 2007, the assumed value of the 2007 dummy variable equals 1 so the overall impact of corn in 2007 is the addition of both terms in Equation 4. By substituting the overall average in the first term and the average proportion of corn acres planted in 2007 for the second term, the overall impact of the proportion of corn acres treated on the proportion of acres treated with insecticide is estimated to be 0.119, i.e., (0.2168*0.22 + 0.2546*0.28). The estimate of approximately 12% of total treated acres is attributed to the proportion of corn acres planted is surprising given that 59% of corn acres planted in South Dakota are planted with GMO Bt or stacked variety seed .

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 0.2168 in the 1978 to 2002 period to 0.4714 in 2007. This steepening of the slope relationship increased the contribution of corn acres planted to total acres treated from 4.8% to 12%. The analysis provides strong evidence that corn production in South Dakota has experienced a recent intensification of insecticide use.

The results for hay are similar to that of corn because regression results indicate positive and significant coefficients for both the main effect and the interaction affect. An estimate of the effect of the proportion of hay acres planted, ceterus paribus, is shown in Equation 5.

$$Y_2 = 0.2002*Hay + 0.1053*Hay*07 \quad (5)$$

Using the same analysis procedure used for corn, we can determine the overall effect of proportion of hay acres on the proportion of acres treated with insecticide. Using observations from all years, the average proportion of hay acres planted is 0.28; in 2007 the average is 0.22. If we are just considering the impact overall, the 2007 dummy variable is equal to 0, the effect is 0.056. Overall hay contributes 5.6% to the proportion of acres treated with insecticide. Evaluation of Equation 5, including the 2007 interaction term will help determine the effect of the proportion of hay acres on the proportion of acres treated with insecticide in 2007. The estimated effect in 2007 is 0.0792 meaning that 7.92% of the proportion of acres treated can be explained by the proportion of hay acres planted. Although these are rough estimates the increase, from 5.6% to 7.9%, indicates intensification of insecticide use on hay in 2007 relative to previous census years.

For sunflowers, the overall variable is not significant but the 2007 interaction term is highly significant. This means that the impact of the proportion of sunflower acres planted on the proportion of acres treated is only seen in 2007. The implication of the 2007 sunflower interaction term is a 1% increase in the proportion of sunflower acres translates into a 0.43% increase in the proportion of acres planted. The fact that there is such a difference between the results for all years and the results for 2007 might suggests that behavior or environmental conditions have changed for sunflower producers. Either producers were spraying more sunflower acres or they were, perhaps, spraying existing acres more intensely. Although specific information is unknown, this could be in response to a pest threat or a change in cultural practices. Taken as a whole the impact of such a change is somewhat muted due to the fact that, in 2007, sunflowers only accounted for 1% of all acres

planted. In 2007 the average proportion of sunflower acres planted in the counties was 0.0059. This multiplied by the coefficient for the sunflower interaction term gives the result of 0.0026, meaning that 0.26% of the proportion of acres treated can be explained by the proportion of sunflower acres planted.

Lastly, the results for soybean suggest that there might be a change occurring as well. The overall soybean variable is significant and negative. This implies that a 1% increase in soybean acres planted translates into a 0.10% decrease in the proportion of acres treated. The 2007 interaction term, though, is not significant. The overall impact of the proportion of soybean acres planted on the proportion of acres treated with insecticide is difficult to assess given the impact of the soybean aphid. The soybean aphid was dropped from this regression because of multicollinearity. Given that the soybean aphid had infested all soybean producing counties in 2007 it is a reasonable assumption that these counties had a positive effect on total acres treated. However, we cannot comment on whether there has an intensification of soybean acres treated.

USDA data indicates that there was an increase in the proportion acres treated with insecticide in 2007 and our analysis indicates that corn, sunflower, and hay all contributed to this increase. There are many reasons why corn, sunflower and hay may have contributed to the increase in the proportion of acres treated with insecticide in 2007. Producers may be responding to new or burgeoning pest threats. All three crops face significant pest pressures. Also, risk averse behavior could be contributing to this increase, perhaps a lack of accurate pest information is leading producers to spray prophylactically as Lazarus and Swanson found (1983, 738). While the results provide insight into factors affecting insecticide use, the specific cause of the increase in insecticide use in 2007 is still unknown.

7. 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 6 shows the proportion of acres treated with insecticide from 1987 to 2007. Of the thirteen 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 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, didn't encounter an increase until the 2007 year where the proportion remained relatively low, though variable, until an increase in 2007. The differences between states could be the result of varying or spreading pest populations or possibly the result of technology adoption.

The thirteen states listed in Figure 6 make up the mid-west 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 2007 increase in the proportion of acres planted being treated with insecticide.

8. Conclusion

Due to data limitations the full extent of the relationship between the type of crops planted and the impact of cropping patterns on insecticide use is not fully known. Additional data is needed, mainly data that links insecticide to specific crops is necessary to produce a more precise analysis. The results of this analysis lend themselves to a series of stylized

facts, which taken together tell part of the story of insecticide use in South Dakota and lead to areas of possible future research.

Our analysis suggests there are four variables that have significantly increased the proportion of acres treated with insecticide in South Dakota; corn and hay acres, sunflower acres in 2007, and the presence of the soybean aphid. As total planted acres have decreased slightly over the years of this study and the largest drop was experienced from 2002 to 2007. However, it is interesting to see the jump in acres treated with insecticides from 2002 to 2007.

Overall, hay acres have been decreasing over the years. As a result it is unlikely hay acres account for most of the large upswing in acres treated in 2007. The results from the second regression indicate that of the approximately 20% of acres that were treated, hay accounts for 7.8%. The declining trend in hay acres indicates that those production acres are likely being put into pastureland or the ground broken and planted with grain crops, with the latter being more likely. Of the hay acres treated with insecticide, alfalfa acres are the probable largest contributor to the acres treated.

The overall impact of the proportion of sunflower acres planted in 2007 is quite small. The regression results were positive and significant suggesting that a 1% increase in the proportion of sunflower acres planted leads to a 0.44% increase in the proportion of acres treated. Sunflowers, though, are a dwindling crop, only accounting for 1% of acres planted in 2007. Therefore sunflowers' bearing on the proportion of acres treated with insecticide is estimated to be less than 1%.

Another important variable is the presence of the soybean aphid which was present in every soybean producing county in 2007. Perhaps more importantly, the soybean aphid

variable displays the ability of pest threats to change rapidly how difficult it can be to accurately predict pest threats. Producers are aware of these potentially extensive and fast-growing threats which can impact their likelihood to apply insecticides and their willingness to accept the risk of potential pest threats. With the continuously changing insect threats it is possible producers are behaving in a risk averse manner and treating prophylactically to protect their investments. This type of behavior is akin to buying an insurance policy where there is potential for it to pay off during years when there is an infestation.

Corn has a major impact of the proportion of acres treated, based on the magnitude of the coefficient and the large number of acres planted with corn in the state. This is interesting as GM adoption continues to rise. GM use likely reduces target pest threats with genetic defenses reducing the need for insecticides. Producers may be treating more acres to protect themselves against non-target pest threats that the GM varieties are not targeting and are not willing to take the risk if a non-target infestation occurs. One possible candidate is the corn leaf aphid (*Rhopalosiphum maidis*). It is a highly sporadic pest that has been in South Dakota for many years. 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.

An additional factor is the changing market demands for corn, i.e. ethanol. These new demands may be affecting crop rotation which was a common cultural method for pest management practices. Producers may now be relying on insecticide application methods and biological methods (planting GM seed) more heavily than traditional crop rotation to control pests thus increasing the acres being treated.

It is important to note, however, that 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 GMO crop production suggests additional research is needed.

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Figure 1. Adoption of insect-resistant and stack GM varieties for South Dakota and the US

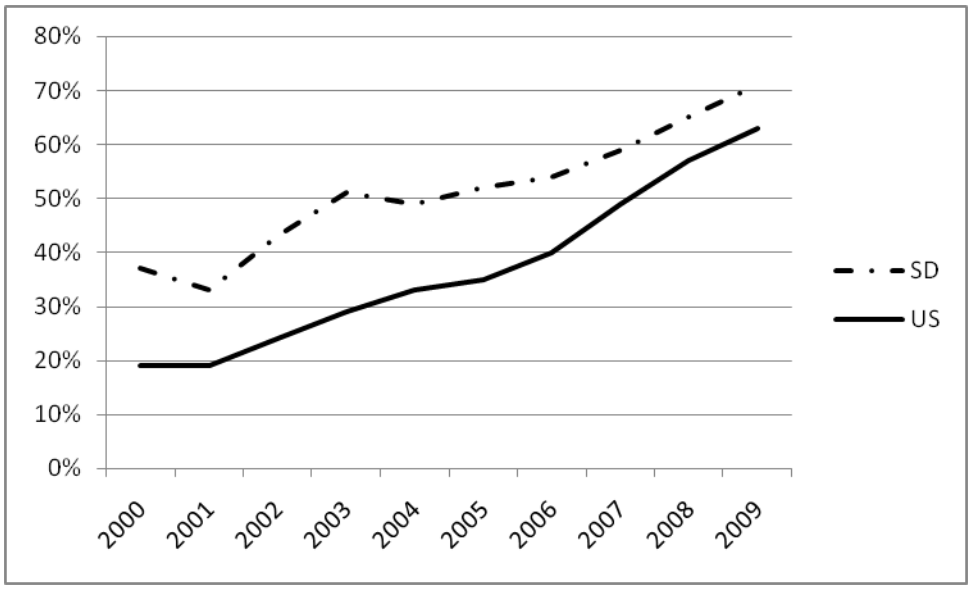

Figure 2. Proportion of planted acres treated with insecticide in South Dakota

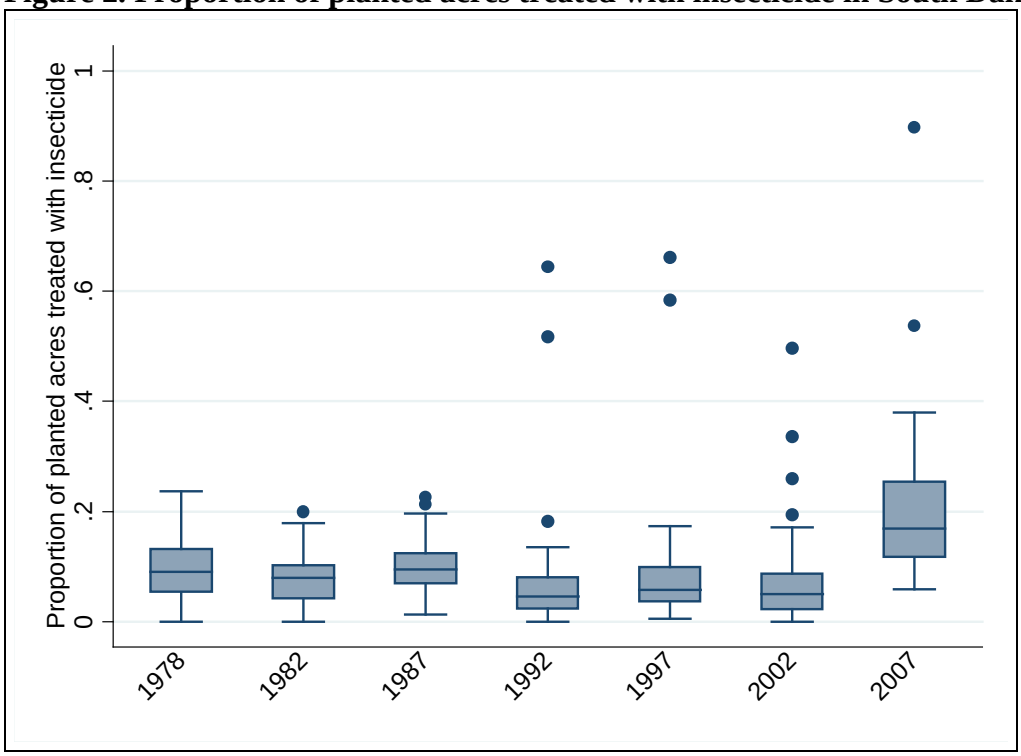

Figure 3. Map of South Dakota county outliers by year

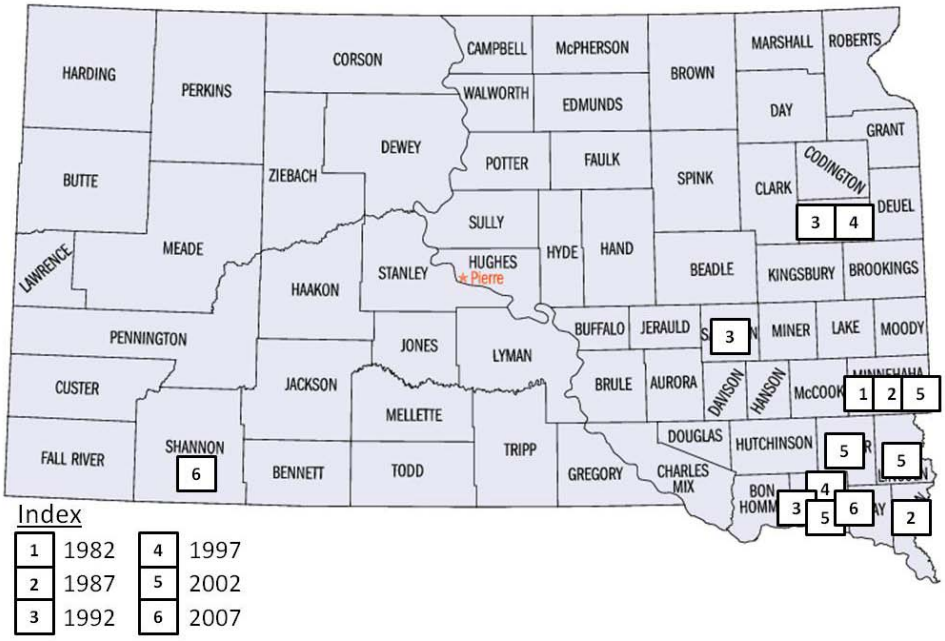

Figure 4. Proportion of acres planted with four crops of interest for South Dakota

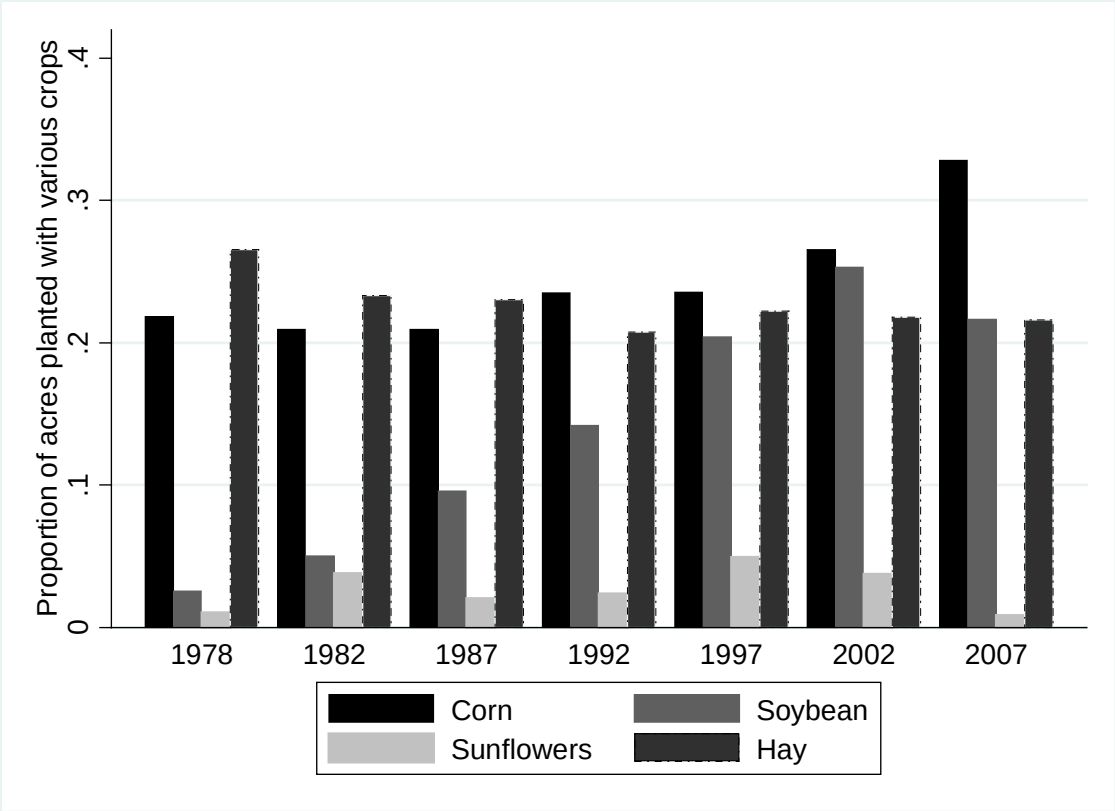

Figure 5. Coefficients from second regression with 95% confidence interval

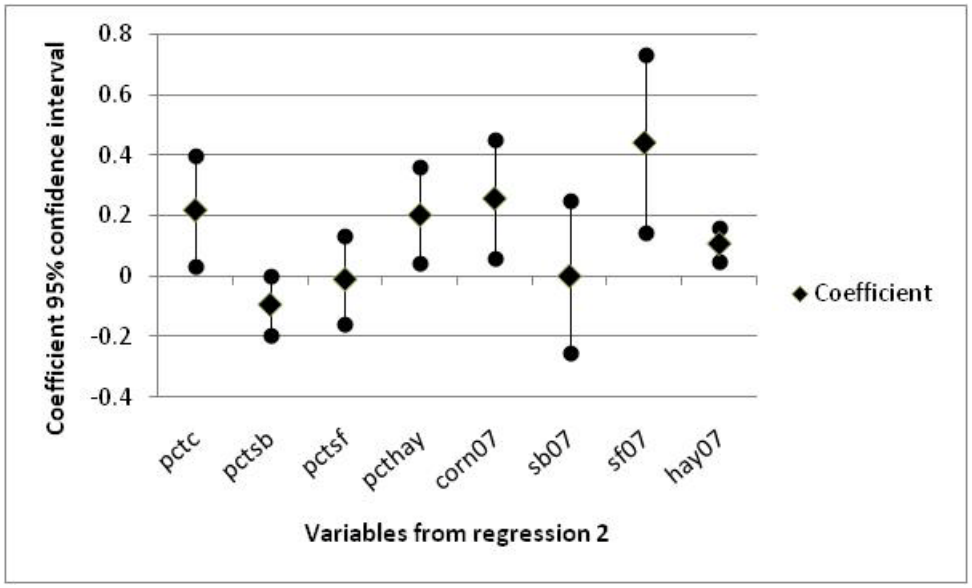

Figure 6. Proportion of acres treated with insecticide for mid-west states

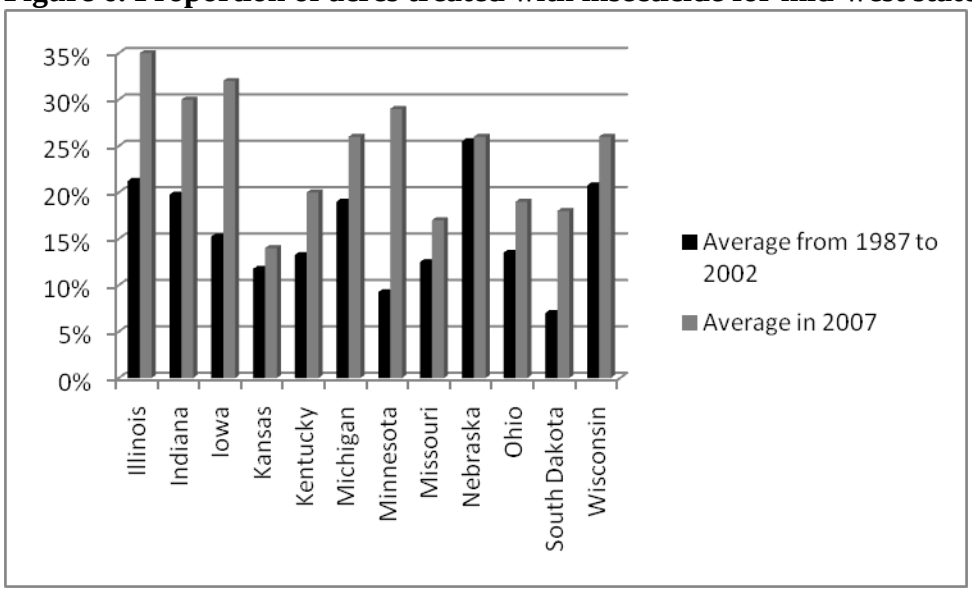

Table 1. Variables used in panel regression

Variable Name	Definition	Source/Description
Pest	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 extension educators (Catangui 2005)
Intercept	Constant term	

Table 2. Results from first panel regression

Variable	Coefficient	Robust standard error	t-statistic
Yr07	0.0822	0.0139	5.93***
Corn	0.2592	0.0847	3.06***
Soybean	-0.1208	0.5416	-2.23**
Sunflower	0.0522	0.0731	0.71
Hay	0.2286	0.0834	2.74***
Aphid	0.0325	0.0174	1.87*
Intercept	-0.0245	0.0327	-0.75

***significant at 1% level
**significant at 5% level
*significant at 10% level

Table 3 Results from panel regression analysis with interaction terms

Variable	Coefficient	Robust standard error	t-statistic
Corn	0.2168	0.0928	2.34**
Soybean	-0.0961	0.0504	-1.91*
Sunflower	-0.0124	0.0734	-0.17
Hay	0.2002	0.0806	2.48**
Corn*07	0.2546	0.0992	2.57**
Soybean*07	-0.0020	0.1277	-0.01
Sunflower*07	0.4392	0.1498	2.93***
Hay*07	0.1053	0.0287	3.66***
Intercept	-0.007	0.0320	-0.23

***significant at 1% level
**significant at 5% level
*significant at 10% level