Conservation Tillage, Herbicide Use, and Genetically Engineered Soybeans in the U.S.A.

J. Fernandez-Cornejo, Ch. Hallahan, R. Nehring, S. Wechsler, and A. Grube

Introduction

Many of the positive environmental impacts of conservation tillage systems are well documented[1]. By leaving substantial amounts of crop residue on the soil surface, conservation tillage reduces soil erosion by wind and water, increases water retention, and reduces soil degradation as well as water and chemical runoff. In addition, conservation tillage reduces the carbon footprint of agriculture.

Less is known about the interaction of adoption of herbicide tolerant (HT) crops and conservation tillage as well as their effects on herbicide use. These are important issues. For example, if adoption of HT crops induces the adoption of conservation tillage, then HT crop adoption may indirectly benefit the environment in the form of reduced soil losses and runoff. However, if herbicide use increases with conservation tillage, then (some of) the environmental gains from reduced soil erosion may be offset by increased reliance on herbicides[2]. Consequently, HT crop adoption, conservation tillage and herbicide use should be examined together.

The objective of the study is to analyze the long term relationship between conservation tillage, HT adoption, and herbicide use for soybeans.

Trends in Conservation Tillage and HT Adoption

The use of conservation tillage systems increased steadily throughout the 1980's and 1990's. While only 30 percent of soybean farmers used conservation tillage systems in 1996, 63 percent of soybean farmers used conservation tillage in 2006 (**Fig. 1**).

HT crops, developed to survive the application of specific herbicides that previously would have destroyed the crop along with the targeted weeds, provide farmers with a broader variety of options for effective weed control. U.S. farmers have adopted genetically engineered (GE) crops widely since their introduction in 1996. HT soybeans have been the most widely and rapidly adopted GE crop in the U.S., followed by HT cotton[2]. Based on USDA survey data, adoption of HT soybeans went from 17 percent of U.S. soybean acreage in 1997 to 68 percent in 2001 and 93 percent in 2010 (**Fig. 2**).

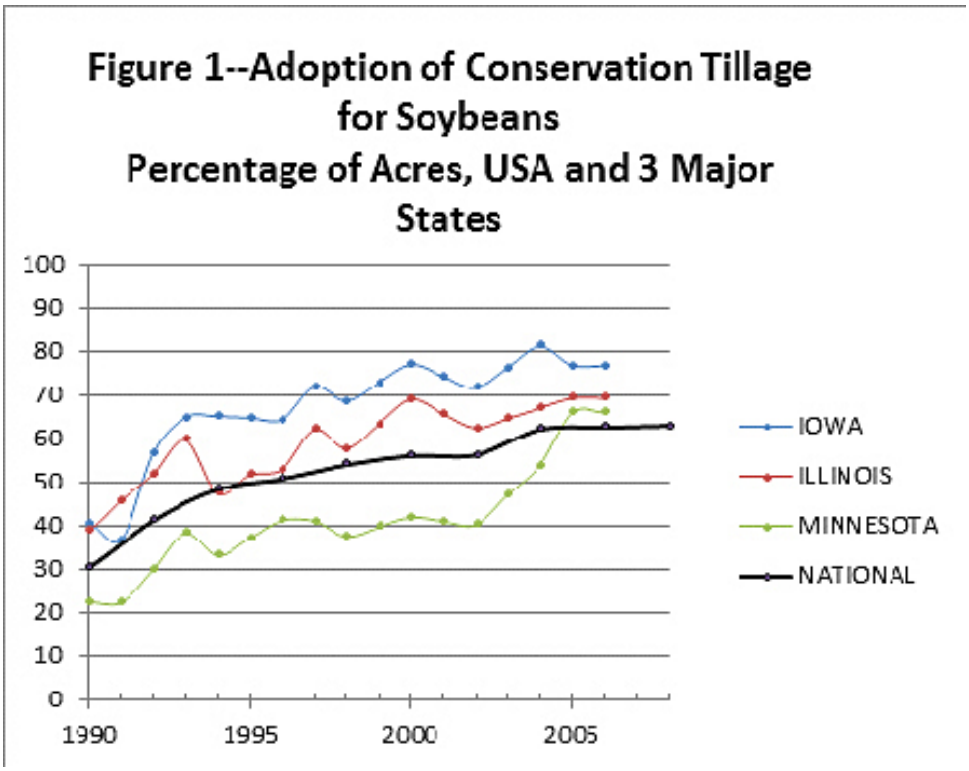
Anecdotal evidence indicates that the adoption of HT crops (particularly HT soybeans) has facilitated the use of conservation tillage systems because the use of HT seeds tends to make weed control more effective and less costly[3].

Researchers have carried out empirical analyses to examine the relationship between the decision to adopt HT crops and the decision to use conservation tillage systems. While most studies have found that the decisions to adopt conservation tillage and to adopt HT seeds are correlated[4], it is difficult to demonstrate whether HT adoption induces farmers to adopt conservation tillage practices, or whether adoption of conservation tillage practices induces farmers to adopt HT seeds.

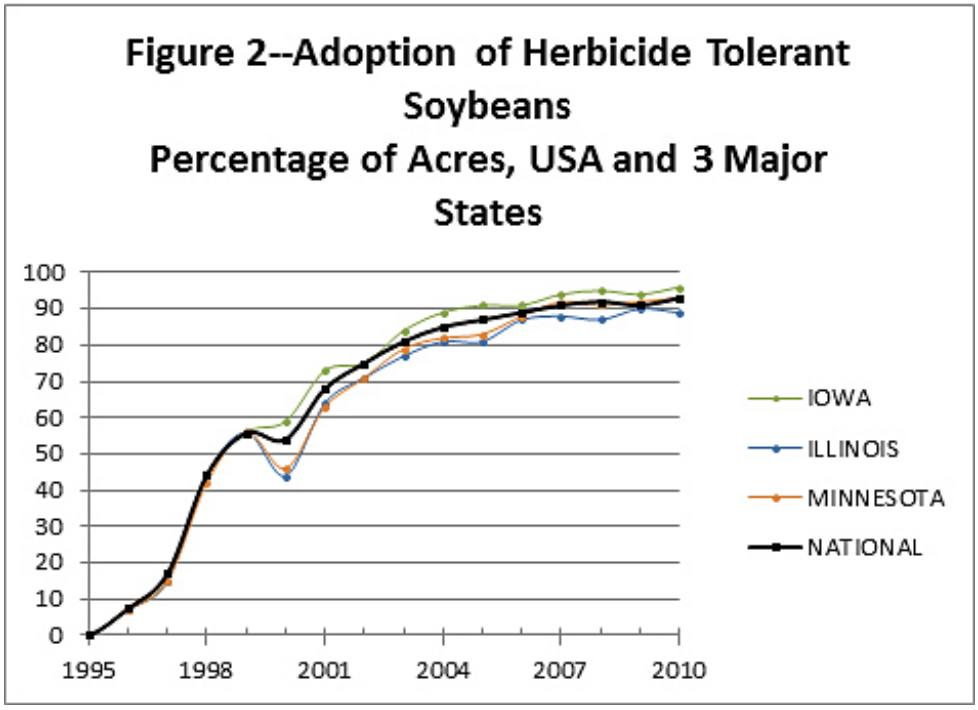
There are many differences among previous studies: the crops analyzed, periods considered, unit of analysis (farm vs. state level), methodology, and even the concepts involved. For that reason, caution should be exercised to make definite conclusions. Still, in most cases examined, it appears that adopting HT crops facilitates the use of conservation tillage systems and vice versa. This implies that by encouraging farmers to adopt conservation tillage, HT crop adoption indirectly benefits the environment by reducing soil losses and erosion, runoff, fuel use and the carbon footprint of agriculture[5].

[1]Conservation tillage systems are cropping production systems that leave at least 30 percent of crop residues on the soil after planting. There are several types of these systems, including mulch till, ridge till and no-till systems.

[2]While the term pesticide includes herbicides, insecticides and fungicides, in the case of soybeans, most of the pesticides used are herbicides: More than 95 percent of the pesticides applied to soybeans in 2006 were herbicides. This paper focuses on herbicides.



Source: CTIC (2010); USDA ARMS data.



Sources: Fernandez-Cornejo (2010); Vialou et al. (2008).

Herbicide Use and HT Crops

Several studies have examined the adoption of HT crops and herbicide use. The results of these studies are mixed, particularly in the case of soybeans. Some studies suggest that herbicide use on HT soybeans may be slightly higher than herbicide use on conventionally grown soybeans in the U.S.[4,5,6,]. However, glyphosate (the herbicide used in most of the HT crops) is less toxic to humans, and not as likely to persist in the environment as the herbicides it replaces[5]. Consequently, increased herbicide use on HT soybeans is not necessarily indicative of worse environmental outcomes.

Herbicide Use and Conservation Tillage

There is no clear consensus on how conservation tillage affects herbicide use. Results tend to depend on the type of conservation tillage system employed, the location, the weather, the soil type, the metric used to measure herbicide use, and endemic pest pressure. For example, a 1998 USDA[7] report citing Fawcett[8] observes that herbicide use may decrease with conservation tillage after a few years of adoption. Knake[9] states that, "as tillage is reduced, some weeds (such as velvetleaf) may become less of a problem. Other weeds such as fall panicum, mare's tail, hemp dogbane, and common milkweed may increase." Using 1991-1992 Cornbelt data, Fuglie[10], finds "no evidence that herbicide or fertilizer application rates are higher on fields with conservation tillage systems than on fields with conventional tillage." On the other hand, analyses of USDA Cropping Practices Survey data collected for corn and soybeans from 1990-1995[7] showed that herbicide applications rates were higher for conservation tillage than for conventional tillage systems.

Data and Research Methodology

Herbicide use in soybeans is hypothesized to be related to location, weather (temperature and precipitation during the plant growing season), crop prices, herbicide prices, tillage practices, and HT adoption decisions. We have constructed a panel data set of 12 major soybean producing states for 1996 through 2006 using: tillage data obtained from the Conservation Technology Information Center[11] for the years 1996-2004 supplemented by USDA's ARMS data for more recent years; HT adoption rates obtained from USDA[12]; crop prices obtained from USDA's *Agricultural Prices Summary*; and data on herbicide use obtained from USDA's *Agricultural Chemical Usage* reports[13] supplemented by data from the Doane Countrywide Farm Panel Survey. **Table 1** provides descriptive statistics for the main variables in the dataset.

Table 1 - Summary Statistics of Main Variables, US Soybean Farmers, 1996-2006

Variable	Means
Share of acreage under conservation tillage	0.55
Share of acreage planted with HT soybean seeds	0.60
Soybean price (relative to corn)	4.61
Quality-adjusted quantity of herbicide used, index	9.37
Quality adjusted herbicide Price, index	5.12

Note: Summary Statistics are calculated from state level means.

Because herbicides contain active ingredients with different characteristics, aggregating herbicide-use statistics across herbicide types produces results that are difficult to interpret. In order to analyze herbicide trends across states and over time while accounting for changes in the quality of the herbicides used, we use quality adjusted indices of herbicide prices and quantities using the procedure developed by Fernandez-Cornejo and Jans[14]; Fernandez-Cornejo et al.[15], and Vialou et al.[16].

To determine the appropriate specification for our model, it is necessary to test certain assumptions about the data. First, we tested whether the model variables are stationary. After determining that the model variables were stationary, we used Granger Causality Tests to confirm that adoption of HT soybean "Granger-causes" conservation tillage adoption for soybeans, but that conservation tillage adoption does not Granger-cause the adoption of HT soybean.

Next, we used Hausman tests that allow us to conclude that state level HT soybean adoption rates are exogenous to state level tillage rates and state level quality adjusted herbicide use for the 1996 – 2006 period. Because the Granger causality tests indicate that state level HT soybeans adoption rates can be used to predict state level conservation tillage rates, and because the Hausman tests indicate that HT adoption rates are exogenous, our data can be analyzed using a recursive, two-equation system. The first regression equation models conservation tillage rates as a function of the adoption rate of HT soybeans and the real price of soybeans. The second regression equation models quality-adjusted quantity of herbicide applied to soybeans as a function of the adoption rate of conservation tillage, the HT soybean adoption rates, and lagged quality adjusted herbicide price.

Main Results

Table 2 shows the regression results for the first regression, which analyzes the effect of HT adoption on conservation tillage adoption. Our results indicate that HT soybean adoption has a positive and highly significant impact on adoption of conservation tillage amongst U.S. soybean farmers. This suggests that farmers who adopt HT soybean seeds are also more likely to adopt conservation tillage systems than farmers using conventional seeds. Thus, in addition to shifting usage from relatively toxic traditional herbicides (such as Trifluralin and Pendimethalin) to glyphosate (which is known to be relatively benign), HT adoption induces farmers to adopt more environmentally friendly tillage techniques.

Table 2 - Effect of HT Soybean Adoption on Conservation Tillage,1996-2006

Observations	132	
R-Squared	0.17	
Variable	**Parameter Estimate**	**P value**
HT Soybean Adoption	0.19 ***	<0.0001
Lagged Relative Soybean Price	0.02 **	0.03
Constant	0.34 ***	<0.0001

Expressing the results of **Table 2** as elasticities, we find that the elasticity of the adoption of conservation tillage with respect to the adoption of herbicide-tolerant soybeans (at the means) is 0.21 (**Table 3**). This means that a one-percent increase in adoption of HT soybeans leads to 0.21 percent increase in adoption of conservation tillage.

Table 3 - Elasticities of Conservation Tillage and Quality Adjusted Herbicide Use with respect to HT Soybean Adoption

Dependent Variable	Elasticity
Conservation Tillage	0.21
Quality Adjusted Herbicide Use	-0.30

Table 4 shows the regression results for the second regression, which analyzes how HT adoption affects quality-adjusted herbicide use. Our results indicate that HT adoption has a very significant impact on quality-adjusted herbicide use, but that conservation tillage does not significantly affect quality adjusted herbicide use. Given that the use of HT seeds induces farmers to shift herbicide usage towards glyphosate, it is not surprising that adopting HT seeds induces farmers to use fewer quality adjusted pounds. After all, glyphosate is less toxic than many other herbicides.

Table 4 - Effect of HT Soybean Adoption and Conservation Tillage on Quality Adjusted Herbicide Use, 1996-2006 - Random Effects Model

Observations	132	
R-Squared	0.33	
Variable	**Parameter Estimate**	**P value**
Conservation Tillage	0.72	0.78
HT Soybean Adoption	-4.67 ***	<0.001
Lagged Relative Soybean Price	0.04	0.81
Lagged Quality Adjusted Herbicide Price	0.22	0.55
Constant	10.36 **	0.02

*** indicates that p<0.01, ** indicates that p<0.05, * indicates that p<0.1.

From the results of **Table 4** we calculated that the elasticity of quality-adjusted quantity of herbicide use with respect to HT adoption (at the means) is -0.30 (**Table 3**). This means that a one-percent increase in adoption of HT soybeans leads to a 0.3 percent decrease in the quality-adjusted quantity of herbicide use.

Conclusions

Using a panel data set covering 12 States and 11 years (from 1996 to 2006) we find that HT soybean adoption leads to a significant increase in the adoption of conservation tillage. A one-percent increase in HT soybean adoption leads to a 0.21 percent increase in conservation tillage. In addition, HT soybean adoption leads to a decrease in the quality-adjusted quantity of herbicide used: A one-percent increase in HT soybean adoption leads to 0.3 percent decrease in quality adjusted herbicide use. Thus, this study finds that the adoption of herbicide-tolerant crops benefits the environment directly by reducing quality-adjusted herbicide use and indirectly by increasing conservation tillage.

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Jorge Fernandez-Cornejo, Charlie Hallahan, Richard Nehring, and Seth Wechsler*
US Department of Agriculture, Economic Research Service

Arthur Grube
US Environmental Protection Agency

**JORGEF@ers.usda.gov.edu*

Fernandez-Cornejo, Hallahan, Nehring, and Wechsler are with the Economic Research Service, USDA; Grube is with the U.S. Environmental Protection Agency. The views expressed are those of the authors and do not necessarily represent the views or policies of the U.S. Dept. of Agriculture or the U.S. Environmental Protection Agency.