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Impact of GE Crop Adoption on Quality-Adjusted Herbicide Use in U.S. Corn Production

Richard Nehring*
Andrew Martin
Jorge Fernandez-Cornejo*,
Charlie Hallahan*
Alexandre Vialou
Seth Wechsler*
Arthur Grube♦

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* Economic Research Service, USDA; ♦ U.S. Environmental Protection Agency

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Controversies over genetically engineered (GE) crops remain because of uncertainties regarding their long term impact on pesticide consumption, and consequently on the environment if weeds and/or insects develop resistance to them. Updated USDA and other data on pesticide use and GE adoption rates enable us to present a comprehensive analysis that spans across more than 20 years for corn (comparing pesticide use trends during GE adoption since the late 1990s with earlier years provides insight into the role of nonglyphosate herbicides in weed control), a crop that has benefited from intensive bioengineering research in the United States because of its important role as a source of livestock feed, biofuel feedstock and other uses.

The debate over the costs and benefits of GE crops has been underway for over a decade, and has recently increased with accumulating evidence of weed resistance to glyphosate in major Corn Belt states. Weed scientists at universities in the Corn Belt have observed that some weeds do not respond to the "program of choice--post emergence herbicide applications using glyphosate." For example, Iowa State extension weed specialists have identified evolving resistance to glyphosate for 16 weeds in Iowa, now controlled by "residual" pesticides-e.g. mesotrine plus atrazine used as an additive to glyphosate, while widely dispersed glyphosate resistance is reported in neighboring states; for example glyphosate-resistant waterhemp and giant rag weed in Minnesota (Gunsolus, 2008).

U.S. farmers have adopted GE) crops widely since their introduction in 1996. Soybeans and cotton genetically engineered with herbicide-tolerant traits have been the most widely and rapidly adopted GE crops in the U.S., followed by insect-resistant cotton and corn (Fernandez-Cornejo, 2009).

Herbicide-tolerant (HT) crops, developed to survive 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. Based on USDA survey data, adoption of HT corn went from 12 percent of U.S. corn acreage in 1997 to 20 percent in 2001 and 63 percent in 2008 (figure 1). Plantings of HT cotton expanded from about 10 percent of U.S. acreage in 1997 to 56 percent in 2001 and 71 percent in 2009. The adoption of HT soybeans, which had been above 80 percent by 2002, has soared above 90 percent in the last five years.

This paper presents preliminary findings on the use of HT corn and quality-adjusted herbicide use for 12 key corn producing states using a panel data set for 1986-2008.

Pesticide Use, GE Crops, and Weed Resistance

Several studies have attempted to establish whether the adoption of conservation tillage and GE crops affects pesticide use.[1] The results depend on the period studied, type of data used, the different approaches to measuring pesticide use, and various statistical procedures. Cross section studies provide evidence but they are affected by the particular condition of the year of study and may not be representative of the overall situation. On the other hand, many time series studies have been tainted by econometric problems.

Most previous studies found that adoption of GE crops is associated to lower pesticide use and/or lower pesticide toxicity. However, while in most cases pesticide use rates (in terms of active ingredient) are lower for adopters of GE crops than for non adopters, there are some studies that suggest that herbicide use on HT soybeans may be slightly higher than herbicide use

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[1] The term pesticide use in this paper includes herbicides and insecticides.

on conventionally grown soybeans in the U.S. (Fernandez-Cornejo and Caswell, 2004). (Fernandez-Cornejo and McBride, 2002).[2]

More recently, concerns about weed resistance to glyphosate use have developed. For example, recent evidence confirms that weeds in Iowa (horseweed, waterhemp, and giant ragweed) are resistant to glyphosate (Hertzler, 2011). “As ISU Weed Science has suggested for years, it is not if herbicide resistant weeds will evolve in Iowa: it is when the resistant populations are recognized.” (Owen 2011). The leveling off of the drop of nonglyphosate herbicides (and increases in selected corn states) shown in Figure 1 suggests that corn farmers are accommodating the weed resistance to glyphosate by diversified weed management systems, including maintaining high doses of old line herbicides such as atrazine as well as doses of newer herbicides such as mesotrione. The available pesticide use data suggests that particularly high doses of nonglyphosate pesticide use relative to glyphosate (hence overcoming gylphosate resistence) are developing on HT corn in areas that have relatively high rainfall and temperature regimes compared to the average in the corn states analyzed.

The evidence on the effect of tillage on herbicide use is mixed and depends on the type of conservation tillage used, the location, weather, soil type, endemic weed problems, and the metric used to measure pesticide use. In addition, as a USDA (1998) report citing Fawcett (1987) indicates herbicide use may decrease with conservation tillge after a few years of adoption: “when a farmer uses conservation tillage, dormant weed seeds in the soil will no longer be transferred to the germination zone near the soil surface by tillage. Consequently, as annual weeds are controlled, the overall weed problem may decrease after a few years when fields are converted to conservation tillage and if effective weed control is practiced.”

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[2] Still, glyphosate (the herbicide usedon most HT crops))-s is less than one-third as toxic to humans, and not as likely to persist in the environment as the herbicides it replaces (Fernandez-Cornejo and McBride, 2002).

Data and Research Methodology

Herbicide use in major crops such as corn (on a per acre basis) is hypothesized to be related to crop and herbicide prices, the extent of adoption of continuous corn and conservation tillage and the adoption of genetically engineered crops, in addition to factors related to location and weather. We have constructed a panel data set for the 1988-2008 period for the major corn-soybeans producing states. Conservation tillage data are obtained from the Conservation Technology Information Center's (CTIC) supplemented by USDA's ARMS data; adoption of HT crops data are obtained from USDA (Fernandez-Cornejo, 2009), crop price data are from USDA's Agricultural Prices and pesticide data are quality adjusted based on chemical usage data from USDA/NASS pesticide use surveys and from Doane Countrywide Farm Panel Survey. The procedure to quality-adjust the pesticide series is shown in Fernandez-Cornejo et al. (2009) and Vialou et al. (2008) and is summarized below.

A list of herbicides used in corn production are shown in Table 1. In recent years the pesticide data set used indicates that in terms of pounds applied, glyphosate, atrazine, acetachlor, and metolachlor are the most important, followed by gufosinate and mesotrione. And the use of non-glyphosate quantities per harvested acre of corn differs dramatically by region and state, suggesting highly regionalized weed management systems to account for weed resistance to glyphosate.

Table 2 presents the summary data at the regional level for the corn producing states used in this analysis (with the exception of Texas, omitted from preliminary econometric estimates in this study, but included in Table 2). The regions considered were the eastern Corn Belt (Illinois, Indiana, Ohio), the western Corn Belt (Missouri, Iowa, Minnesota), the Lakes (Michigan, Wisconsin), the Plains (North Dakota, South Dakota, Nebraska, and Kansas) and the South

(Kansas and Texas). The data is presented as an average for three distinct periods: the beginning (from 1986 to 1988)-:, the first years following the introduction of the HT varieties (from 1996 to 1998); and the end of the period (from 2004 to 2008).

Corn acreage increased in all regions of the sample except in the last period for the Lakes region (table 1). In 2000-2008, acres planted to corn averaged 72.6 million, a 26% increase over the 1986-1988 average. Expected corn price decreased from almost $2.70 per bushel national average in 1986-1988 and 1996-1998, when the HT varieties were first adopted, but rebounded to $3.90 per bushel in 2004-2008. Most regions have experienced an increase in the quality-adjusted pounds of herbicide applied followed by a decrease except in the eastern Corn Belt where it kept increasing in the last years (from 3.45 to 4.41 pounds per acre) and in the South where quality-adjusted pounds of herbicides started to decrease even before the introduction of GE varieties (from 3.81 to 3.09 pounds per acre). At the same time, adoption of the HT varieties has increased in all regions. The South (with a 47% average in the last period) and the Plains (with 52%) regions have the highest adoption rates-- much above the average from our sample (40%). The eastern Corn Belt region has the lowest adoption rate with 30%, while the western Corn Belt level is close to the average (38%). The deflated price of glyphosate has been decreasing significantly even before its patent expiration in September 2000 from $28.25 per pound at the beginning of the period to $17.25 per pound at the middle of the period to $8.32 per pound on average after 2004. Other herbicides' prices almost doubled from $6.41 to $11.03 per pound over the entire period.

Conservation tillage in corn fields has been a practice representing approximately a third of all acreages. Its use peaked at the end of the nineties, reaching 38% for the entire sample. The region with the highest share of conservation tillage was the Plains with 44% in the last period. The share of total acreages under continuous corn cultivation remained constant around 40%

everywhere except in the South where it increased from 21% to 36% and the western Corn Belt from 39% to 42%, but it decreased slightly in the Plains, from 38% to 34%.

Measuring Pesticide Use

In the past, agricultural chemical use has been measured and reported in pounds. This approach is straightforward, but limits the analysis of trends over time and across chemicals. One pound of a pesticide counts the same as one pound of another pesticide that is twice as effective. To account for these differences in characteristics and provide a standard measure of pesticide usage, the prices and quantities of pesticides are adjusted for quality using hedonic estimation as in Fernandez-Cornejo and Jans (1995). This approach allows comparisons of chemical usage over time, as measures take into account the dynamic efficacy and safety characteristics of the product mix.

More precisely, hedonic methods take into account the concept that inherent differences in pesticide characteristics or quality prevent the direct comparison of observed prices of pesticides over time and across regions. A hedonic price function expresses the price of a good or service as a function of the quantities of the characteristics it embodies. Thus, a pesticide hedonic function may be expressed as $w = W(X, D)$, where w represents the price of pesticide, X is a vector of characteristics or quality variables and D is a vector of other variables. If the main objective of the study is to obtain price indexes adjusted for quality, the only variables that should be included in D are dummy variables, which will capture all price effects other than quality. After allowing for differences in the levels of the characteristics, the part of the price difference not accounted for by the included characteristics will be reflected in the year (or state) dummy coefficients. Inherent differences in pesticide characteristics or quality prevent the direct comparison of observed prices of pesticides over time and across regions. Hence, a hedonic price function expresses the price of a good or service as a function of the quantities of the characteristics it embodies--pesticide potency, hazardous characteristics, and persistence. Quality-adjusted price indices are calculated for pesticides using these hedonic functions. In this study, we use the results of Fernandez-Cornejo et al. (2009) and Vialou et al. (2008) who obtained quality-adjusted price and quantities of herbicide used in corn and soybeans. They adopted a generalized linear form, where the dependent variable and each of the continuous independent variables is represented by the Box-Cox transformation. This is a mathematical expression that assumes a different functional form depending on the transformation parameter, and which can assume both linear and logarithmic forms, as well as intermediate non-linear functional forms. The analysis employed a new pesticide database that was compiled from USDA pesticide use surveys and the Doane's Countrywide Farm Panel Survey. A detailed, state panel dataset was developed for 1986 to 2007, and has been, subsequently updated through 2008. Additionally, a set of physical characteristics was collected for each active ingredient for close to 300 pesticides.

Avoiding Spurious Regression Results

In order to minimize the potential for spurious results in regressions using time series the disturbances must be stationary (stationarity is necessary to satisfy the assumption of classical econometrics).

Thus, we first examine whether the behavior of the economic variables is consistent with a unit root or not. That is, whether the series is non-stationary or stationary. Typically, this analysis has been carried out using tests such as the augmented Dickey and Fuller's test or semiparametric tests, such as the Phillips and Perron's test. The main problem is that, in a finite sample, any unit root process can be approximated by a trend-stationary process. The result is that unit root tests have limited power against the stationary alternative.

Recently, researchers have been exploiting the extra information provided by the pooling of time-series and cross-sectional data and the subsequent power advantages of panel data unit root tests. Starting from the seminal works of Levin and Lin (1993, 2002, 2003) and Im, Pesaran and Shin (1997), many tests have been proposed for unit roots in panel data. Levin and Lin (2002, 2003) show that by combining the time series information with that from the cross-section, the inference about the existence of unit roots can be made more straightforward and precise, especially when the time series dimension of the data is not very long and similar data may be obtained from a cross-section of units such as countries or industries.

Many tests have been developed to test for unit roots or stationarity in panel datasets (Levin–Lin–Chu, 2002; Harris–Tzavalis, 1999; Breitung, 2000; Breitung and Das, 2005; Im–Pesaran–Shin, 2003; Choi 2001). These tests have as the null hypothesis that the panels contain a unit root. But some of them (Levin–Lin–Chu, 2002; Harris–Tzavalis, 1999) are more useful because their alternative hypothesis is that the panels are stationary, while for others (e.g., Im–Pesaran–Shin) the alternative hypothesis is that "some panels are stationary."

Because the Levin–Lin–Chu test requires that the ratio of the number of panels to time periods tend to zero asymptotically, it is not well suited to datasets with relatively few time periods. In this paper we use the Levin–Lin–Chu test to examine whether the variables contain a unit root (Levin–Lin–Chu, 2002; STATA, 2010).

After having examined the stationarity of the variables, we estimate the relationship between adoption of biotech crops and pesticide use for soybeans in the United States. We specify two regressions. The first regression considers the quantity of quality-adjusted herbicides applied to produce corn (CORNHERB_2008) as a function of adoption of herbicide tolerant corn and soybeans (SHARE-GE_CORN, SHARE-GE_SOY), the corn/soybean price ratio (CORN_SOYPRICE) and the quality adjusted price of glyphosate and non-glyphosate herbicides (REL_GLY_PRICE, REL_NONGLY_PRICE), the fraction of continuous corn (CCORN), and the fraction of conservation tillage (CTILLCORN) . The second regression used the same specification except that we included the states with high application rates (per acre) of nonglyphosate herbicides relative to glyphosate (based on regional data underlying trends shown in Figure 1) as the base—where glyphosate resistant weeds are likely strongest as indicated by relatively high use of non-gylphosate herbicides (we denote this as the “High” group of states). We used interaction dummies for the states with low application rates (per acre) of non-glyphosate herbicides relative to glyphosate (based on regional data underlying trends shown in Figure 1) (the “Low” group of states) and medium application rates of non-glyphosate relative to glyphosate (based on regional data underlying trends shown in Figure 1). In each regression we estimate a fixed effects model. Figures 2 and 3 relative shares of HT corn and continuous corn for the whole sample and for selected states. Wisconsin is the base for the cross-section fixed effects and 2008 is the base for the time fixed effects.

The fixed effects model is usually used to control for omitted variables that are constant over time. Using Baltagi’s notation (Baltagi, 2001), the fixed effect model is:

$$Yit = \alpha + X'it\,\beta + uit, \quad i = 1\ldots N;\ t=1\ldots.T \qquad (1)$$

$$uit = \mu i + \lambda t + \nu it \qquad (2)$$

where ***i*** represent States and ***t*** denotes time; α is an scalar, β is Kx1 and Xit is the ith observation on the K explanatory variables. μi is the unobservable individual specific effect; it is time invariant and accounts for any individual effects not included in the regression (Baltgi, 2001). λt is the unobservable time effect; it is individual-invariant and accounts for any time-specific effect not included in the regression; νit is the remainder disturbance In the two-way fixed effects model the μi and the λt are assumed to be fixed parameters to be estimated. The Xit is assumed to be independent of vit for all i and t (Baltgi, 2001).

To estimate the models we use the PANEL procedure from SAS. Fixed effects models, as noted in SAS (2002) "are essentially regression models with dummy variables that correspond to the specified effects. For fixed-effects models, ordinary least squares (OLS) estimation is the best linear unbiased estimator."

Preliminary Results

The stationarity (unit root) test results using the Levin–Lin-Chu (2002) are shown in table 1. As seen there, all variables are stationary since the null hypothesis that the panel contains unit roots is rejected at the 1 percent level in favor of the alternative hypothesis that the panel is stationary for all the variables, except HT corn adoption, where we used first differences and conservation tillage corn, which is close to stationary in the test used and generally nonstationary (5 of 7 tests) in most tests employed preliminarily.

Table 4 show the regression results for the fixed effects model of the quality-adjusted quantity of herbicide use equation for the US, while Table 5 shows the fixed effects model with the regional interaction terms. We find no significant impact of HT corn adoption on herbicide use in the US. model. This result partially contradicts Vialou (2008) who found a significant and negative association between HT corn adoption and herbicide use. We ascribe this difference to two reasons: 1) we have added two years of data to the data set—years in which glyphosate weed resistance may have been intensifying, and 2) this study includes a panel estimation and checks for stationarity, avoiding spurious regression results.

However, we find a significant association of HT corn adoption on herbicide use in the Indiana, Missouri, and Ohio region, which corresponds to the group of states that are high users of non-glyphosate relative to glyphosate herbicides as identified in Figure 2. We also find that both, the states that are low users of nonglyphosate relative to glyphosate herbicides, (Figure 3) and the medium users (Figure 4) regions are significantly different from the base region. Moreover, the Wald tests for Low and Medium in Table 6 show that only in the states that are high users of non-glyphosate relative to glyphosate herbicides is adoption of HT corn associated to increased herbicide use, providing some evidence of major regional differences in the impact of HT corn adoption on herbicide use, as corn grower experience with weed resistant glyphosate plays out by region. Herbicide data, just becoming available for 2009 to 2010, will provide further evidence on regional differences occurring as HT corn adoption has continued to increase in all 12 states analyzed.

Concluding Comments

This paper presents findings on the use of HT corn and quality-adjusted herbicide use for 12 key corn producing states using a panel data set for 1986-2008. Our preliminary findings indicate an insignificant impact of HT corn on herbicide use, conditioning or accounting for HT corn with other important drivers of corn herbicide use: HT soy, corn output price, glyphoste price, nonherbicide glyponsate price, and percentage of continuous corn and low-till corn. However, we find a positive and significant impact of HT corn on herbicide use in selected states, using regional interaction terms. We use econometric techniques to avoid spurious regression results. Other preliminary runs indicated that the results hold when running the US and regional interactions on 1986-2006 and 1986-2007 data.

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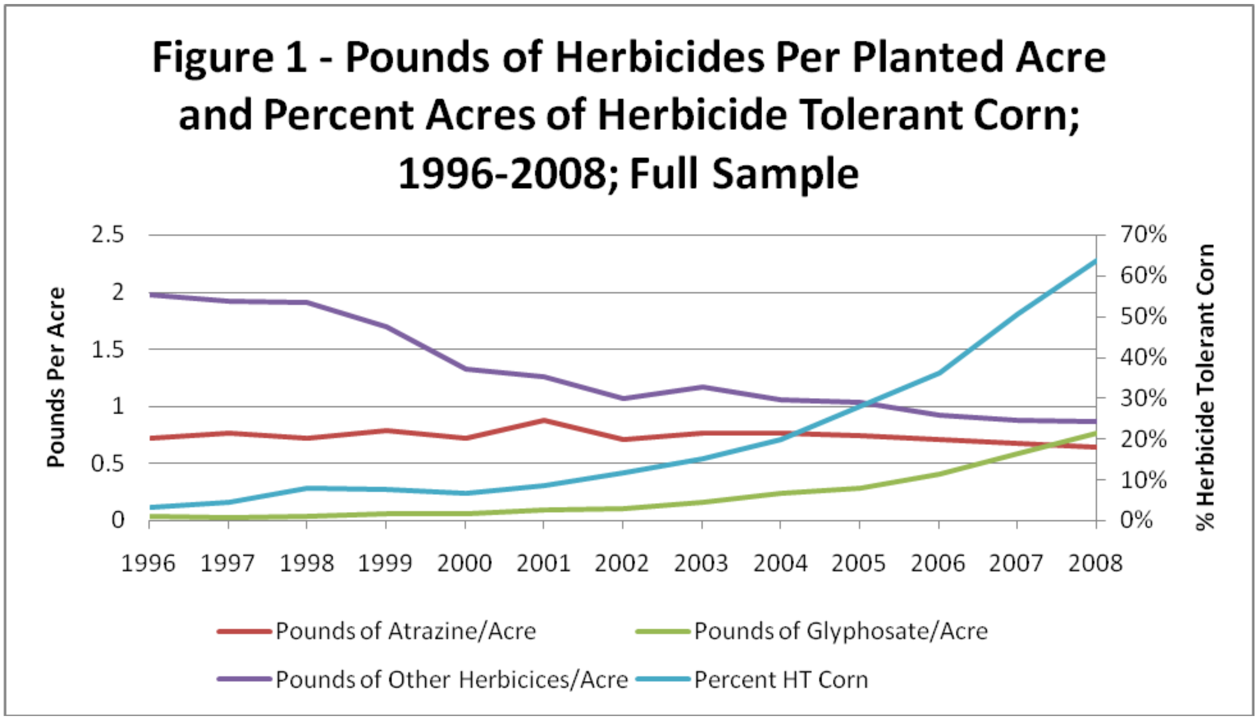
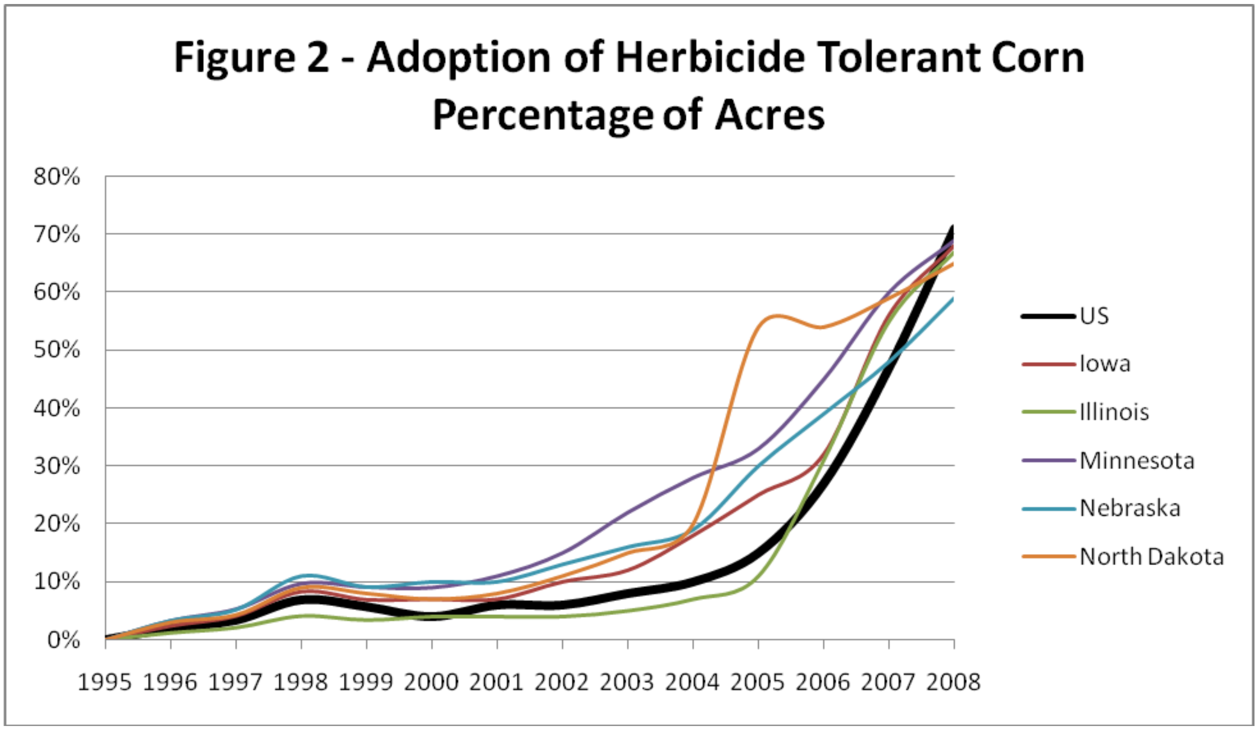
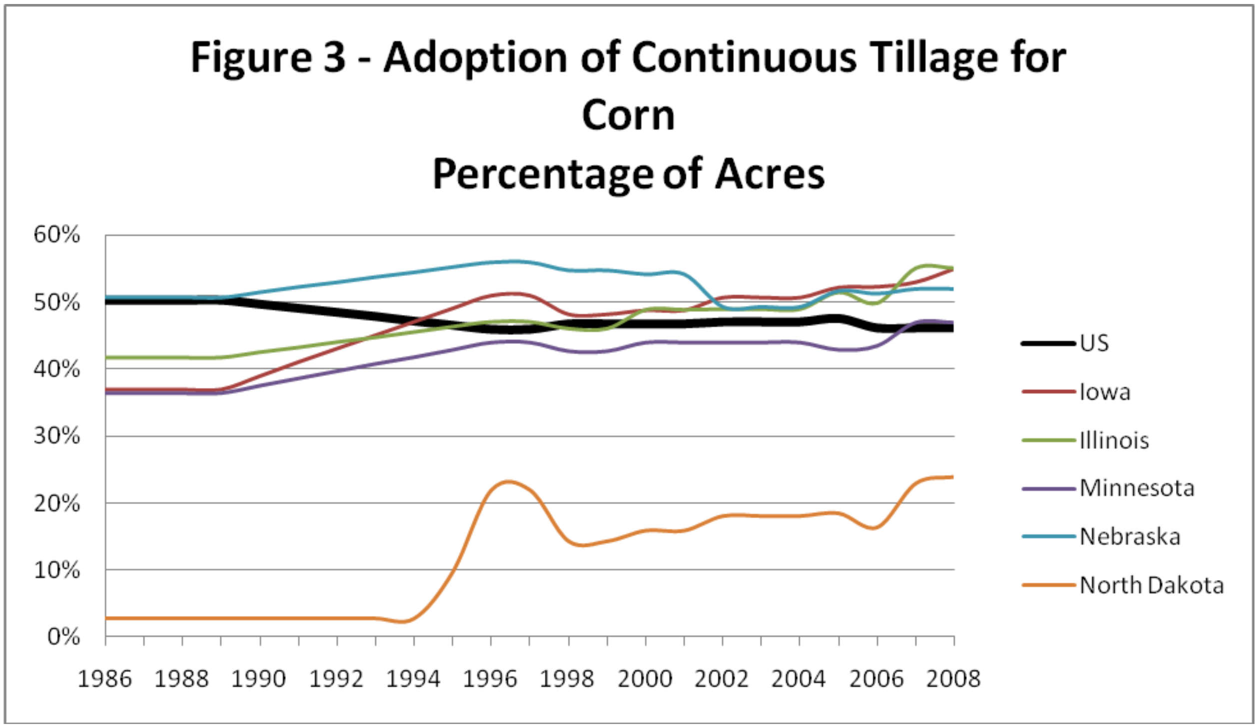


Figure 1 - Pounds of Herbicides Per Planted Acre and Percent Acres of Herbicide Tolerant Corn; 1996-2008; Full Sample

Sources: NASS/ERS and Doane Surveys



Source: NASS/ERS



Source: NASS/ERS

Table 1. The Most Important Active Ingredients Included

Common Name	Proprietary Name	Type	Chemical Class	Firm Registrant	Origin	Share[1]
Glyphosate	Roundup	H	Phosphorus	Monsanto	1972	10.5%
Metolachlor	Dual	H	Amide	Ciba-Geigy	1974	8.4%
Acetochlor	Guardian	H	Chloroacetamide	Monsanto	1995	7.3%
Atrazine	Aatrex	H	Triazine	Ciba-Geigy	1959	6.6%
Imazethapyr	Pursuit	H	Imidazolione	American Cyanamid	1996	5.6%
Alachlor	Axiom	H	Amide	Monsanto	1967	5.4%
Cyanazine	Bladex	H	Triazine	DuPont	1968	3.6%
S-metolachlor	Prefix	H	Chloroacetanilide	Syngenta	1997	3.3%
Nicosulfuron	Accent	H	Sylfonylurea	DuPont	1990	2.7%
Dicamba	Banvel	H	Organochlorine	Sandoz (Velsicol)	1965	2.7%
Pendimethalin	Prowl	H	Nitroaniline	American Cyanamid	1972	2.6%
Trifluralin	Treflan	H	Dinitroaniline	Elanco	1959	2.6%
Terbufos	Counter	I	Organophosphate	American Cyanamid	1973	2.3%
Chlorpyrifos	Dursban	I	Organophosphate Heterocyclic	Dow	1966	2.0%
Metribuzin	Sencor	H	Triazine	Mobay (Bayer)	1969	1.9%
Bentazone	Basagran	H	Heterocyclic	BASF	1970	1.8%
Dimethenamid	Frontier	H	Amide	BASF	1991	1.6%
Tefluthrin	Force	I	Pyrethroid	Zeneca	1989	1.5%
EPTC	Eptam	H	Carbamate	Stauffer	1959	1.4%
Mesotrione	Callisto	H	Triketone	Syngenta	2001	1.2%
Imazaquin	Scepter	H	Imidazole	American Cyanamid	1984	1.1%

Source: Farm Chemical Handbook, EXTONET

[1] Share in total pesticide expenditures from 1986 to 2006

Table 2: Summary statistics for Herbicide Use in Corn

	1986-1988					
	East CB	West CB	Plains	South	Lakes	All Sample
Acres Planted[/1]	18,800	19,467	10,883	2,750	6,033	57,933
Herbicides (lbs/acres)[/2]	1.92	1.69	1.62	2.01	1.87	1.80
Expected Corn Price[/3]	$2.76	$2.60	$2.65	$2.95	$2.69	$2.69
Glyphosate Price[/3]	$24.82	$24.46	$28.45	$24.19	$30.45	$25.94
Other herbicides Price[/3]	$5.69	$6.08	$5.97	$5.75	$5.37	$5.85
Conservation Tillage[/4]	38%	28%	33%	32%	29%	32%
Continuous corn[/4]	41%	39%	38%	21%	38%	38%
	1996-1998					
	East CB	West CB	Plains	South	Lakes	All Sample
Acres Planted[/1]	20,150	22,400	13,467	4.917	6,283	67,217
Herbicides (lbs/acres)[/2]	2.20	2.31	2.02	1.68	2.11	2.30
HT Share[/4]	6%	6%	6%	6%	3%	5%
Expected Corn Price[/3]	$2.78	$2.64	$2.53	$2.84	$2.63	$2.67
Glyphosate Price[/3]	$15.27	$14.86	$14.11	$16.47	$15.30	$14.99
Other herbicides Price[/3]	$8.08	$9.59	$9.82	$8.88	$9.31	$9.11
Conservation Tillage[/4]	29%	36%	48%	46%	47%	38%
Continuous corn[/4]	43%	40%	35%	29%	37%	39%
	2004-2008					
	East CB	West CB	Plains	South	Lakes	All Sample
Acres Planted[/1]	21,390	23,760	15,752	5580	6,120	72,602
Herbicides (lbs/acres)[/2]	2.34	1.97	1.62	1.72	1.93	2.06
HT Share[/4]	30%	38%	52%	47%	34%	40%
Expected Corn Price[/3]	$3.11	$3.00	$2.89	$3.41	$3.00	$3.04
Glyphosate Price[/3]	$9.02	$8.97	$7.38	$7.28	$8.51	$8.33
Other herbicides Price[/3]	$8.44	$11.01	$12.24	$7.72	$10.62	$10.13
Conservation Tillage[/4]	34%	35%	41%	45%	30%	36%
Continuous corn[/4]	44%	42%	34%	36%	36%	40%

[/1] in 1,000 acres (total by region)

[/2] in pounds of constant quality per acres

[/3] in 2006 constant dollars deflated with a Crop Price Received Index for the output and by the Agricultural Chemical Prices Paid index for the pesticides

[/4] in percentage of the total acreage planted

East CB includes: Illinois, Indiana and Ohio; Lakes includes Michigan and Wisconsin; Plains includes North Dakota, South Dakota and Nebraska; South includes Texas and Kansas; and, West CB includes: Iowa, Missouri and Minnesota

Table 3. Variables: Definitions, Means, and Stationary Test Results

Variable	Label	Mean	Stationarity? p-value 1/
GCORNHERB_2008	Quality-adjusted quantity for corn	-4.2469	yes 0.0000
SHARE_GE_CORN	Fraction of acres in HT corn	2.1765	no 0.9852
SHARE_GE_SOY	Fraction of acres in HT soybeans	-5.6067	yes 0.0000
CORN_SOY_PRICE	Relative corn price	-6.1981	yes 0.0000
CTILLSOY	Fraction of corn acres using conservation tillage	-0.8077	No 0.2096
CCORN	Fraction of corn acres in continuous corn	-3.9852	Yes 0.0000
REAL GLY PRICE	Relative glyphosate price	-65.7115	yes 0.0000
REAL NONGLY PRICE	Relative non-glyphosate price	-3.8736	yes 0.0001

1/ Using the Levin-Lu-Chu unit root test for panel data (Levin,Lu, and Chu (2002). H0 is that panels contain unit roots and Ha is that panels are stationarity (results obtained using STATA.)

Table 4--Regression Results: Effect of Herbicide Tolerant Corn on Herbicide use: Regional Interaction Model:US Model of 12 states.

Parameter Estimates

Variable	DF	Estimate	Standard Error	t Value	Pr > |t|
CS1	1	14.981	0.4804	31.18	<.0001
CS2	1	4.772595	0.4832	9.88	<.0001
CS3	1	18.62684	0.4591	40.57	<.0001
CS4	1	-5.43221	0.4767	-11.40	<.0001
CS5	1	-2.3923	0.4426	-5.40	<.0001
CS6	1	5.021084	0.4361	11.51	<.0001
CS7	1	-2.88333	0.4429	-6.51	<.0001
CS8	1	4.819801	0.5248	9.18	<.0001
CS9	1	-5.88107	0.5955	-9.88	<.0001
CS10	1	0.198368	0.4534	0.44	0.6622
CS11	1	-1.74772	0.4521	-3.87	0.0001
TS1	1	-3.7568	2.1760	-1.73	0.0856
TS2	1	-4.3078	2.2961	-1.88	0.0619
TS3	1	-3.19474	2.0353	-1.57	0.1179
TS4	1	-2.86429	1.6110	-1.78	0.0768
TS5	1	-2.61948	1.4976	-1.75	0.0816
TS6	1	-1.22733	1.4361	-0.85	0.3937
TS7	1	-0.51018	1.4707	-0.35	0.7290
TS8	1	-0.54277	1.4500	-0.37	0.7085
TS9	1	-0.18827	1.4772	-0.13	0.8987
TS10	1	0.284874	1.3973	0.20	0.8386
TS11	1	-0.21517	1.3037	-0.17	0.8691
TS12	1	-0.6537	1.1085	-0.59	0.5560
TS13	1	1.174328	0.9066	1.30	0.1965
TS14	1	0.087321	0.8347	0.10	0.9168
TS15	1	0.167523	0.8066	0.21	0.8357
TS16	1	-0.91241	0.7766	-1.17	0.2413
TS17	1	-0.18825	0.8154	-0.23	0.8176
TS18	1	0.156259	0.7212	0.22	0.8287
TS19	1	-0.08509	0.7439	-0.11	0.9090
TS20	1	-0.83317	0.7418	-1.12	0.2626
TS21	1	-0.36471	0.5803	-0.63	0.5303
Intercept	1	6.134878	2.6274	2.33	0.0204
D_SHARE_GE_CORN	1	1.921971	2.5543	0.75	0.4526
SHARE_GE_SOY	1	-0.59894	1.3472	-0.44	0.6570
CORN_SOY_PRICE_RATIO	1	5.116065	4.6599	1.10	0.2734
REAL_GLYPHOSATE_PRICE	1	9.368926	9.3939	1.00	0.3197
REAL_NONGLYPHOSATE_PRICE	1	-11.632	5.8682	-1.98	0.0487
CCORN	1	1.892542	1.5956	1.19	0.2368
D_CTILLCORN	1	3.727357	2.1562	1.73	0.0852

Table 5--Regression Results: Effect of Herbicide Tolerant Corn on Herbicide use: Regional Interaction Model with Indiana, Missouri, and Ohio as the Base.

Parameter Estimates

Variable	DF	Estimate	Standard Error	t Value	Pr > |t|
CS1	1	20.02165	2.3711	8.44	<.0001
CS2	1	3.445018	1.8543	1.86	0.0646
CS3	1	18.42344	0.5327	34.59	<.0001
CS4	1	-2.56357	1.5751	-1.63	0.1051
CS5	1	1.45869	1.8971	0.77	0.4428
CS6	1	4.896109	0.4520	10.83	<.0001
CS7	1	-3.56408	1.5874	-2.25	0.0258
CS8	1	10.43055	2.5945	4.02	<.0001
CS9	1	-5.21928	0.9280	-5.62	<.0001
CS10	1	-0.78699	1.7221	-0.46	0.6481
CS11	1	-1.41009	0.4864	-2.90	0.0041
TS1	1	-4.39275	2.2201	-1.98	0.0491
TS2	1	-4.8622	2.2813	-2.13	0.0342
TS3	1	-3.91187	2.0938	-1.87	0.0631
TS4	1	-3.34694	1.6915	-1.98	0.0491
TS5	1	-3.14836	1.5707	-2.00	0.0463
TS6	1	-1.62378	1.4914	-1.09	0.2775
TS7	1	-0.95605	1.5201	-0.63	0.5301
TS8	1	-1.01462	1.5107	-0.67	0.5025
TS9	1	-0.73768	1.5467	-0.48	0.6339
TS10	1	-0.0612	1.4439	-0.04	0.9662
TS11	1	-0.54607	1.3399	-0.41	0.6840
TS12	1	-1.12964	1.1215	-1.01	0.3149
TS13	1	0.666277	0.9229	0.72	0.4711
TS14	1	-0.35245	0.8538	-0.41	0.6802
TS15	1	-0.34502	0.8293	-0.42	0.6778
TS16	1	-1.38858	0.7971	-1.74	0.0829
TS17	1	-0.51872	0.8199	-0.63	0.5276
TS18	1	-0.1763	0.7225	-0.24	0.8074
TS19	1	-0.3428	0.7510	-0.46	0.6485
TS20	1	-1.29346	0.7619	-1.70	0.0910
TS21	1	-0.44256	0.5778	-0.77	0.4445
Intercept	1	4.385892	2.8616	1.53	0.1268
D_SHARE_GE_CORN	1	11.87116	6.6643	1.71	0.0763
SHARE_GE_SOY	1	-0.43316	1.4774	-0.27	0.7697
REAL_CORN_PRICE	1	6.49626	4.5835	0.72	0.1578
REAL_GLYPHOSATE_PRICE	1	11.44869	9.2873	1.22	0.2190
REAL_NONGLYPHOSATE_PRICE	1	-3.40137	8.4259	-0.43	0.6868
CCORN	1	6.081439	2.8794	2.03	0.0358
D_CTILLCORN	1	4.347214	2.5466	1.68	0.0892
LOW_D_SHARE_GE_CORN	1	-12.1248	7.2172	-1.64	0.0944
LOW_SHARE_GE_SOY	1	-1.04679	0.5813	-1.79	0.0731
LOW_CCORN	1	-1.3808	4.1857	-0.24	0.7418
LOW_D_CTILLCORN	1	0.128272	2.5207	0.12	0.9595
MEDIUM_D_SHARE_GE_CORN	1	-8.14569	6.6277	-1.22	0.2204
MEDIUM_SHARE_GE_SOY	1	0.496779	0.6601	0.81	0.4525
MEDIUM_CCORN	1	-13.7403	5.6880	-2.30	0.0165
MEDIUM_D_CTILLCORN	1	-2.42643	2.3390	-1.00	0.3007

Table 6 Wald Tests

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                                      The PANEL Procedure
                                    Fixed Two Way Estimates

Dependent Variable: QCORNHERBO_2008

                                         Test Results

         Test            Type            Statistic    Pr > ChiSq    Label

         TEST_LOW        Wald                 0.00        0.9462     D_share_ge_corn
                                                                    +
                                                                    Low_D_share_ge_corn
                                                                    =  0
         TEST_MED        Wald                 0.87        0.3502     D_share_ge_corn
                                                                    +
                                                                    Medium_D_share_
                                                                    ge_corn  =  0
```

These test statistics indicate that while the difference between the base results and the low share of HT corn were statistically significantly different and negatively so, the difference was not of such magnitude to indicate a negative impact of HT share of corn in low states on herbicide use, conditioned for other drivers and fixed effects in the model. The same line of reasoning can be used for the difference between the base results and the medium share of HT corn, except that the difference itself between the base result and the medium Ht corn share result is not significant.