Herbicide Resistant Weeds:

Owner/Renter Behavior and Hazard Model Analysis

by

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STATEMENT BY AUTHOR

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APPROVAL BY THESIS DIRECTOR

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ABSTRACT

Much of the literature on herbicide resistant weeds suggests that farmers do not adopt resistance management practices on rented land to the same extent as on owned land. This study uses data from the USDA Agricultural Resource Management Survey for corn and soybeans to compare adoption of resistance management practices on owned and rented land analyzing national and regional data for a variety of weed management practices. There was little support for the hypothesis that renters adopted resistance management practices less than owners. In most cases, there was no significant difference in adoption rates. In cases where there were statistically significant differences, it was more common that resistance management practice adoption was higher on rented land than on owned land. The second part of this study estimated a hazard model to predict when resistance to glyphosate would first be detected in corn fields in a state. The model was used to test hypotheses about whether adoption of different weed management practices delayed or sped up the onset of resistance. The analysis found evidence that greater use of phosphinic acid herbicides (the herbicide family that includes glyphosate) sped up the onset of glyphosate resistant weeds.

CHAPTER ONE

INTRODUCTION

The introduction of herbicide resistant seeds provided several benefits for the farming industry. The most common of these herbicide resistant seeds is glyphosate resistant seed (Powles 2010). These glyphosate resistant seeds have been adopted in crops like corn, cotton, and soybeans.

Glyphosate resistant seeds provide two main benefits for the farming community. The first of these is the primary goal of herbicide resistant seed and is related to weed control. Weeds are the biggest pest threat to food security and are the cause of more economic and productive loss than all other pests combined (Culpepper 2012). Glyphosate resistant seeds help to minimize this threat by making weeds much more manageable. Because of glyphosate resistant seeds, farmers no longer need to worry that herbicides will kill their crops as well as the weeds. The second main benefit of glyphosate resistant weeds comes in the form of the ease of adoption of conservation tillage. Conservation tillage reduces the amount that soil is moved to the minimum that is necessary for farming. This greatly reduces the possible soil erosion that would normally results from tilling as well as increasing soil quality and water quality (Price 2011). Because of these two benefits, glyphosate resistant weeds have been seen as both more efficient for farmers saving them time on weed control and more environmentally friendly by reducing soil erosion damage.

The evolution of glyphosate resistant weeds, however, threaten these benefits. As glyphosate resistant weeds emerge, the benefits of weed control that the glyphosate resistant seeds provide are reduced. As weed control through herbicide becomes more difficult, that in turn makes it more difficult for farmers to adopt conservation tillage.

Because of the threat that glyphosate resistant weeds present to the benefits of glyphosate resistant seeds there have been many practices proposed to manage the weed resistance. When the potential challenges to herbicide resistant weed management are discussed, one consistent challenge that is brought up is that farmers who rent their land have a less secure future of the farm and are less likely to adopt resistance management practices that provide future (as opposed to current) benefits. However, none of the studies in which the owner/renter issue is presented as a challenge investigate whether or not the data supports these claims. The first part of this study will investigate this owner/renter question using the data on resistance management adoption rates. Before the data is investigated, a theoretical model is developed which shows conditions where optimal adoption rates for owners are indeed higher than for renters. The results of the analysis using the data are somewhat mixed, but there is no clear indication that renters are behaving differently when it comes to resistance management. Because of these results, a second theoretical model is proposed with differing assumptions which shows possible cases where owners and renters would behave the same when adopting resistance management practices.

The second part of this study looks to investigate what resistance management practices may slow down the emergence of resistant weeds or what other farming practices may significantly affect the speed at which herbicide resistance emerges. The benefit of this analysis would be to ascertain how effective, if at all, the best management practices are at preventing herbicide resistant weeds. The study uses state-level management data to estimate a hazard model to predict the probability of resistance over time. The results of this analysis provide evidence that increased use of glyphosate increases the speed at which a state gets glyphosate resistant weeds, but other management practices had no consistent significant impact on the speed of resistance.

The structure of this study is as follows. Chapter 2 discusses the literature and motivation for the owner/renter analysis. Chapter 3 discusses the theoretical model for management adoption for owners and renters. Chapter 4 discusses the owner/renter data. Chapter 5 describes the method used to compare owner and renter behavior. Chapter 6 reports the owner/renter results. Chapter 7 introduces the hazard model. Chapter 8 discusses the data used for the hazard model. Chapter 9 introduces the econometric specification of the hazard model. Chapter 10 reports the results for the hazard model. Chapter 11 concludes.

CHAPTER TWO

LITERATURE/MOTIVATION

A significant problem faced by farmers currently is the case of herbicide resistant weeds. Weeds for farmers can reduce yields and increase costs. According to a study of Australian farmers, in the 1998-1999 growing season weeds were responsible for a loss of AU$1,278.9 million in economic surplus. This loss represented 17% of the total economic surplus of Australia's grain and oilseed production (Jones et al., 2005). This loss in economic surplus is even higher in Australian wheat where it is 22% of total surplus (Jones et al., 2005).

Herbicide resistant weeds are species of weeds that will survive even when herbicide is used on them. For example, if one were to say that there was a glyphosate resistant weed, then that would refer to a weed that the herbicide glyphosate would not be able to kill. It is possible that an herbicide resistant weed could be killed by a different herbicide to which the weed is not resistant.

The rise of herbicide resistant weeds can be attributed to changes in weed management practices that accompanied the introduction and use of genetically modified crop seeds making those crops resistant to herbicide. Herbicide resistant crops are grown from genetically modified seeds. These seeds are genetically modified so that the crop will survive when a particular herbicide is applied. This type of crop allows farmers to safely kill weeds with herbicide without the worry that the crop will be harmed.

When farmers have a crop that is resistant to a particular herbicide, the incentive for a farmer to use that herbicide on their fields increases. Then the situation arises where many farmers are using the same herbicide so as to take advantage of the benefits. However, the diversity in the types of herbicide used is decreased and leads to the rise of herbicide resistant weeds (Norsworthy, 2012). As mentioned in the introduction, one of the main benefits of herbicide resistant crops is that they make it easier for farmers to adopt conservation tillage. However, herbicide resistant weeds threaten conservation tillage: “The practice of conservation tillage is now threatened by the emergence and rapid spread of glyphosate-resistant Palmer amaranth (p. 265)” (Price et al., 2011). This is because of the fact that tilling can help deal with herbicide resistant weeds: “In some instances, tillage is one of the few effective options to manage particular HR weeds. For example, Palmer amaranth (Amaranthus palmeri) has become the dominant weed problem in southeastern U.S. cotton production because of evolved resistance to glyphosate. (p. 2)” (Culpepper 2012). Thus, along with the economic loss, herbicide resistant weeds could result in more tillage which in turn would result in more soil erosion and reduced soil and water quality.

To avoid herbicide resistant weeds, it is recommended that farmers follow the management practices outlined in “Reducing the risks of herbicide resistance: best management practices and recommendations.” (Norsworthy 2012). Research has found that adoption rates for many of the most important of these practices is low (Frisvold et al., 2009). The first recommendation of a 2010 report of the National Research Council report on genetically modified crops was that, “Federal and state government agencies, private-sector technology developers, universities, farmer organizations, and other relevant stakeholders should collaborate to document emerging weed-resistance problems and to develop cost-effective resistance-management programs and practices that preserve effective weed control in HR crops (p. 14).” (Ervin et al., 2010). Two subsequent policy summits have been held in Washington, DC to among other things identify barriers to adoption of resistance management practices (NRC, 2014; WSSA, 2014).

One of the factors affecting adoption of resistance management practices that has been discussed is land tenure patterns. Thus, we have the following question about weed resistance management: Do farmers of rented land behave differently from land owners by being less likely to manage resistance? Some researchers have argued that farmers have less of an economic incentive to prevent herbicide resistant weeds on leased than owned land. For example, Binimelis et al. (2009) argue, “As a result, from an individual farmer’s point of view, investing in preventing the emergence of herbicide resistant populations in a field, might not capture the future benefits of having avoided the costs of managing the herbicide-resistant weed (Llewellyn and Allen, 2006), **especially in a situation of annual lease regimes** (p. 632)” [emphasis added]. Norsworthy et al (2012) state, “Preventative weed management can be complex and challenging. As a result, farmers are often unwilling to adopt costly preventative practices, **especially if the land is rented or leased** (p. 47)” [emphasis added]. Owen (2000) states, “More than 50% of the land under cultivation in Iowa is rented. Thus, esthetics becomes a significant consideration to the renter/farmer.” However, the hypothesis that farmers manage resistance differently on leased land than owned land has not, to date, been formally and directly tested. Frisvold et al. (2009) and Dong et al. (2015) found the percentage of operated land that was owned had no significant effects on adoption rates of a variety of practices. These two studies, however, did not examine differences in behavior directly on owned versus leased land. Farmers often manage a mix of the two. Thus, it is our goal to investigate the claim that owners behave differently than renters in weed resistance management.

One other study which looks at owner and renter behavior in their adoption of conservation tillage is Soule, Tegene, & Wiebe (2000). The authors establish the economic incentives that may cause renters to behave differently from owners. They state that the lack of security of the tenure for a renter gives them little incentive to have good long-term conservation practices. These conservation practices would help maintain the soil quality and help to control erosion. The results of this kind of study would have implications on the policies and conservation programs necessary to consider the different incentives of owners and renters. The authors also note the type of renter can be important for considering how they will behave. Their theoretical model assumes that farmers maximize profits for two time periods. They maximize profit for the current time period and the discounted profit for the future time period. However, renter farmers also must consider the probability that they will continue to farm the same land in the future time period. This probability factors into how much the renter farmer will discount profits in the future. The authors also examine how the profits of cash renters will differ from share renters. Because of different profit equations for owners and renters it may be possible that renters will behave differently when deciding whether to adopt the conservation practice or not. The authors find some mixed results when modeling the probability that a farmer will adopt a particular conservation practice. We will similarly look at owner and renter behavior when adopting weed resistance management practices.

The goal specifically for this study is to investigate owner and renter management practice adoption rates using the available data. This contributes to the literature as a whole by providing solid evidence about owner/renter adoption rates.

CHAPTER THREE

THEORETICAL MODEL

To illustrate why owners and renters might make different choices in regards to managing resistance we can look to the theoretical model of how they will maximize profits. Consider the producer's profit function as:

(1) $\pi = py(1 - \delta) - cX$

Where:

$\pi =$ Per-acre profits

$p =$ Crop price

$y =$ Crop yield per acre

$\delta =$ Proportion of yield lost to weed damage

$X =$ Herbicide resistance management activities

$c =$ A constant

We can then assume that weed damage is a function of a producer's resistance management activities and the amount of resistance that the producer already has. This produces the following equation:

(2) $\delta = \varepsilon - aln(X) + bR$

Where:

$R =$ Current level of herbicide resistance

$\varepsilon, a, b =$ Constants

Now we consider that the producer faces a two-period optimization problem where they maximize profit in the present and in the future. We make the assumption that price and yield are the same for both time periods. We can then express the total profit in the two time periods in the following equation:

$$(3)\quad \pi_0 + \pi_1 = py[1 - (\varepsilon - aln(X_0) + bR_0)] - cX_0 + \frac{\gamma}{1+r}(py[1 - (\varepsilon - aln(X_1) + bR_1)] - cX_1)$$

Where:

$r =$ The discount rate

$\gamma =$Probability that the farmer will operate the land and in the future

The 0 subscript denote choices and outcomes in period one (the present) and 1 subscript denotes second-period (future) choices and outcomes. In this case, we assume that $\gamma = 1$ for land a farmer owns, but it may be the case that, for renters $0 \leq \gamma \leq 1$. We also need to consider that the resistance in the future is a function of the resistance in the present and the weed resistance management practices in the present. This relationship can be shown in the following equation:

$$(4)\quad R_1 = \alpha - \beta ln(X_0) + R_0$$

Thus by substituting equation 4 into equation 3 we obtain the profit equation which an operator will be maximizing:

$$(5)\quad \pi_0 + \pi_1 = py[1 - (\varepsilon - aln(X_0) + bR_0)] - cX_0 + \frac{\gamma}{1+r}(py[1 - (\varepsilon - aln(X_1) + b(\alpha - \beta\ln(X_0) + R_0))] - cX_1)$$

Using this equation, it is our goal to find X_0^* and X_1^*. These are the choices of resistance management effort chosen to maximize $\pi_0 + \pi_1$. To do that, we take the first order partial derivatives with respect to X_0 and X_1, set them equal to zero and solve for X_0^* and X_1^*:

$$\frac{\partial(\pi_0+\pi_1)}{\partial X_0}=\frac{pya}{X_0}-c+\frac{\gamma}{1+r}\frac{pyb\beta}{X_0}=0$$

$$\frac{\partial(\pi_0+\pi_1)}{\partial X_1}=\frac{\gamma}{1+r}\frac{pya}{X_1}-\frac{\gamma}{1+r}c=0$$

Solving each of these, we find:

$$X_0^*=\frac{(1+r)pya+\gamma pyb\beta}{(1+r)c}$$

And:

$$X_1^*=\frac{pya}{c}$$

With second order conditions:

$$\frac{\partial^2(\pi_0+\pi_1)}{\partial X_0^2}= -\frac{pya}{X_0^2}-\frac{\gamma}{1+r}\frac{pyb\beta}{X_0^2}<0$$

$$\frac{\partial^2(\pi_0+\pi_1)}{\partial X_1^2}=\frac{-\gamma}{1+r}\frac{pya}{X_1^2}<0$$

$$\frac{\partial(\pi_0+\pi_1)}{\partial X_0\partial X_1}=0$$

We will now find the signs of some of the marginal effects to illustrate some expected results from this model. First, we find that X_0^* is larger if an increased resistance management will reduce yield loss in the present time period, (i.e. assuming $a>0$):

$$\frac{dX_0^*}{da} = \frac{py}{c} > 0$$

We also want to illustrate that X_0^* will decrease as costs increase and X_0^* will increase if resistance management practices were subsidized. Currently, Monsanto provides producers with rebates on purchases of alternative herbicides to glyphosate, even if they are sold by other companies. The purpose of such a rebate program is to delay resistance to glyphosate. (Frisvold and Reeves, 2010) that is, if c decreases then we should expect X_0^* to increase:

$$\frac{dX_0^*}{dc} = \frac{-((1+r)pya + \gamma pyb\beta)}{(1+r)c^2} < 0$$

We can also illustrate here that lower output prices will reduce X_0^*. That is to say that a decrease in *p* will result in a decrease in X_0^*:

$$\frac{dX_0^*}{dp} = \frac{(1+r)ya + \gamma yb\beta}{(1+r)c} > 0$$

Lastly, we can illustrate that X_0^* is higher for owners than for renters. That is X_0^* will decrease as γ decreases:

$$\frac{dX_0^*}{d\gamma} = \frac{pyb\beta}{(1+r)c} > 0$$

In this case we can also compare the extreme case, comparing an owner $(\gamma = 1)$ to a renter who will certainly <u>not</u> manage the field in the future time period $(\gamma = 0)$:

When $(\gamma = 0)$:

$$X_0^* = \frac{(1+r)pya + 0(pyb\beta)}{(1+r)c} = \frac{(1+r)pya}{(1+r)c} = \frac{pya}{c}$$

When $(\gamma = 1)$:

$$X_0^* = \frac{(1+r)pya + pyb\beta}{(1+r)c} = \frac{pya}{c} + \frac{pyb\beta}{(1+r)c} > \frac{pya}{2c}$$

So we see that when $\gamma = 1$, X_0^* is greater than when $\gamma = 0$.

We can also summarize all the signs of the marginal effects in the following table:

Table 3.1: Sign chart for marginal effects

	dX_0^*	dX_1^*
dp	$+$	$+$
dy	$+$	$+$
$d\gamma$	$+$	0
da	$+$	$+$
dc	$-$	$-$
dr	$-$	0
db	$+$	0
$d\beta$	$+$	0

Next we will look to the data to see if the actual owner and renter resistance management behavior is consistent with the results that we have found in the theoretical model.

CHAPTER FOUR

OWNER/RENTER DATA

The data used are collected by the USDA Economic Research Service (ERS) by survey of farmers for different years depending on crop. The Agricultural Resource Management Survey (ARMS) data provides data on crop production practices, which can be used to analyze how farmers manage herbicide resistant weeds. ERS only samples a subsample of fields and farms each survey year and uses the data from those fields and farms to give estimates on farming practices. According to the USDA ERS webpage overview for the ARMS, the survey targets about 5,000 fields and over 30,000 farms each year (USDA ARMS overview).

The ARMS survey is a multi-phase, multi-frame, stratified, and probability-weighted sample (USDA ARMS documentation). When we say that the ARMS survey is multi-phase, we specifically refer to the three phases of the survey. Phase 1 of the survey contacts farmers during the summer of the year asking whether they are operating or not and asking if the farmer is producing the commodities that the other phases of the survey may ask about. The ARMS website states that the purpose of Phase 1 of the survey is mostly to improve the efficiency of the later phases of the survey. Phase 2 surveys a randomly selected group of farmers from phase 1 who are operating and asks them about their crop production practices and chemical use. The data used in this analysis come from this phase 2 survey. Phase 3 of the survey is a nationally representative sample of farmers from Phase 1 and asks those farmers about their finances and costs of production (USDA ARMS documentation).

The term multi-frame from the description of the ARMS survey refers to the two sampling frames that the ARMS survey uses. The first of these is the list frame which is simply a list of farms that the National Agricultural Statistics Service (NASS) already has data for, which can be helpful in allowing the sorting of farms based on knows variables. The second frame used is the geographic frame which is used in support to the list frame. The area frame can be useful in capturing farms that the list frame misses because of the change in farm ownership during the year or farms entering or exiting the market. Around 94% of farms in the ARMS survey sample come from the list frame (USDA ARMS documentation).

The ARMS survey is also stratified by several variables which could include production region or state, commodities produced, or size of the farm. Within each of these stratum, particular units will be given a weight based on their probability of having been selected.

To construct the estimates for the farming production practices, each survey unit is given a weight, which can also be called an expansion factor. Those weights are determined by the probability of each sample unit being selected in the sample. Then using the weights, population estimates are calculated. A jackknife resampling process which uses 30 different sets of weights for each sample to get an estimate for the variance of the first estimate (ARMS documentation). These 30 sets of weights will determine the degrees of freedom which we will use when calculating t statistics as will be seen later.

The specific data used is the 2012 survey data for soybeans and 2010 data for corn growers for weed control management practices, selected pest management practices, and herbicide family application. Both 2012 and 2010 are the most recent years' data for the respective crops. From those groups, data on 9 variables are used. Those variables are:

- Percentage of farmers scouting fields for weeds
- Average number of treatments with herbicide
- Average treatment rate with herbicide
- Percentage of farmers using burn down herbicide
- Percentage of farmers tilling, chopping, mowing, or burning to control pests
- Percentage of farmers cleaning equipment to reduce spread of pests
- Percentage of farmers alternating pesticides to prevent pest resistance
- Percentage of farmers adjusting row spacing/plant density for pest control
- Percentage of farmers applying phosphinic acid herbicides

These variables relate to the best management practices for herbicide resistance outlined in Norsworthy et al 2012. One of these practices is frequent scouting of a field for weeds and record keeping. Records of weeds from the previous year are necessary for proper weed management in the current year. Practices like treatments with herbicide and treatment rate could increase the probability of resistance and it is recommended to use other methods weed control when appropriate. Some of these include tilling, chopping, mowing, or burning to control pests. When it comes to burn down herbicide, Norsworthy says, "Use of a burndown herbicide indicates that producers are attempting to plant into a weed-free field… This practice is used extensively in reduced tillage systems where the burndown herbicide replaces preplant tillage to control existing weeds. (p. 50)" (Norsworthy et al., 2012). Cleaning equipment, alternating pesticides, and adjusting row spacing/plant density are all part of the best management practices for preventing resistance. The clearest link to herbicide resistant weeds is the last variable: application of phosphinic acid herbicides. Glyphosate is in the family of phosphinic acid herbicides (which also includes glufosinate ammonium and sulfosate) that have a similar mode of action to kill weeds. Repeated use of a single herbicide or herbicides with a similar mode of action has been shown to speed the evolution of weed resistance to that particular herbicide or mode of action. More farmers using phosphinic acid will increase the likelihood of resistance to phosphinic acid. Phosphinic acid use should also be related to the alternating of pesticides as more farmers alternating will go along with less phosphinic acid use.

With the exception of number of treatments with herbicide and treatment rate with herbicide, each observation for a particular variable is the percentage of farmers in a particular geographic area who adopted that particular practice. There is data for both owners and renters so that their adoption rates can be compared. The data will also be separated by farming production region. Each observation in the data also includes the residual standard error as a percentage of the estimate, so each of those are used to calculate normal standard errors which can be used to test for significant differences in adoption rates.

To estimate each of the residual standard errors, the Agriculture Resource Management Survey uses the DAG (Delete-a-group) Jackknife variance estimator (Kott, 2001). When using the DAG Jackknife estimator, each of the estimates for standard errors have degrees of freedom equal to 29 in our case. This is because of the 30 different sets of weights used to calculate the variances minus one. Thus when we calculate t statistics for testing a difference in means between owners and renters we must use degrees of freedom equal to 58.

CHAPTER FIVE

OWNER/RENTER METHOD

The method that will be used to examine if owners and renters behave differently is a simple comparison of means to test for any statistically significant difference. A similar approach has been used to test differences in behavior across different farm types in previous studies on agri-tourism, vertical integration, and practice adoption among beef producers (Bagi et al., 2012; Azzam, 1998; Pruitt et al., 2012).

To do this, a simple t statistic is calculated. As mentioned before, because the ARMS survey uses the DAG jackknife variance estimator we will have degrees of freedom equal to 58 when we calculate the p-values for our t-statistic. Standard errors for each estimate are available in the data and are calculated using the 30 probability weighted estimates. The t statistics are calculated as:

$$T\ Stat = \frac{Estimate_{Owner} - Estimate_{Renter}}{\sqrt{Variance_{Owner} + Variance_{Renter}}}$$

CHAPTER SIX

OWNER/RENTER RESULTS

First we will look at how owners and renters behave on a national level for both corn and soybean producers. However we also want to know if the differences between owners and renters are statistically significant, so we calculate t statistics and associated p-values. The results of this are shown in the following table:

Table 6.1: National Corn owner/renter comparisons, 2010

Weed Management Practice		Estimate	S.E.	P-Value
Field scouted for weed (% of acres)	Owner	87.31	1.29	0.26
	Renter	88.76	1.76	
Number of treatments with herbicide (Number)	Owner	2.80	0.07	0.21
	Renter	2.89	0.09	
Treatment rate with herbicide (Pounds active ingredient per treated acre)	Owner	2.24	0.06	0.45
	Renter	2.26	0.07	
Burn down herbicide used (% of acres)	Owner	5.09	0.76	0.46
	Renter	4.97	0.81	
Tilling, chopping, mowing, burning to control pests (% of acres)	Owner	41.70	2.92	0.15
	Renter	46.31	3.19	
Clean equipment to reduce spread of pests (% of acres)	Owner	37.19	2.86	0.04
	Renter	30.29	2.69	
Alternate pesticides to prevent pest resistance (% of acres)	Owner	24.21	2.57	0.02
	Renter	30.51	1.80	
Adjust row spacing/plant density for pest control (% of acres)	Owner	12.36	1.79	0.26
	Renter	13.99	1.69	
Phosphinic acid (herbicide acre-treatments)	Owner	35.64	1.45	0.07
	Renter	32.88	1.18	

Source: USDA, ARMS

In this table, we see statistically significant differences in three of the variables. We see that owners clean equipment to reduce the spread of pests more than renters. However, renters alternate pesticides to prevent pest resistance more than owners and use less phosphinic acid than owners which are both better for managing resistance to glyphosate (a phosphinic acid herbicide). Thus as a whole, the data for corn shows mixed results for the behavior of owners and renters.

We can then look at the national data for soybeans from 2012 to try to examine this question. Once again, the goal is to see if there are any statistically significant differences between the behavior of owners and renters. In the same way as was done with Corn, this question can be answered by looking at the calculated P-values in the table below.

Table 6.2: National Soybeans owner/renter comparisons

Weed Management Practice		Estimate	S.E.	P-Value
Field scouted for weeds (% of acres)	Owner	93.31	0.65	0.05
	Renter	94.83	0.66	
Number of treatments with herbicide (Number)	Owner	2.92	0.06	0.08
	Renter	3.02	0.05	
Treatment rate with herbicide (Pounds active ingredient per treated acre)	Owner	1.81	0.04	0.04
	Renter	1.9	0.03	
Burn down herbicide used (% of acres)	Owner	32.63	1.60	0.22
	Renter	34.22	1.30	
Tilling, chopping, mowing, burning to control pests (% of acres)	Owner	42.7	1.79	0.39
	Renter	43.42	1.87	
Clean equipment to reduce spread of pests (% of acres)	Owner	33.87	2.37	0.48
	Renter	34.05	1.91	
Alternate pesticides to prevent pest resistance (% of acres)	Owner	22.43	1.32	0.09
	Renter	25.48	1.86	
Adjust row spacing/plant density for pest control (% of acres)	Owner	16.44	1.74	0.09
	Renter	19.34	1.28	
Phosphinic acid (herbicide acre-treatments)	Owner	50.69	2.33	0.46
	Renter	50.41	1.56	

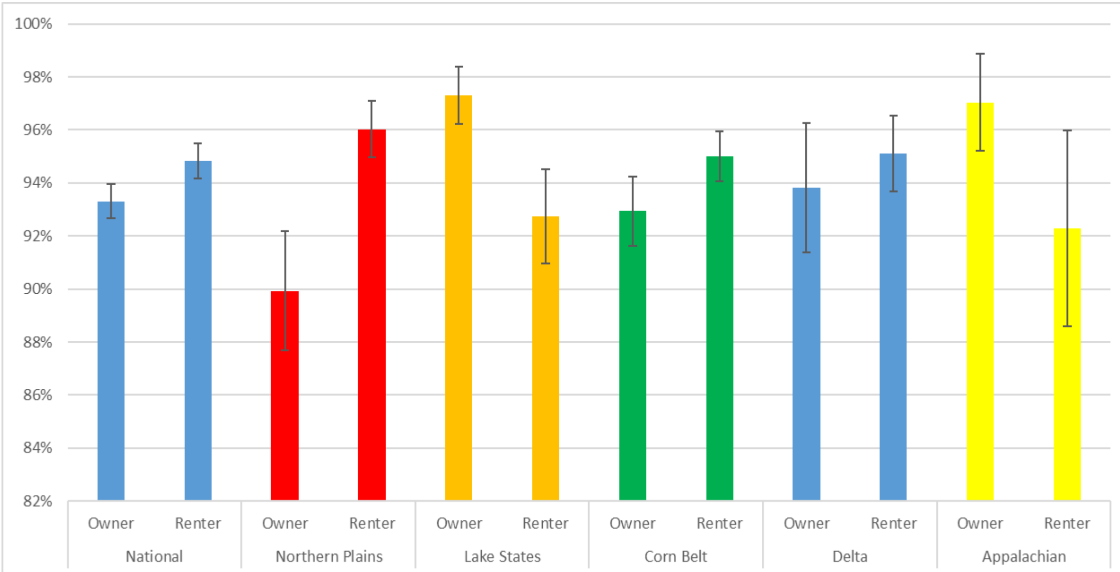
Source: USDA, ARMS

Here, the data shows that renters have a higher treatment rate and a higher number of treatments with herbicide than owners. While total herbicide applications appear to be higher on rented land, there is no difference in phosphinic acid herbicide use between owners and renters. This suggests that renters are using more non-phosphinic acid herbicides. However, renters also scout their fields for weeds at a higher rate while also alternating pesticides and adjusting row spacing/plant density at a higher rate than owners. So, similarly to the national data for corn, there is little evidence of greater resistance management on owned land.

To examine further, we can look at the soybeans and corn data further by separating the national data into data representing the behavior of owners and renters in each farm production region separately. It might be possible that this separation is necessary to see the difference in resistance management for renters.

The first variable examined is the percentage of farmers who scouted their fields for weeds. The estimates along with standard error bars are shown in the following graph.

Figure 6.1: Field scouted for weeds by region – soybeans

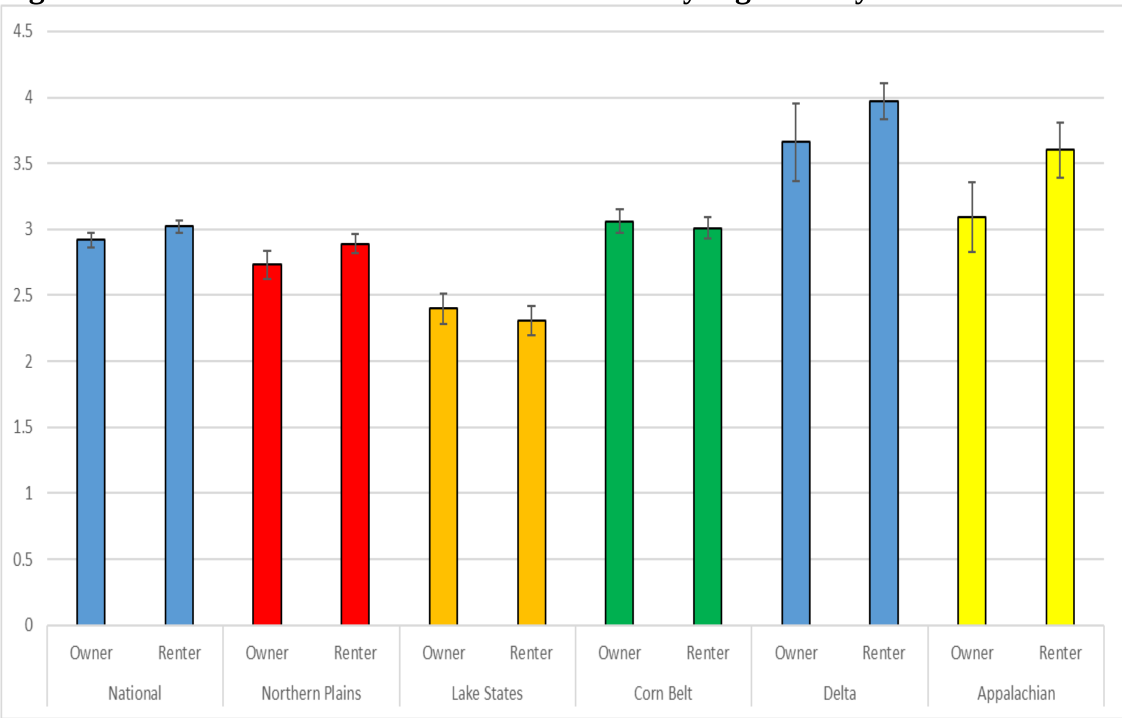


Source: USDA, ARMS

First, we see that the National estimate for renter is weakly significantly larger than the estimate for owners nationally at 10% significance. There is also a significant difference at 1% when comparing Northern Plains owners to renters with renters having the higher adoption rate. The last significant difference is a significant difference at 5% for Lake State owners to renters with the estimate for owners being higher.

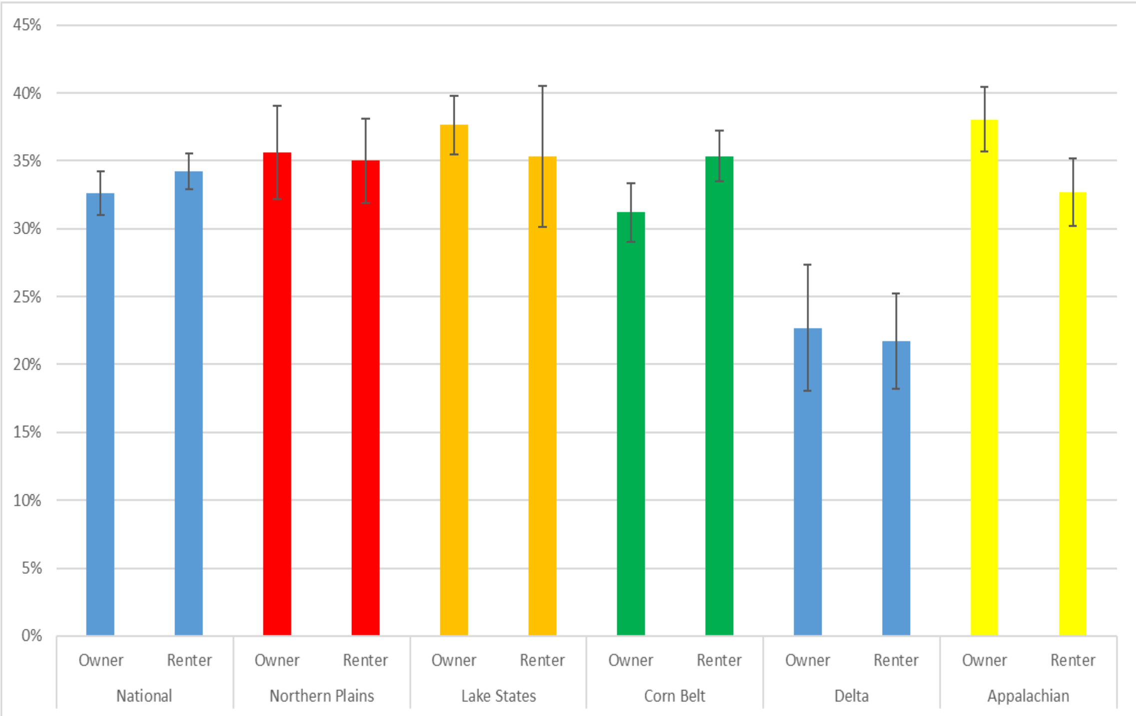
The next two variables which can be used to compare owner and renter behavior are the number of treatments with herbicide and the treatment rate with herbicide. For both variables there is a significant difference in the national estimates with the renter estimate being higher in both cases. There is also a significant difference at the 10% level in the number of herbicide treatments for the Appalachian production region with the estimate for renters being larger.

Figure 6.2: Number of treatments with herbcide by region – soybeans



Source: USDA, ARMS

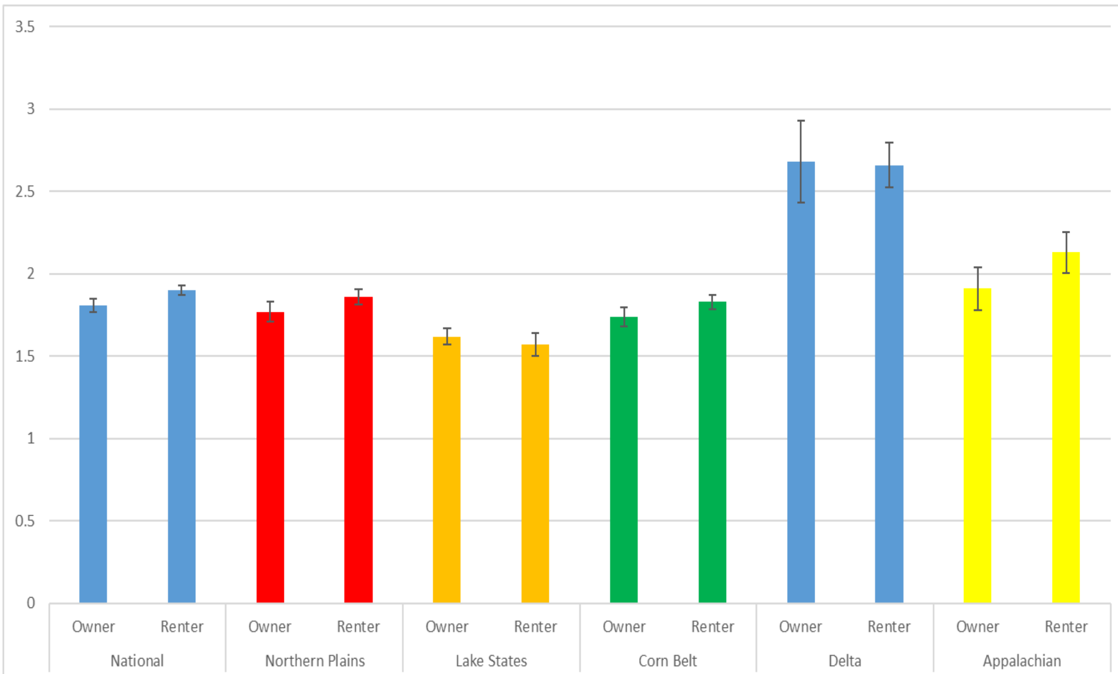
Figure 6.3: Burn down herbicide by region – soybeans, percentage of acres



Source: USDA, ARMS

We see some significance at the 10% level for both differences in the Corn Belt and Appalachian farming production regions for the Burn down herbicide use variable with renters being higher in the Corn Belt and owners higher in Appalachia.

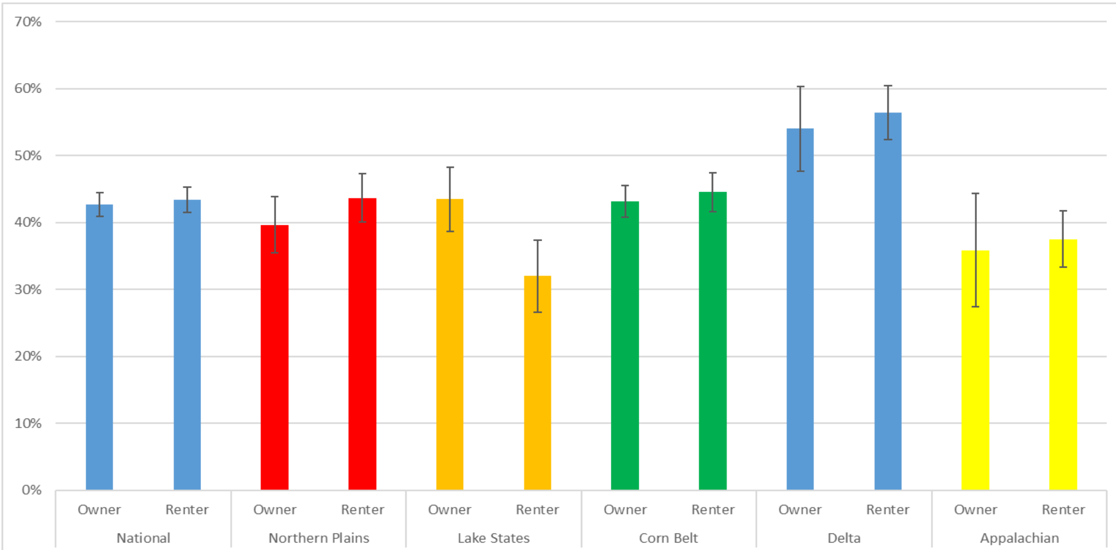
Figure 6.4: Treatment rate by region – soybeans, active ingredient applied per treated acre



Source: USDA, ARMS

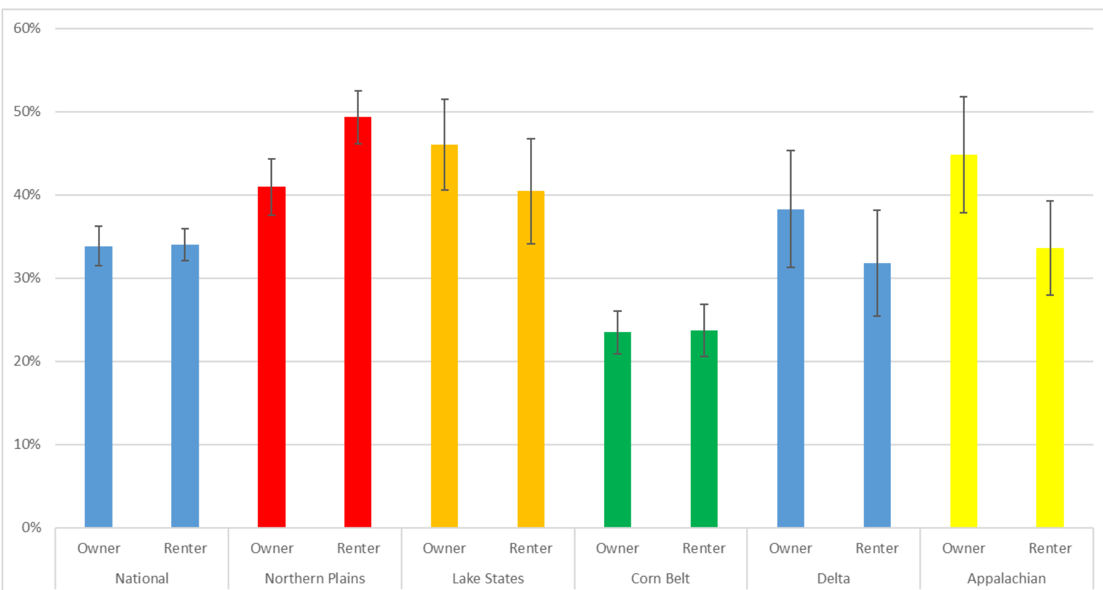
The next several variables which we examine are ralated to how gowers deal with pests and how they manage pest resistance. There is at least one farm production region for each variable with a least a weakly significant difference in the estimates of owners and renters.

Figure 6.5: Tilling, chopping, mowing, and burning by region – soybeans, percentage of acres



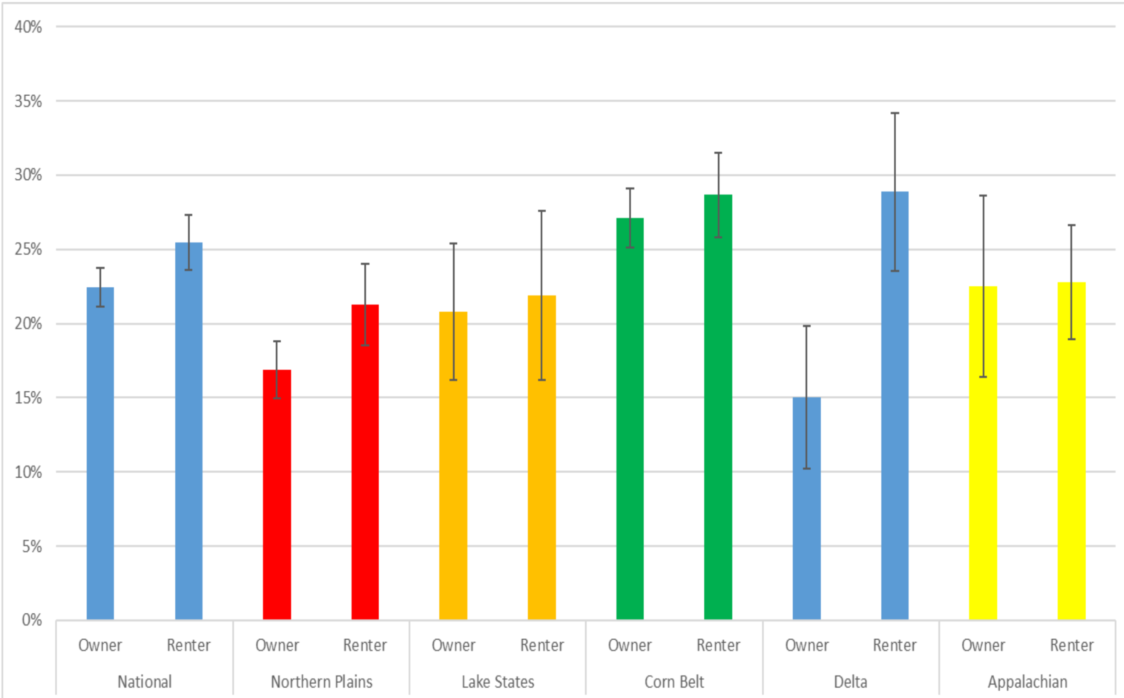
Source: USDA, ARMS

Figure 6.6: Cleaning equipment by region – soybeans, percentage of acres



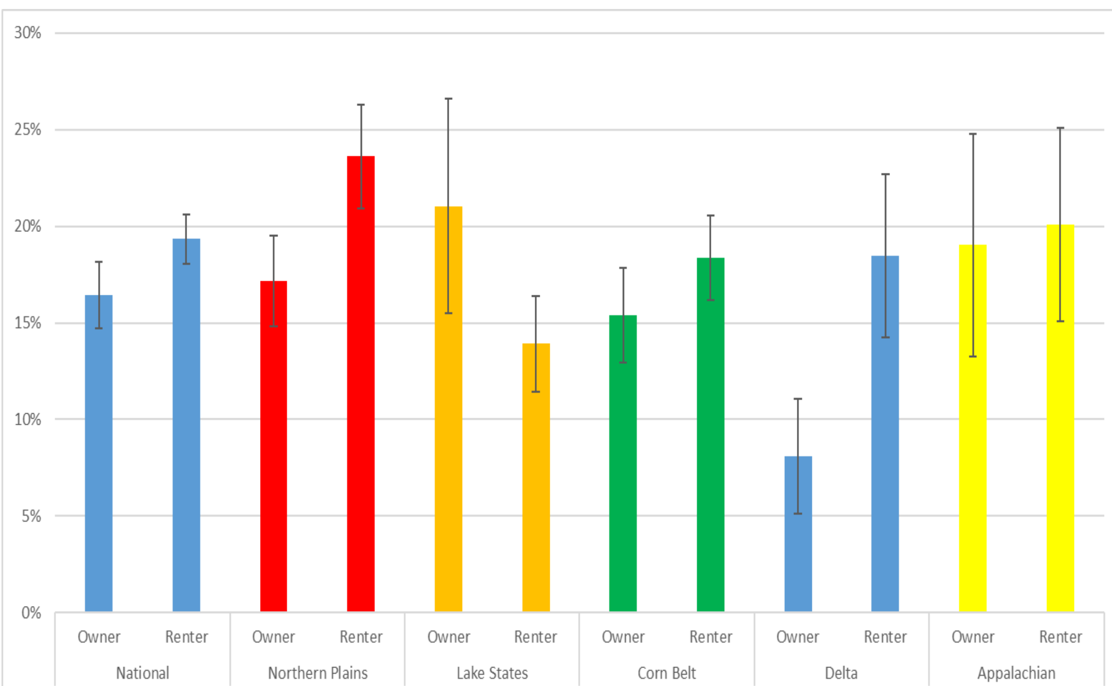
Source; USDA, ARMS

Figure 6.7: Alternating pesticides by region – soybeans, percentage of acres



Source: USDA, ARMS

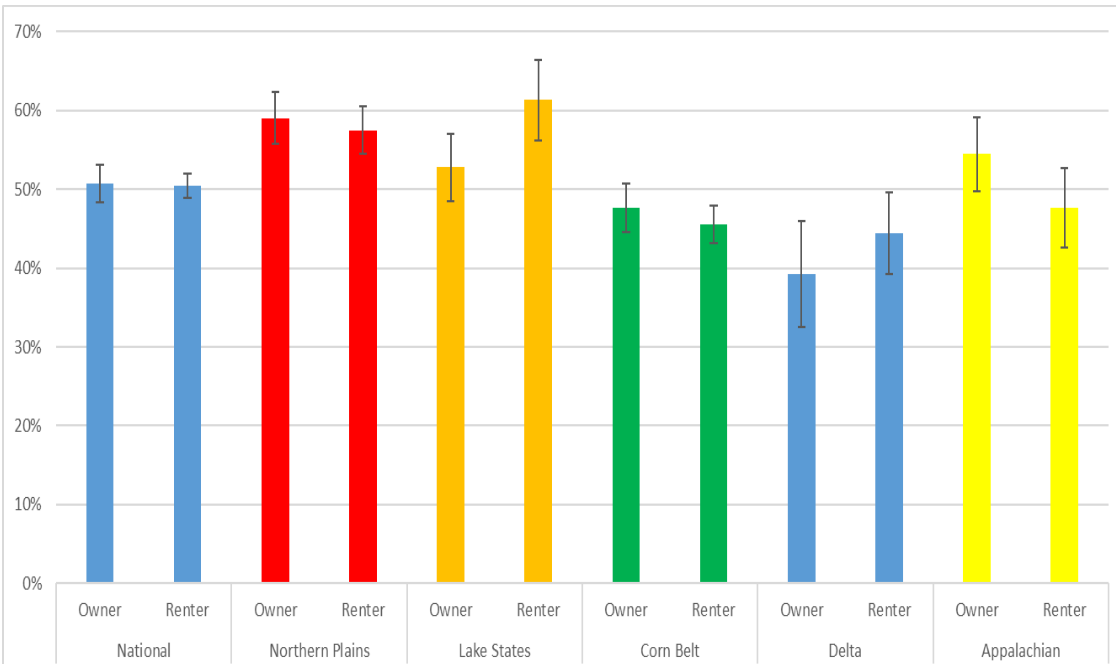
Figure 6.8: Adjusting row spacing by region – soybeans. Percentage of acres



Source: USDA, ARMS

The last variable to look at is the usage rate of phosphinic acid herbicides by growers. Phosphinic acid herbicide use is almost entirely accounted for by use of glyphosate. Glyphosate use has grown rapidly in its popularity as an herbicide because of the introduction of glyphosate-resistant transgenic seed varieties. Thus glyphosate resistant weeds are a main concern when considering weed resistance management.

Figure 6.9: Phosphinic acid by region – soybeans, percentage of herbicide acre-treatments



Source: USDA, ARMS

There are no statistically significant differences between owner and renter usage rates of phosphinic acid in any farming production region for soybeans. We even see here that in 4 out of 6 of the cases shown above, the owners are using slightly more phosphinic acid than renters.

We can summarize these results in the following table which shows in what cases there is a significant difference between owner and renter behavior. The level of significance is also shown.

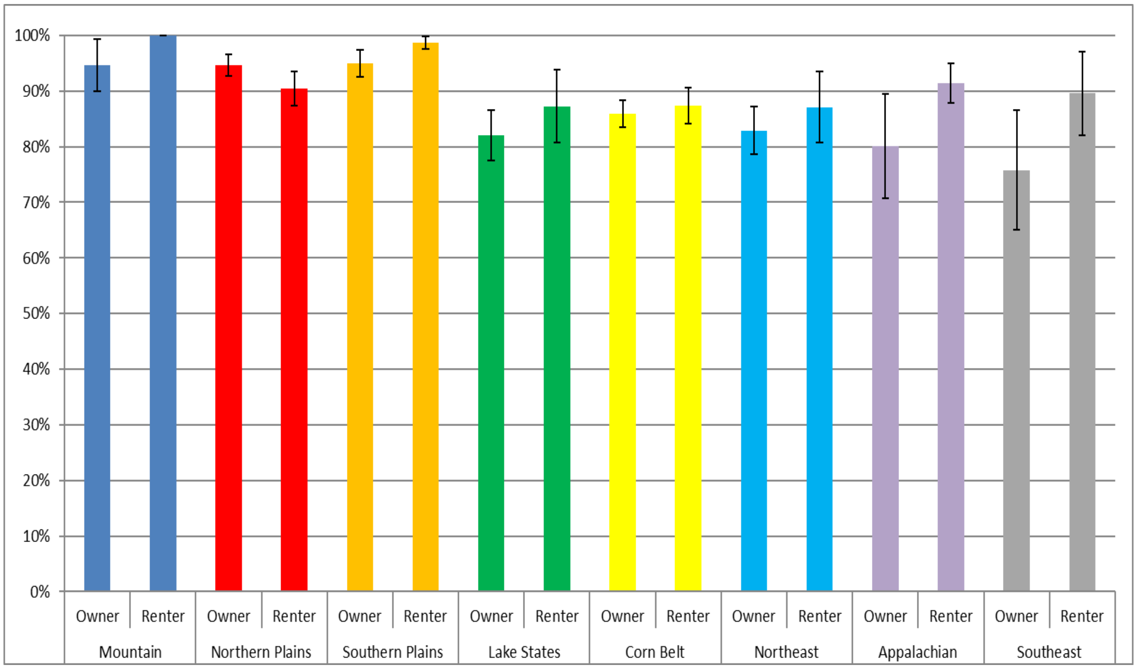
Table 6.3: Siginificance levels for owner/renter comparisons – soybeans

	National	Northern Plains	Lake States	Corn Belt	Delta	Appalachian
Field scouted for weeds (% of acres)	R *	R ***	O **			
Number of treatments with herbicide (Number)	R *					R *
Treatment rate with herbicide (Pounds active ingredient per treated acre)	R **					
Burn down herbicide used (% of acres)				R *		O *
Tilling, chopping, mowing, burning to control pests (% of acres)			O *			
Clean equipment to reduce spread of pests (% of acres)		R **				
Alternate pesticides to prevent pest resistance (% of acres)	R *	R *			R **	
Adjust row spacing/plant density for pest control (% of acres)	R *	R **			R **	
Phosphinic acid (herbicide acre-treatments)						
Note "O" indicates owner adoption is higher, "R" for renter				* = 10%	** = 5%	*** = 1%

Source: USDA, ARMS

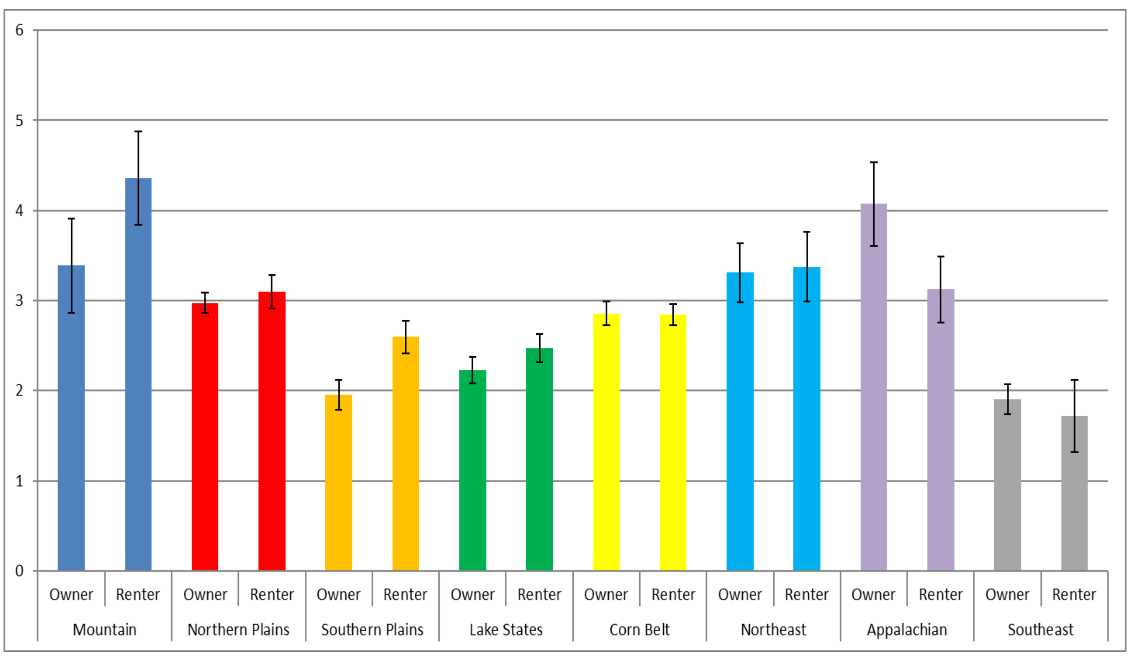
We perform the same analysis as above for corn data from 2010. For the corn data we include three additional variables which were not available for soybeans. The additional variables are: Pre-emergence weed control, cultivated for weed control, and number of tillings. The results for corn follow.

Figure 6.10: Fields scouted for weeds by region – corn, percentage of acres



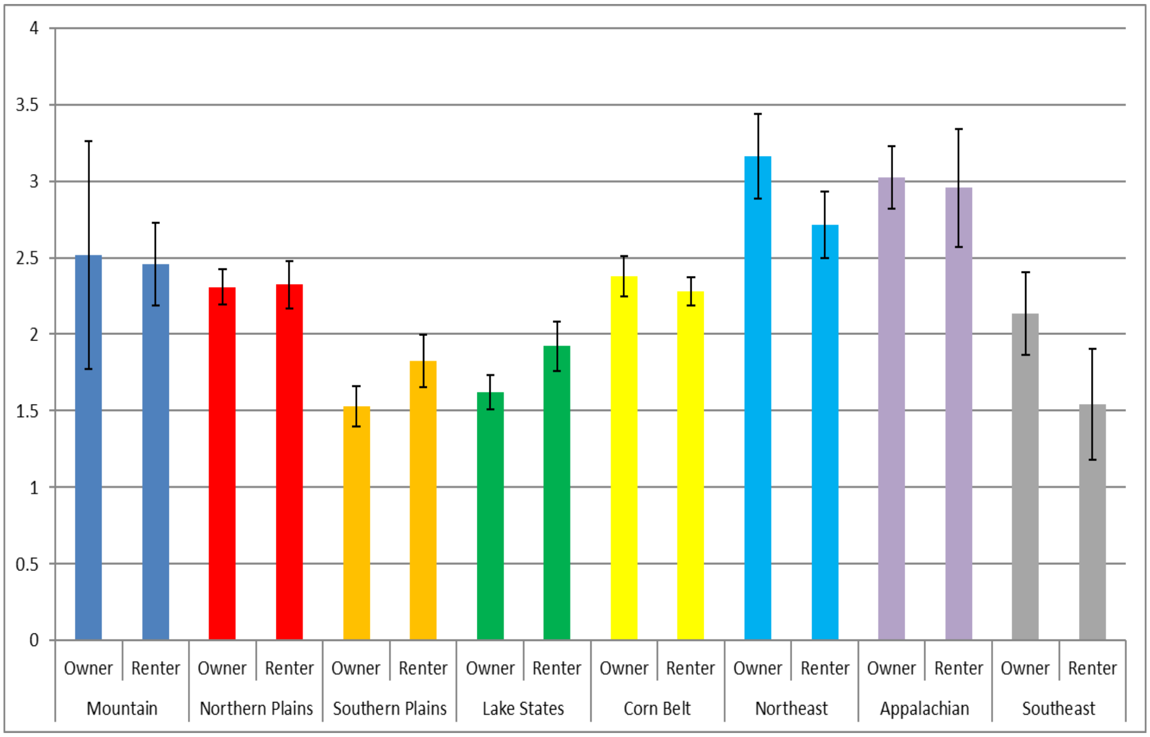
Source: USDA, ARMS

Figure 6.11: Number of treatments with herbicide – corn



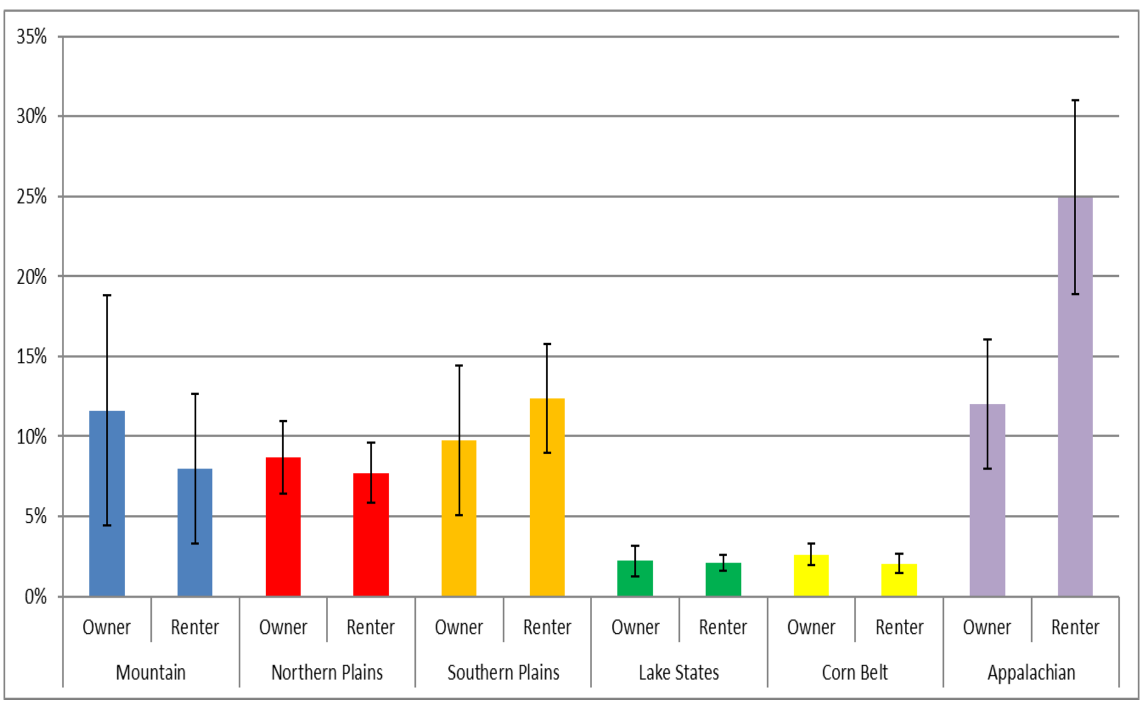
Source: USDA, ARMS

Figure 6.12: Treatment rate with herbicide – corn, active ingredient applied per treated acre



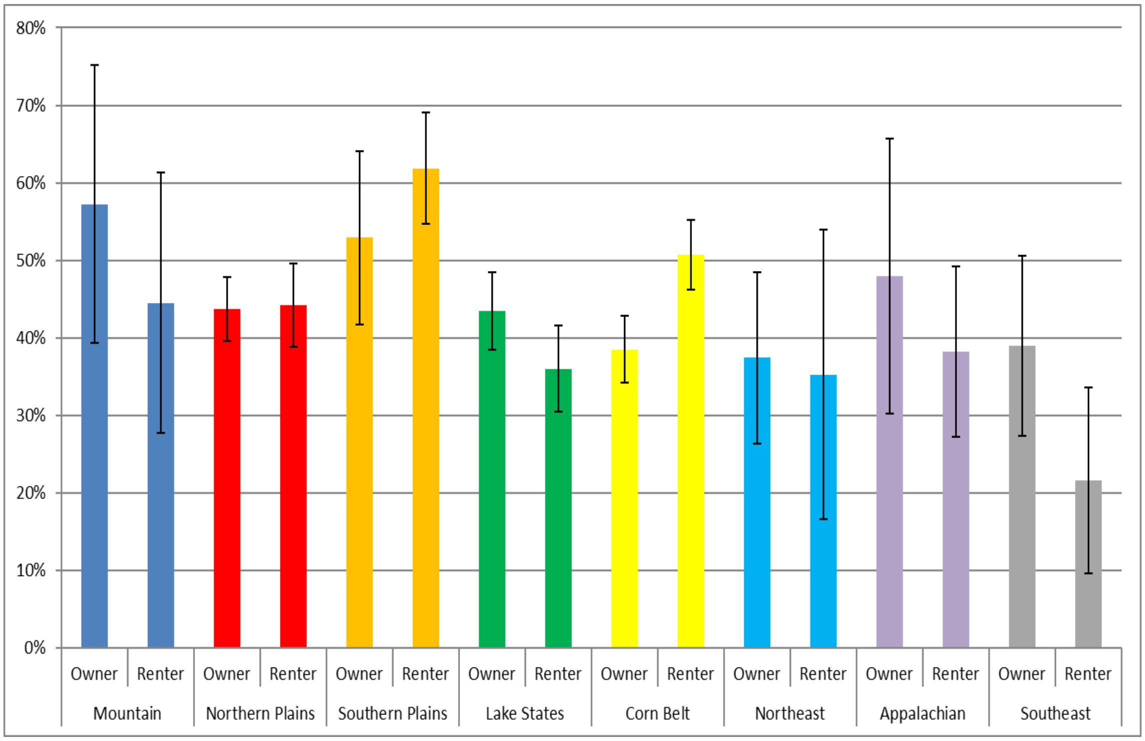
Source: USDA, ARMS

Figure 6.13: Burn down herbicide used – corn, percentage of acres



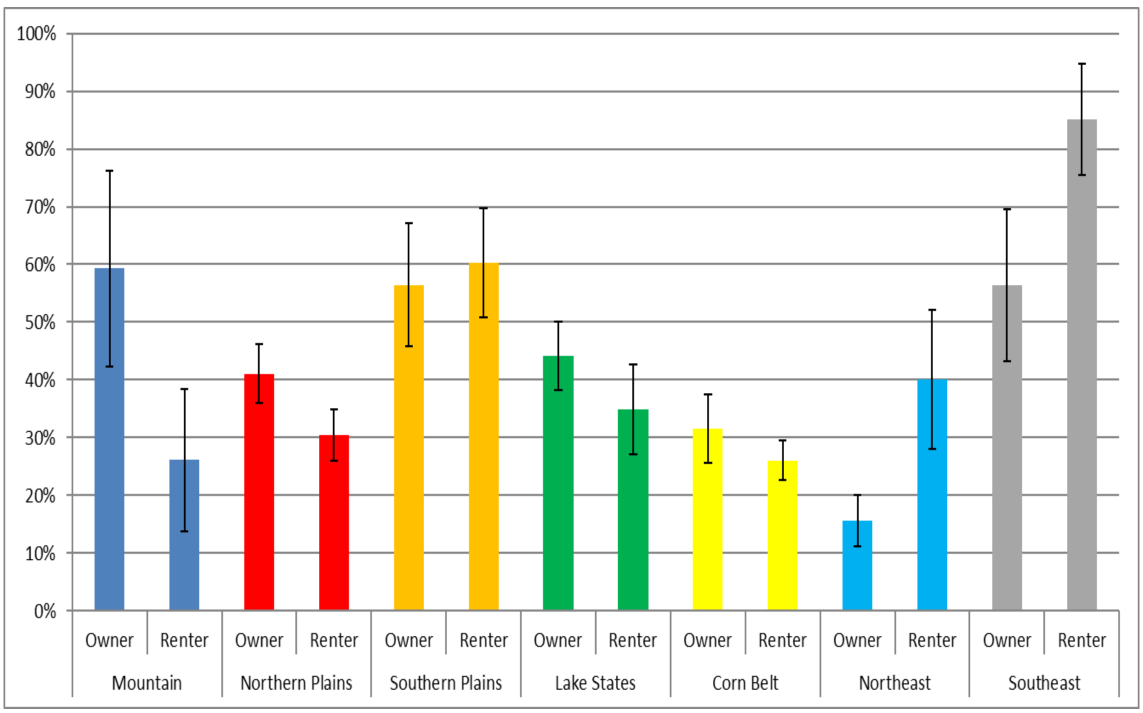
Source: USDA, ARMS

Figure 6.14: Tilling, chopping, mowing, burning to control pests – corn, percentage of acres



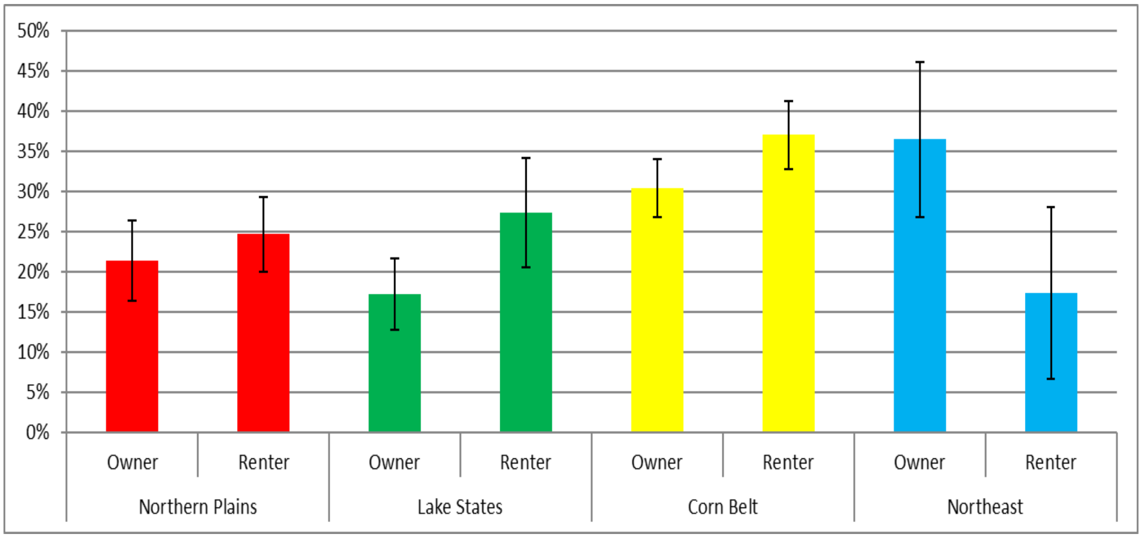
Source: USDA, ARMS

Figure 6.15: Clean equipment to reduce spread of pests – corn, percentage of acres



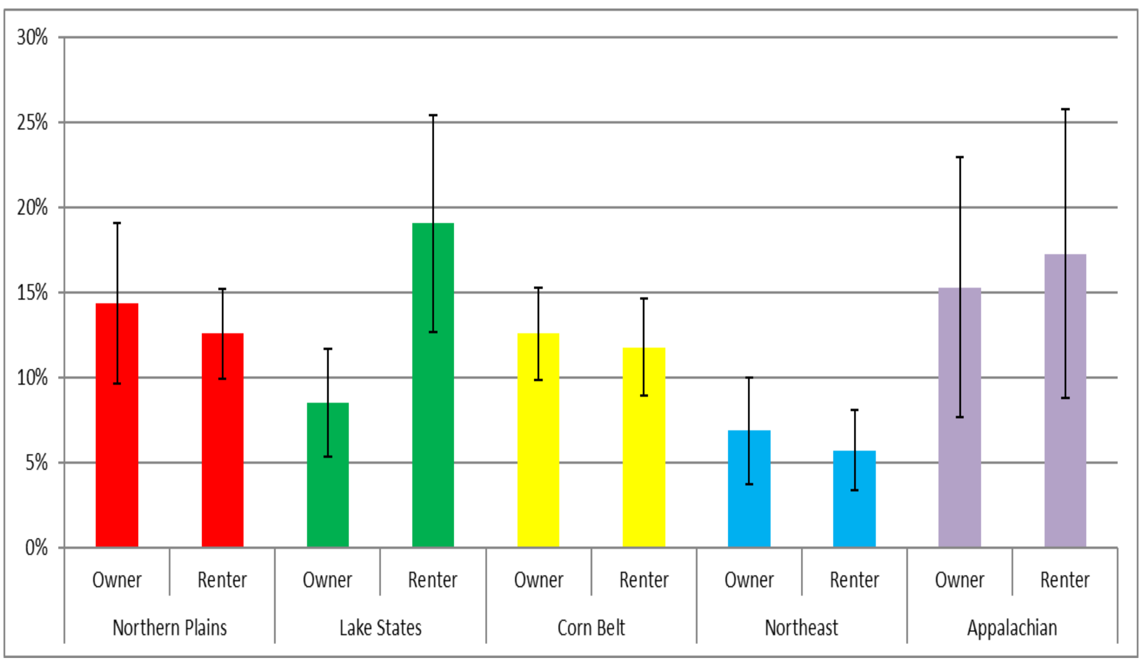
Source: USDA, ARMS

Figure 6.16: Alternate pesticides to prevent pest resistance – corn, percentage of acres



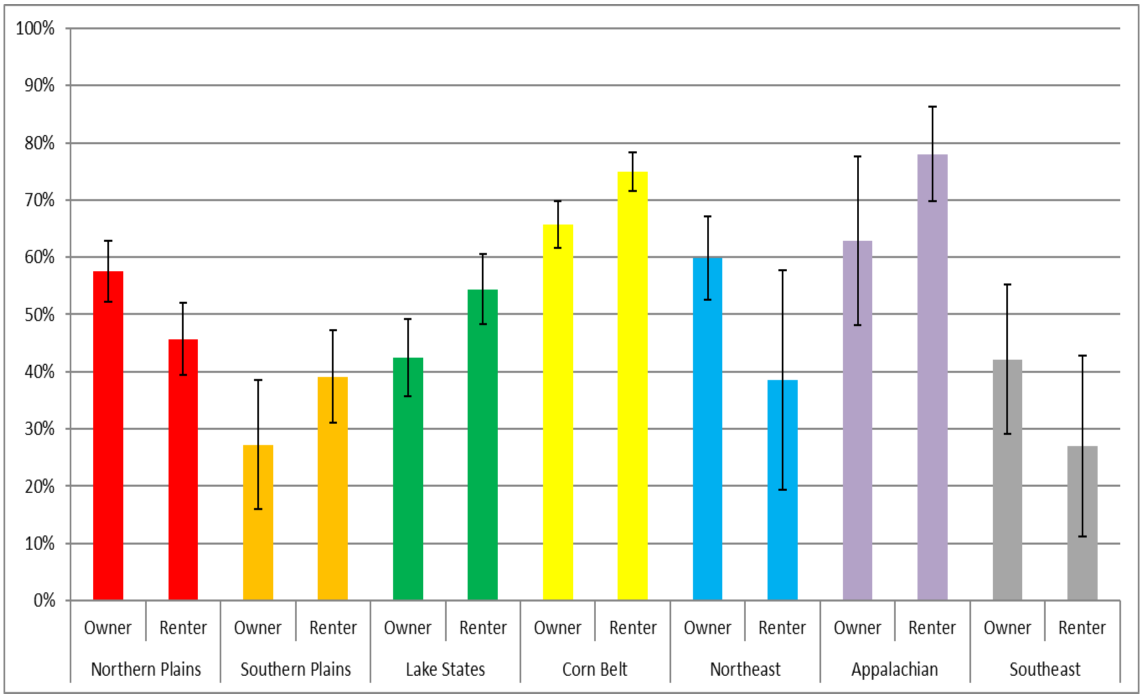
Source: USDA, ARMS

Figure 6.17: Adjust row spacing/plant density for pest control – corn, percentage of acres



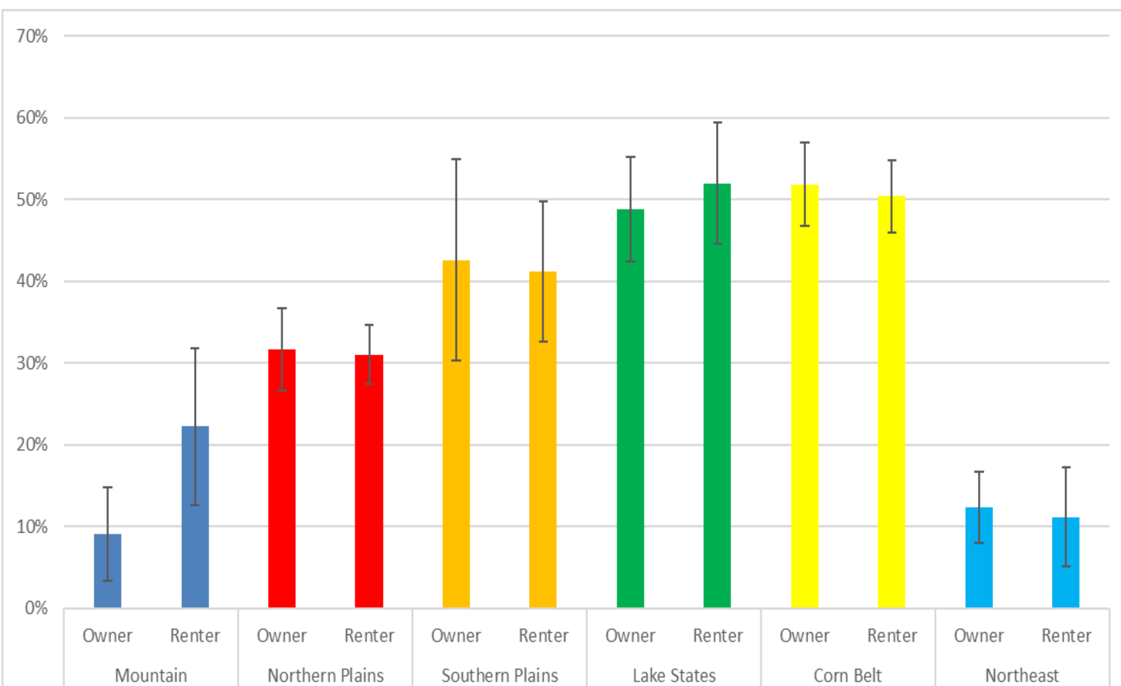
Source: USDA, ARMS

Figure 6.18: Pre-emergence weed control – corn, percentage of acres



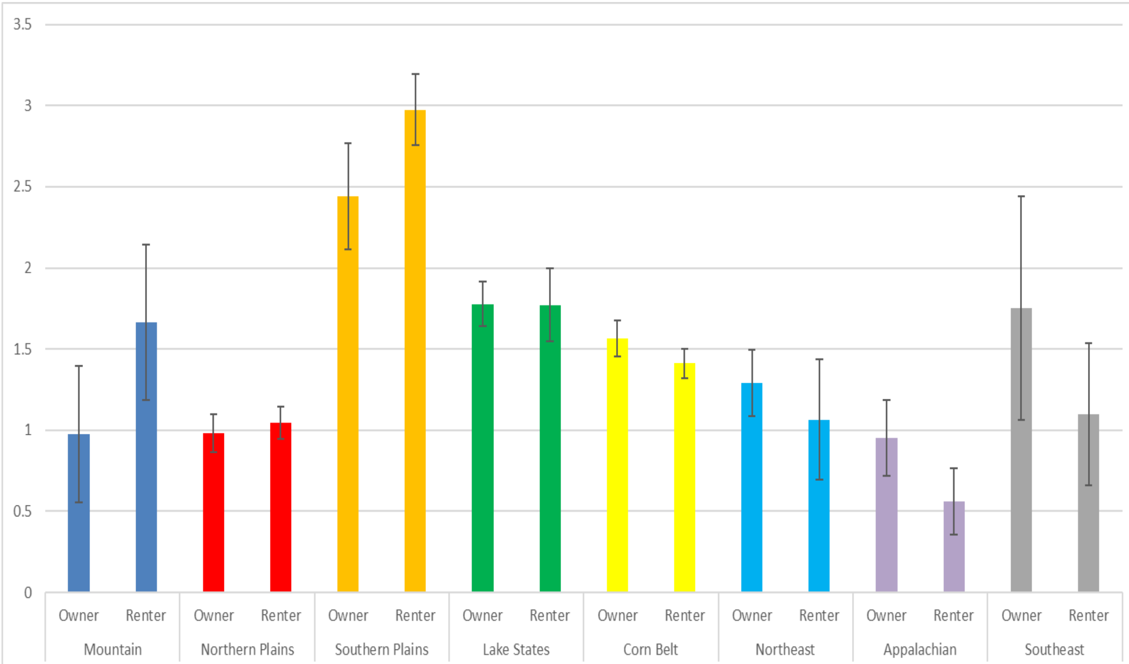
Source: USDA, ARMS

Figure 6.19: Cultivated for weed control – corn, percentage of acres



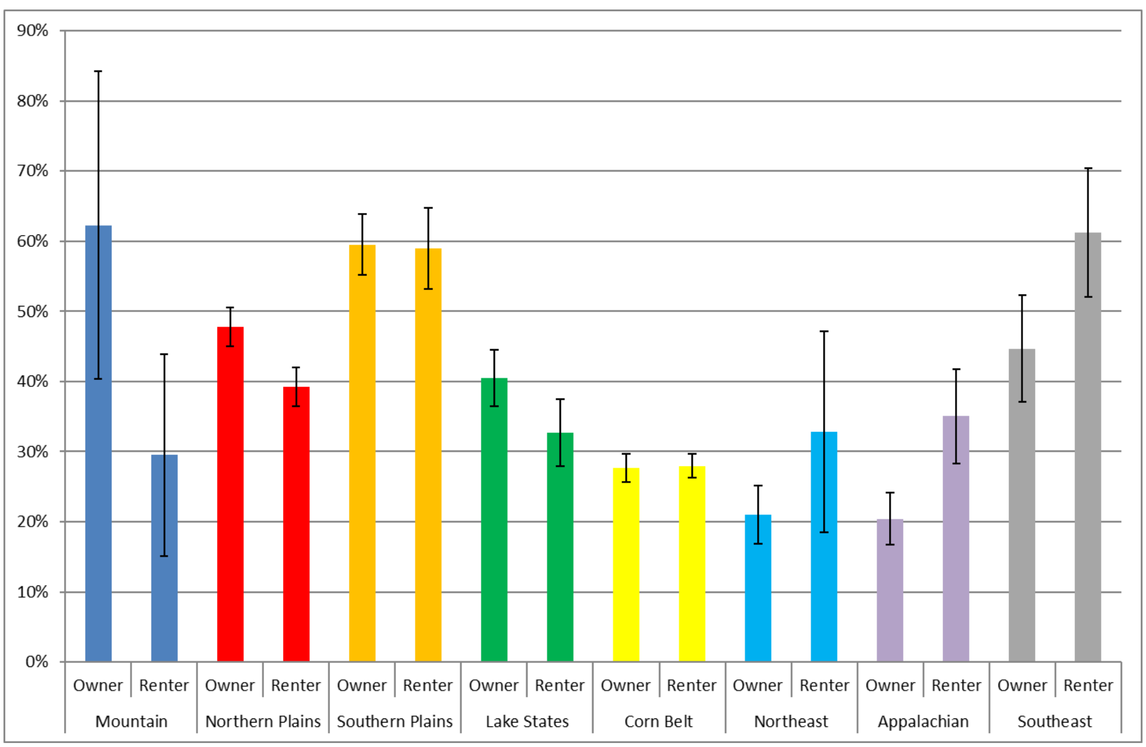
Source: USDA, ARMS

Figure 6.20: Number of tillings – corn



Source: USDA, ARMS

Figure 6.21: Phosphinic acid – corn, percentage of total herbicide acre-treatments



Source: USDA, ARMS

Just as with soybeans, we check for statistically significant differences in owner/renter management behavior. The significance table for corn follows, however some owner/renter comparisons could not be made because of missing data. Those comparisons which could not be made have been greyed out.

Table 6.4: Significance levels for owner/renter comparisons – corn

	Mountain	Northern Plains	Southern Plains	Lake States	Corn Belt	Northeast	Appalachian	Southeast
Field scouted for weeds (% of acres)			R *					
Number of treatments with herbicide (Number)	R *		R ***				O *	
Treatment rate with herbicide (Pounds active ingredient per treated acre)			R *	R *				O *
Burn down herbicide used (% of acres)							R **	
Tilling, chopping, mowing, burning to control pests (% of acres)					R **			
Clean equipment to reduce spread of pests (% of acres)	O *	O *						R **
Alternate pesticides to prevent pest resistance (% of acres)						O *		
Adjust row spacing/plant density for pest control (% of acres)				R *				
Pre-emergence weed control (% of acres)		O *		R *	R **			
Cultivated for weed control (% of acres)								
Number of tillings (Number)								
Phosphinic acid (herbicide acre-treatments)		O **					R **	R *
Grey cells indicate that the test could not be performed due to missing data								
Note "O" indicates owner adoption is higher, "R" for renter						* = 10%	** = 5%	*** = 1%

Source: USDA, ARMS

It appears from the results that owners and renters are not consistently behaving differently when it comes to resistance management. This is different than what the theoretical model implies when it shows the optimal resistance expenditure for owners as being higher than for renters.

The foregoing analysis can be redone if resistance management is considered in a different way. Instead of assuming that resistance management is a continuous variable, we will assume that resistance management is a discrete choice. That is, assume that if management practices are adopted then X_0 or X_1 is at a fixed level of $\underline{X} > 1$. If the farmer decides not to manage resistance then $\underline{X} = 1$. Then the profits for those adopting management practices is:

$$(6)\quad \Pi_{manage} = py\left[1 - \left(\varepsilon - aln(\underline{X}_0) + bR_0\right)\right] - c\underline{X}_0$$

$$+ \frac{\gamma}{1+r}\left(py\left[1 - \left(\varepsilon - aln(\underline{X}_1) + b(\alpha - \beta\ln(\underline{X}_0) + R_0)\right)\right] - c\underline{X}_1\right)$$

For those who do not adopt management practices the profit equation is:

$$(7)\quad \Pi_{not} = py[1 - (\varepsilon + bR_0)] + \frac{\gamma}{1+r} py[1 - (\varepsilon + b(\alpha + R_0))] - 2c$$

Then it can be concluded that a management practice will be adopted in both periods if

$$\Pi_m - \Pi_n \geq 0$$

Or:

$$(8)\quad \Pi_m - \Pi_n = pyaln(\underline{X}_0) - c\underline{X}_0$$

$$+ \frac{\gamma}{1+r}\left[py\left(aln\left(\underline{X}_1\right) + b\beta\ln\left(\underline{X}_0\right)\right) - c\underline{X}_1\right] + 2c \geq 0$$

Because we want to compare owner and renter behavior, we want to focus on how the value of γ will affect whether farmers choose to adopt management practices or not. Thus we can solve the previous equation for some critical value:

$$\gamma^* = \frac{(1+r)\left(c\underline{X}_0 - pyaln(\underline{X}_0) - 2c\right)}{py\left(aln(\underline{X}_1) + b\beta ln(\underline{X}_0)\right) - c\underline{X}_1}$$

Then consider the following three cases:

1. If $\gamma^* > 1$ then neither the owner nor the renter will adopt the practice.

2. If $0 < \gamma^* < 1$ and for renters $\gamma > \gamma^*$ then both owners and renters will adopt the practice.

3. If $0 < \gamma^* < 1$ and for renters $\gamma < \gamma^*$ then owners will adopt the practice but renters will not.

Equation 8 can also be solved for a transformation of the discount rate as follows:

$$\frac{1}{1+r} = D^* = \frac{c\underline{X}_0 - pyaln\left(\underline{X}_0\right) - 2c}{\gamma[py\left(aln(\underline{X}_1) + b\beta ln(\underline{X}_0)\right) - c\underline{X}_1]}$$

With this additional consideration the fourth case might occur. That is if $D < D^*$ for Owners and $D > D^*$for renters then it could be the case that the renter will adopt the management practice but the owner will not. So, if owners have a higher discount rate than renters (if for example, they are older) they may be less likely to adopt the practice, all else equal. For renters to be more likely to adopt the resistance management practice, there could be other sources of heterogeneity across owners or renters. For example, renters could have more productive land or be better managers, in which case their weed-free base yields, y, could be higher.

CHAPTER SEVEN

HAZARD MODEL

Here we will focus on how herbicide resistance management can be examined in the context of a hazard model. For this discussion, much guidance is taken from Beck, Katz, and Tucker (1998) who themselves are expanding on the Cox (1975) proportional hazards model. The Cox proportional hazards model is as follows,

$$h\left(t|x_{i,t}\right) = h_0(t)e^{x_{i,t}\beta}$$

(Beck 1998). Here $x_{i,s}$ is a vector of independent variables measured at time t. So here the dependent variable depends on both the independent variables, along with some hazard, based on the amount of time that the unit has been at risk, represented by $h_0(t)$. In this study, the units at risk will be states, and the hazard will be the first identification of a weed in a corn crop field in the state that is resistant to the herbicide glyphosate. Sometimes this hazard model is called a survivor model. In that case, one can estimate the probability of survival for people over time, depending on factors that may affect their chances of survival. Survival time can be influenced by human behavior but it is still dependent on time and eventually everyone will die regardless of behavior. Another context in which this type of model can be used is in the world of quality control. Imagine one wanted to find the likelihood of his car tires failing. This would likely be a function of his driving behavior, but again there is the underlying inevitable failure as a result of the passage of time. One last example is modeling the amount of time that passes between times of peace and the next conflict for countries. One could expect that the behavior and characteristics of a country would impact the length of peace time, but there is still an underlying risk each year that a conflict will break out. So we can use this model to look at how the recommended best management practices for preventing herbicide resistance will impact the time that it takes for states to get herbicide resistant weeds.

CHAPTER EIGHT

HAZARD MODEL DATA

The data used in this section comes from two sources. The first source, used to construct the dependent variable, is the International Survey of Herbicide Resistant Weeds (Heap, 2016). The survey provides information about where and when a weed resistant to a specific herbicide is identified by a weed scientist. The database identifies the species of weed, herbicide, country, state, or province of the discovery and the cropping system in which the weed was found. This information spans many different crops, but we will focus on three major US crops: corn, cotton, and soybeans. The units for this data will be the available states where the crop is grown and has either already seen glyphosate resistance in the state or has yet to have resistance in their state. For each incidence of resistance, the weed science website will report the state or location, the species of weed which became resistant, the first year that this resistance emerged, and the site of action (Heap, 2016). In this case we construct our data using the state, and the year for a particular site of action. When survey reports the site of action as “EPSP synthase inhibitors (G/9)” that is the indicator that there are glyphosate-resistant weeds in that state.

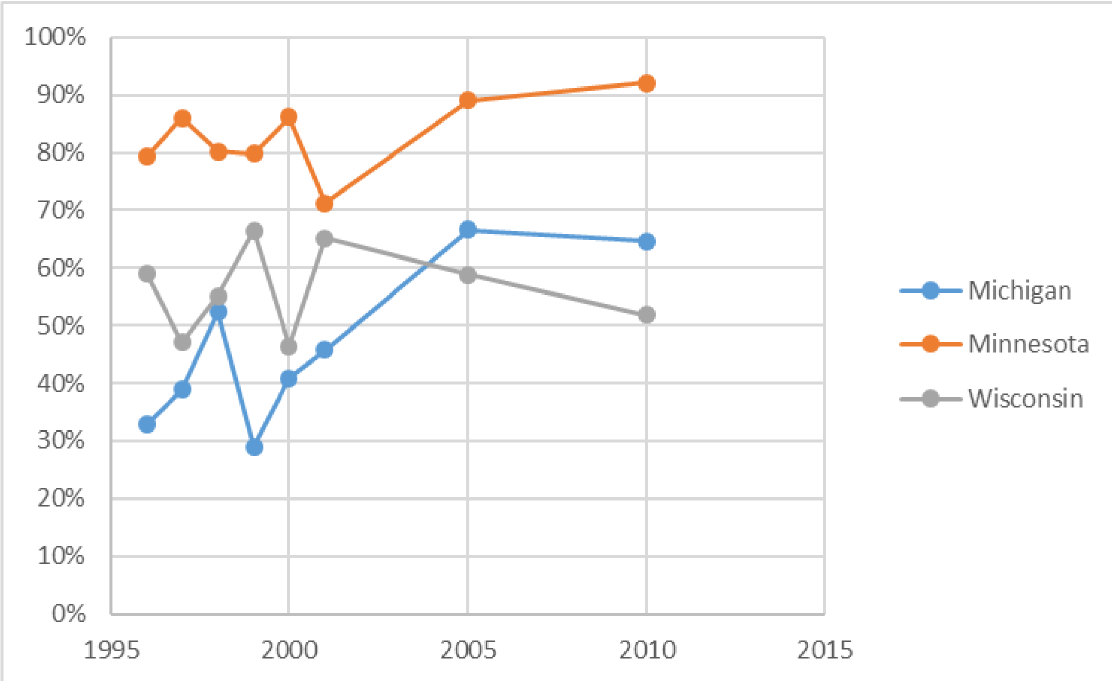
Using the information about the first year of resistance for each state, the dependent variable is constructed. The earliest year for each state is equal to the year that the first state discovered an herbicide-resistant weed. Each state will then have observations for the dependent variable equal to 0 for every year before the first year that a weed resistant to glyphosate was found. Constructing the data in this way, the dependent variable is essentially the collection of the lifespans of each state ending when resistance occurs.

The second source of data is the USDA ERS Agricultural Resource Management Survey (ARMS), which gives estimates of the adoption rates of weed management practices of farmers in the United States. In this case, ARMS data may be separated by state and year. So we are able to match each year of the survey and the estimates of management behavior with the resistance status given by the constructed dependent variable. The years that this data span from 1996 to 2010 for corn. The earliest state to have glyphosate resistant weeds was Missouri in 2002.

The variables collected from this data source are: field scouted for weeds, number of treatments with herbicide, treatment rate with herbicide, burn down herbicide used, tilling, chopping, mowing, burning to control pests, clean equipment to reduce spread of pests, alternate pesticides to prevent pest resistance, adjust row spacing/plant density for pest control and use of a phosphinic acid herbicide (i.e. glyphosate). These are the potential independent variables which may increase or decrease the number of years before a state experiences glyphosate-resistant weeds.

One major limitation of this data set is that data were not collected in every year after 2001. The years surveyed for corn are: 1996-2001, 2005, and 2010. Instead of deleting the missing observations, the years for which there was no survey were filled in with values along the line that connects the nearest non-missing data points (i.e. through linear interpolation). For example, the years 2006-2009 would be filled in by calculating the estimate on the line connecting the 2005 and 2010 estimates. A visual example is given below.

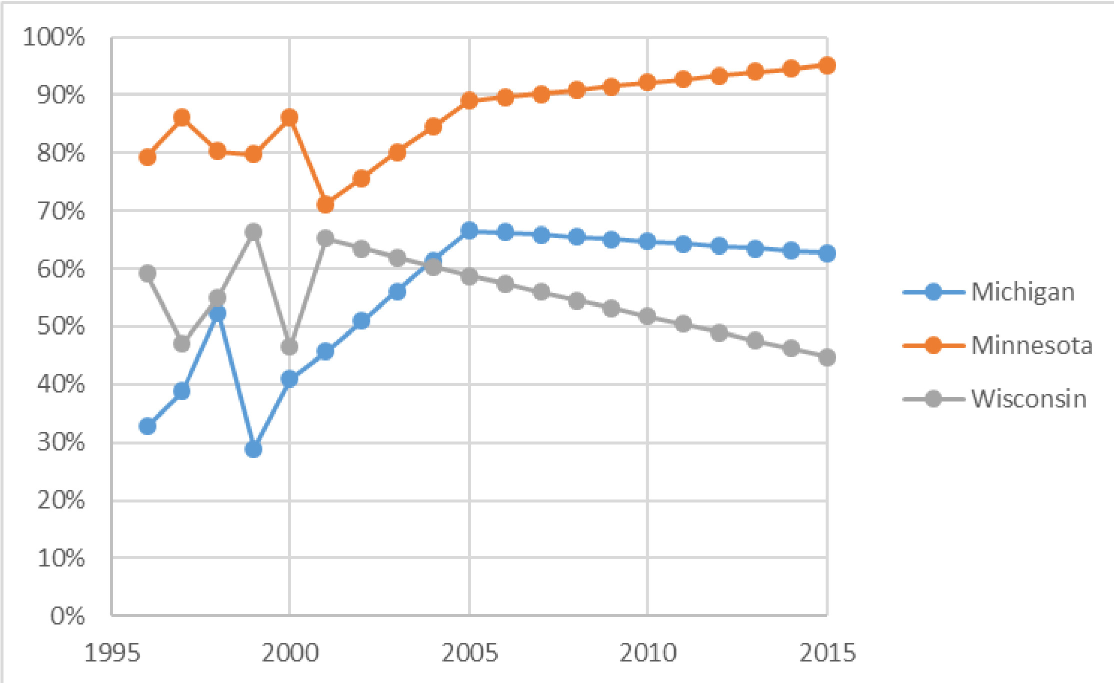
Figure 8.1: Post-emergence weed control before interpolation



Source: USDA, ARMS

Here is the state-level data for the Lake States on adoption rates of post-emergence weed control. The first thing to notice is that there is no available data after 2010. Second, there are other years which are missing data, which in this case are 2002-2004 and 2006-2009. So these missing values are filled in by plotting along the already existing lines connecting the non-missing data points. The same line graph above can be seen below with the missing values filled in.

Figure 8.2: Post-emergence weed control after interpolation



Source: USDA, ARMS

When filling in the values for years 2011-2015, the slope of the line between the previous two non-missing values is used to extend that line for the remaining years. In the case above, the line connecting 2005 to 2010 is continued to the right side to fill in for the remaining five years.

Despite the fact that this method of filling in missing observations leads to many filled in data points (at least 12 out of 20 for each state), not as many of those filled in data points are included in the final dataset used for regressions. The reason for this is that the data for a particular state stops once the first year of resistance is reached. For example, if a particular state had the first glyphosate resistant weed in 2004. Then none of the resistance management data after 2004 is included for the model. Thus, not as much filled in data is actually used when estimating the model as was calculated.

CHAPTER NINE

HAZARD MODEL METHOD

To determine which farming behaviors impact the speed at which resistance occurs, the following model is used:

$$P_{st} = \frac{1}{1 + \exp(-(a + t\beta_0 + h(X'_{st}\beta) + \varepsilon))}$$

Where P is the probability of resistance occurring, X is the vector of independent variables which may speed up or slow down resistance, β is a vector of regression coefficients, and ε is the error term. Beck et al. (1998) provide evidence that this simple logit model with a time trend is a close discrete approximation of a Cox proportional hazard model.

CHAPTER TEN

HAZARD MODEL RESULTS

The first set of regressions have all the time-varying variables lagged by one year. Only the results for corn are presented here. This is because there are no data on weed management practices for cotton or soybeans more recent than 2007. There are also fewer states in the surveyed years that have data for cotton and soybeans. We focus on three particular resistance management practices. These are: percent of acres applied with pre-emergence herbicides, percent of acres cultivated for weed control, and percent of herbicide treatments that are phosphinic acid. Because more attention needs to be paid to these variables, parsimonious models are included for those three variable as well as a full model.

Table 10.1: 1 year lag estimation results

	Model 1		Model 2		Model 3		Model 4	
	Estimate	Std. Error	Estimate	Std. Error	Estimate	Std. Error	Estimate	Std. Error
Intercept	-3.66***	1.32	-2.10**	0.87	-3.71***	0.74	-12.37*	7.02
Time	0.07	0.08	-0.01	0.09	-0.03	0.10	-0.05	0.24
Pre-emergence weed control	0.01	0.02					0.12**	0.06
Cultivated for weed control			-0.04	0.03			-0.09**	0.04
Phosphinic Acid					0.045**	0.02	0.30***	0.11
Field scouted for weeds							-0.05	0.06
Number of treatments							2.74	1.72
Treatment rate							-3.03	2.00
Burn down herbicide used							0.001	0.03
Post emergence weed control							-0.07	0.05
Tilling, chopping, mowing, burning to control pests							0.04	0.03
Clean equipment to reduce spread of pests							-0.01	0.05
Alternate pesticides to prevent pest resistance							0.13*	0.08
Adjust row spacing/plant density for pest control							-0.03	0.06
Sample Size	183		183		183		155	
Pseudo R Square	0.0057		0.0221		0.0267		0.1646	

Note: * ,** and *** denote statistical significance at the 10%, 5% and 1% levels respectively
All non-time independent variables are lagged 1 year

Here there is no significance for the variables of interest in the first two simple models. In model 3, the phosphinic acid coefficient is positive and statistically significant. This means that using more phosphinic acid increases the probability that a state will get resistance. In the full model all three of the focus variables are significant, however the pre-emergence weed control variable does not have the expected sign.

The same models can be estimated with a change in how the lag for the independent variables is calculated. For these models, each independent variable data point is the average of the previous three years of data.

Table 10.2: 3 year average estimation results

	Model 1		Model 2		Model 3		Model 4	
	Estimate	Std. Error	Estimate	Std. Error	Estimate	Std. Error	Estimate	Std. Error
Intercept	-3.22**	1.3102	-2.11**	0.87	-3.55***	0.70	-10.51	6.47
Time	0.0701	0.0775	-0.003	0.09	-0.06	0.11	-0.13	0.22
Pre-emergence weed control	0.00199	0.02					0.12*	0.07
Cultivated for weed control			-0.03	0.02			-0.08**	0.03
Phosphinic Acid					0.05**	0.02	0.28***	0.10
Field scouted for weeds							-0.03	0.06
Number of treatments							1.84	1.59
Treatment rate							-3.36*	1.86
Burn down herbicide used							0.011	0.03
Post emergence weed control							-0.06	0.05
Tilling, chopping, mowing, burning to control pests							0.05	0.04
Clean equipment to reduce spread of pests							-0.02	0.05
Alternate pesticides to prevent pest resistance							0.12*	0.07
Adjust row spacing/plant density for pest control							-0.05	0.08
Sample Size	183		183		183		155	
Pseudo R Square	0.0044		0.0195		0.0281		0.1547	

Note: * ,** and *** denote statistical significance at the 10%, 5% and 1% levels respectively
All non-time independent variables are an average of the previous 3 years

These results are similar to those using the 1-year lag data. In the simple models, only phosphinic acid is positive and statistically significant. In the full model it is the case again that all three focus variables are significant but pre-emergence weed control is not the expected sign.

There is one potential issue in the way that data was filled in. Because the last year of real data was 2010, we can have more confidence in the accuracy of filled in data points that are for years in between non-filled years. The issue could come with the fact that post 2010 data is extrapolated using the 2005 and 2010 data. Thus the last set of results uses none of the 2011-2015 data. However, to minimize the amount of data points lost, each variable in the following estimations is lagged 3 years. The results, as will be seen, are similar to the previous two sets of results.

Table 10.3: 3 year lag estimation results – no estrapolation

	Model 1		Model 2		Model 3		Model 4	
	Estimate	Std. Error	Estimate	Std. Error	Estimate	Std. Error	Estimate	Std. Error
Intercept	-3.254**	1.29	-2.635***	0.97	-3.708***	0.75	-1.61	5.10
Time	0.15	0.09	0.09	0.11	0.02	0.13	-0.05	0.21
Pre-emergence weed control	-0.004	0.02					0.01	0.07
Cultivated for weed control			-0.02	0.02			-0.06**	0.03
Phosphinic Acid					0.0488*	0.03	0.11	0.09
Field scouted for weeds							0.03	0.05
Number of treatments							-0.52	1.51
Treatment rate							-1.34	1.34
Burn down herbicide used							0.023	0.03
Post emergence weed control							-0.01	0.05
Tilling, chopping, mowing, burning to control pests							0.03	0.05
Clean equipment to reduce spread of pests							-0.06	0.04
Alternate pesticides to prevent pest resistance							0.03	0.06
Adjust row spacing/plant density for pest control							-0.09	0.10
Sample Size	167		167		167		142	
Pseudo R Square	0.0168		0.0262		0.0354		0.1269	

Note: * ,** and *** denote statistical significance at the 10%, 5% and 1% levels respectively
All non-time independent variables are lagged 3 years

From these sets of results, it seems consistent that a key to the amount of time before resistance occurs is the use of phosphinic acid. In almost every case, the models indicated that the use of phosphinic acid increased the probability that a state got resistance. This is consistent with what the literature says and is also intuitive.

CHAPTER ELEVEN

CONCLUSION

It is important to focus on what conclusions these results lead to and what contributions to the literature of herbicide resistant weeds they have made. In the first part of this study, the question of owner and renter behavior was investigated. The results of this investigation showed no significant difference in the management behavior for owners and renters. This result goes against what many in the resistance management field have thought. Because of that, this finding is valuable in that there is no challenge where there was thought to be one. This knowledge would also help in potentially saving the time and money that may be spent on trying to get specifically renters to adopt management practices.

In the second part of this study, we investigated what management behaviors would affect the speed at which resistance emerges at a state level. From the results of this analysis we found evidence that increased use of glyphosate increased the probability that a particular state would get resistance over time. This result may seem obvious and expected, but it is significant to note that the glyphosate variable was consistently positive and significant while the variables for other management practices were not. This result would emphasize the importance of glyphosate use as basically being by far the most important factor to consider when managing resistance. The implication for policy would then be to try to reduce overreliance on glyphosate.

One last thing to mention that was learned during this study concerns the availability of the ARMS data. As was discussed earlier, the most recent data for corn is from 2010. The most recent data for Cotton and Soybeans in even a few years older. This along with the fact that there are gaps of up to five years in between the existing data points forced the interpolation of much of the data. If the topic of herbicide resistant weeds is an important one to the USDA, then it would be beneficial if the survey were conducted more frequently for each crop as was done in the late 1990s.

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