Adoption of Best Management Practices to Control Weed Resistance By Cotton, Corn, and Soybean Growers

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Abstract

This study examined adoption of ten best management practices (BMPs) to control weed resistance to herbicides. Using data from a survey of 1,205 U.S. cotton, corn, and soybean growers, count data models were estimated to explain the total number of practices frequently adopted. Ordered probit regressions were used to explain the frequency of individual BMP adoption. Growers practicing a greater number of BMPs frequently (a) had more education, but less farming experience; (b) grew cotton, (c) expected higher yields relative to the county average; and (d) farmed in counties with a lower coefficient of variation (CV) for yield of their primary crop. Yield expectations and variability were significant predictors of the frequency of adoption of individual BMPs. Most growers frequently adopted the same seven BMPs. Extension efforts may be more effective if they target a minority of growers and the three practices with low adoption rates. Counties with a high yield CV would be areas to look for low BMP adoption.

Keywords: weed, herbicide, resistance management, corn, cotton, soybeans, adoption

JEL codes: Q12, Q16

Introduction

In 2008, agricultural producers planted more than 80% of U.S. cotton and corn acreage and more than 90% of soybean acreage to transgenic glyphosate-tolerant, Roundup Ready® seed varieties (USDA, AMS; USDA, NASS). Many studies report significant pecuniary and non-pecuniary benefits to growers from using glyphosate-tolerant varieties (Gianessi, 2008; Marra, Pardey, and Alston, 2002; Marra and Piggott, 2006; Mensah, 2007; Piggott and Marra, 2008). The evolution of glyphosate-resistant weeds, however, threatens the sustainability of these benefits.

Commodity groups, extension specialists, and Monsanto have recommended that growers adopt various best management practices (BMPs) to prevent or delay the spread of glyphosate-resistant weeds (Steckel, Hayes and Rhodes, 2004; Burgos, et al., 2006; Stewart, 2008; Culpepper, York, and Kichler 2008; Monsanto 2009a, 2009b). This study examines the frequency of grower adoption of ten different best management practice (BMPs) to prevent or delay weed resistance. It also examines which factors encourage or discourage frequent adoption of these BMPs.

Data

Data were collected via a telephone survey conducted by Marketing Horizons for Monsanto in November-December of 2007. The survey was designed to be a random, representative sample of corn, cotton, and soybean growers from the Great Plains, eastward. Data collection was restricted to farms with 250 or more acres of the targeted crop. Responses were obtained from 401 cotton growers, 402 corn growers and 402 soybean growers. While growers were "targeted" to respond to questions about a particular crop, they often also produced other crops. For example, many cotton growers asked detailed questions about cotton production also grew corn or soybeans.

The survey included four sections. The first asked questions about operator and farm characteristics. These included operator education and experience, acres operated, percentage of operated land owned, acres of different crops grown, acreage planted with herbicide tolerant crops, crop rotation practices, and extent of livestock production. The second section asked growers about their current weed management; adoption of weed resistance best management practices (BMPs); herbicides and/or tillage used for pre-plant, pre-emergent and post-emergent weed control; and timing and frequency of post-emergent weed management. The third section asked growers their attitudes regarding various weed management concerns such as crop yield, crop yield risk, crop price, crop price risk, herbicide costs, seed costs, overhead costs, labor and management time, crop safety, operator and worker safety, environmental safety, erosion control, and convenience. The fourth section asked growers about the cost of their weed management program and the value of the benefits they derived using a Roundup Ready® weed management program.

The potential for pests or weeds to develop tolerance or resistance to pest management strategies that focus on a single mode of action is well established in the literature (Carlson and Wetzstein, 1993; Holt and Lebaron, 1990; Powles and Shaner, 2001; Shaner, 1995. However, strategies for reducing the risk of pest tolerance or resistance are also well-documented (Nalewaja, 1999; Gressel and Segel, 1990; Mueller et al., 2005; Prather et al., 2000; Steckel, Hayes and Rhodes, 2004; Burgos, et al., 2006; Stewart, 2008; Culpepper, York, and Kichler 2008; Monsanto 2009a, 2009b). For this study, weed resistance practices were categorized into ten separate BMPs:

1. Scouting fields before herbicide applications
2. Scouting fields after herbicide applications
3. Start with a clean field, using either a burndown herbicide application or tillage
4. Controlling weeds early when they are relatively small
5. Controlling weed escapes and preventing weeds from setting seeds
6. Cleaning equipment before moving from field to field to minimize spread of weed seed
7. Using new commercial seed as free from weed seed as possible
8. Using multiple herbicides with different modes of action
9. Using tillage to supplement herbicide applications
10. Using the recommended application rate from the herbicide label

Growers could choose among five responses when asked how frequently they adopted a BMP, (1) always, (2) often, (3) sometimes, (4) rarely, and (5) never. (Growers could respond, “Don’t know”, but these accounted for 0.3% of responses). Six BMPs were always practiced by a majority of growers (Table 1). There were three BMPs, however, that a significant number of growers never practiced. These included cleaning equipment before moving between fields (24%), rotating herbicide mode of action (12%), and using supplemental tillage (26%).

Table 1. Frequency of Weed Resistance Best Management Practice (BMP) Adoption (percent of respondents practicing)

BMP	Always	Often	Sometimes	Rarely	Never
Scout before	57%	26%	11%	3%	2%
Scout after	51%	29%	15%	2%	1%
Clean field	60%	14%	13%	5%	8%
Control early	54%	35%	9%	1%	0%
Control escapes	45%	34%	15%	4%	2%
Clean equipment	15%	11%	20%	22%	31%
New seed	87%	7%	3%	1%	2%
Different modes	18%	21%	33%	15%	13%
Supplemental tillage	11%	10%	26%	21%	32%
Use label rate	74%	19%	4%	1%	0%

Table 2. Frequency of Weed Resistance BMP Adoption (percent of respondents)

BMP	Often or Always	Sometimes	Rarely or Never
Scout before	83%	11%	5%
Scout after	81%	15%	4%
Clean field	75%	13%	12%
Control early	89%	9%	2%
Control escapes	79%	15%	6%
Clean equipment	25%	20%	54%
New seed	94%	3%	2%
Different modes	39%	33%	28%
Supplemental tillage	21%	26%	53%
Use label rate	93%	4%	1%

Table 2 combines the share of BMPs practiced often or always, then rarely or never for the same data. There are seven practices that 80% of cotton growers practice frequently (always or often): use new seed (91%), follow label rate (94%), start with a clean field (80%), scout before (87%), scout after (84%), control weeds early (92%), and control weed escapes (82%) (Table 2). Again, one can see that the remaining three BMPs – rotating modes of action, cleaning equipment, and supplemental tillage – were practiced less frequently (Table 2).

Figure 1a. Percent of Corn Growers Adopting BMPs Often or Always

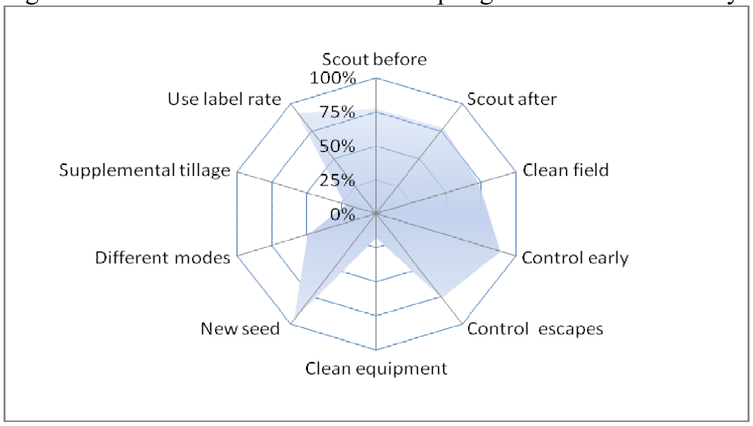


Figure 1b. Percent of Soybean Growers Adopting BMPs Often or Always

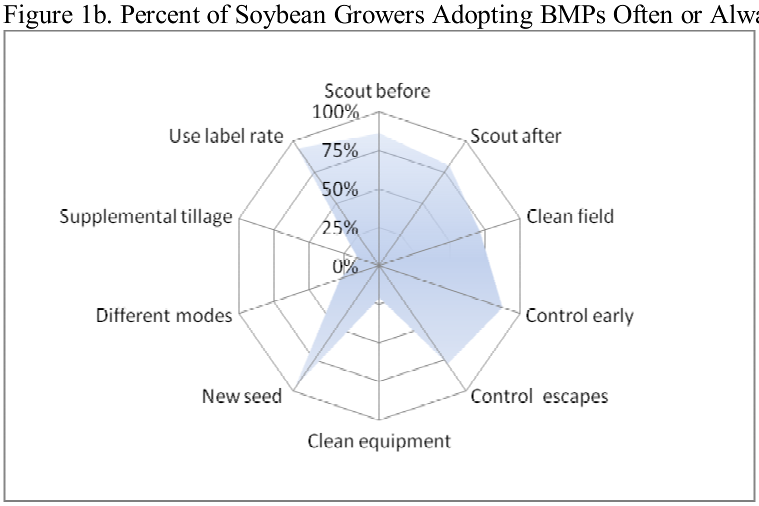
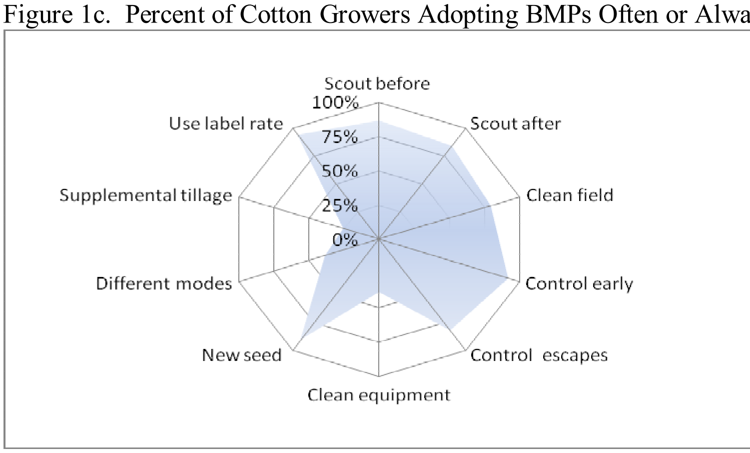


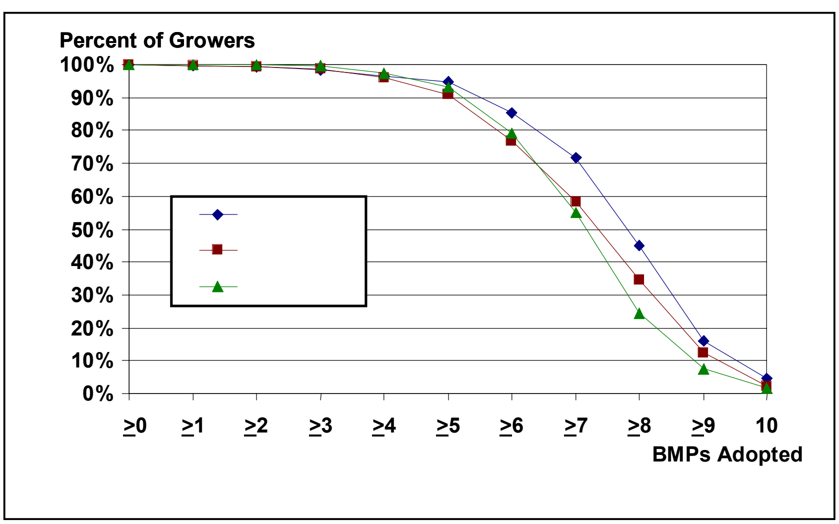
Figure 1c. Percent of Cotton Growers Adopting BMPs Often or Always



Adoption patterns were remarkably similar across producer groups. Seven of the BMPs were practiced by 71% or more of cotton, corn, or soybean producers (Figures 1a, 1b, 1c). Moreover, these were the same seven practices. All three of the producer groups rotated herbicides by mode of action, cleaned equipment, or practiced supplemental tillage much less frequently. Less than half of any of these producers practiced these three BMPs always or often. More corn producers used multiple herbicides with different modes of action often or always (49%) than either soybean (28%) or cotton growers (38%).

Cotton growers were more likely to practice more BMPs often or always than were corn or soybean growers (Figure 2). More than 70% of cotton growers practice seven or more BMPs often or always, compared to 58% of corn producers and 55% of soybean producers. About 45% of cotton growers practiced eight or more BMPs often or always compared to 35% for corn growers and 24% for soybean growers. About 95% of cotton growers always or often adopted 5 or more BMPs.

Figure 2. Percentage of growers often or always adopting BMPs by total number of BMPs adopted and targeted crop



Methods

Data concerning BMP adoption was analyzed in two ways. First, multivariate count data analysis was used to identify which factors explained the total number of BMPs a grower adopted frequently (often or always). For example, which factors help predict whether a grower will adopt eight practices frequently as opposed to seven? Next, multivariate ordered probit regressions were estimated to identify factors that help explain how frequently a grower practiced a particular BMP.

For the multivariate regression analyses, in addition to the Marketing Horizons survey data, county-specific variables were created using data from the USDA, National Agricultural Statistics Service (NASS). These included the coefficient of variation (CV) of county crop yields of the targeted crop. CV is the standard deviation of yields divided by the mean of yields over ten years. The yield CV was included to test the hypothesis that growers in counties with greater yield risk had different patterns of BMP adoption. Growers were asked what they expected their target crop yields would be. An index was created that was the ratio of growers' expected yields to their counties' average yields. This variable was included to test the hypothesis that growers with higher than average county yields (perhaps better managers or growers farming under conditions that are more favorable) were more likely to adopt BMPs more frequently.

Multivariate count data regressions were estimated to identify factors determining the total number of BMPs growers adopt often or always. The number of BMPs a grower adopts often or always can only be an integer from 0, 1, 2, up to 10. This means Poisson (or other count data) regressions are more appropriate than standard linear regression (Greene, 1997). A Poisson regression assumes that the mean and variance of the dependent variable are equal. This assumption can overestimate the statistical significance of regression parameter estimates when there is over-dispersion (variance greater than the mean) or underestimate their statistical significance when there is under-dispersion (variance less than the mean). However, estimation here followed McCullagh and Nelder who fit a Poisson regression that relaxes this restriction. McCullagh and Nelder use the Pearson chi-square method to estimate a scale parameter s, such that $s = 1$ if the mean and variance are equal, $s > 1$ if the variance exceeds the mean (over-dispersion) and $s < 1$ if the variance is less than the mean (under-dispersion). We also estimate a generalized negative binomial regression as an alternative to a Poisson regression because it also allows for separate estimation of mean and variance (Greene, 1997; Cameron and Trivedi, 1998).

Next, ordered probit regressions were estimated separately for each of the ten BMPs. When asked how frequently they adopted a given BMP, respondents could answer: 1 – Always, 2 – Often, 3 – Sometimes, 4 – Rarely, or 5 – Never. In addition, respondents could answer, "Don't know" but few responded this way, so we deleted these few observations from the regression analysis.

The following explanatory variables were obtained directly from the Marketing Horizons survey, (1) dummy variables for target crop grown and whether a grower sold livestock; (2) years of grower education and farming experience; (3) total crop acres and percent of cropland owned; (4) the percentage of target crop planted to Roundup Ready seed varieties in the previous year; (5) percent of herbicide applications carried out by a custom applicator; (6) a Herfindahl index based on the proportion of the crop acreage planted to corn, cotton, soybean, and other crops, which increases as a grower becomes more specialized; and (7) a dummy variable indicating that the grower listed weed resistance as a concern in an open-ended question about weed management concerns; growers were not asked directly if resistance was a concern. As noted above, two variables were constructed by combining survey and NASS data (1) grower expected yield as a percent of county average yield; and (2) the coefficient of variation of target crop yield in the grower's county. Finally, proprietary data obtained from Monsanto was used to include a dummy variable indicating weed resistance to herbicides has been reported in a grower's county and to include the percentage of counties in a grower's crop reporting district reporting weed resistance.

Results – Count Data Analysis

Table 3 reports results of count data regressions where the dependent variable is the total number of weed BMPs that a grower reported using either often or always. Table 3 reports results for generalized Poisson and negative binomial regressions with and without state fixed effects. The Poisson and negative binomial specifications yield similar results. Results from both models suggest that there is under-dispersion. Based on the likelihood statistics, we can reject the hypothesis of no state-level effects. However, only three states appeared to have statistically significant effects. The default state is Iowa and the regression coefficients for Illinois, Indiana, and Kansas were all positive and significant. This suggests that, compared to Iowa, growers in these states tend to practice more BMPs often or always, while growers in other states tend to practice about the same number of weed BMPs as Iowa growers.

A number of variables were significant across all specifications. The number of BMPs adopted:

- increased with a grower's level of education
- increased for growers with expected yields greater than the county average yield
- was lower in counties with more variable yields (measured by the county yield CV)
- was lower in crop reporting districts reporting more resistance problems.

Table 3. Count data regression results for the number of weed BMPs adopted often or always								
	---------- State Effects ----------				---------- No State Effects ----------			
	Poisson		Negative Binomial		Poisson		Negative Binomial	
Variable	Coefficient	Signif.	Coefficient	Signif.	Coefficient	Signif.	Coefficient	Signif.
Intercept	**1.798**	**0.000**	**1.797**	**0.000**	**1.797**	**0.000**	**1.796**	**0.000**
Soybean	-0.009	0.64	-0.01	0.623	-0.016	0.393	-0.015	0.396
Cotton	*0.080*	*0.100*	0.079	0.111	**0.074**	**0.002**	**0.073**	**0.003**
Raise Livestock	-0.002	0.913	-0.002	0.89	-0.006	0.686	-0.006	0.696
Resist Concern	0.005	0.756	0.006	0.704	0.006	0.69	0.006	0.667
Cnty Weed Rst.	0.047	0.172	0.048	0.169	0.050	0.142	0.050	0.147
Education	**0.011**	**0.01**	**0.011**	**0.01**	**0.012**	**0.003**	**0.012**	**0.003**
Years farming	*-0.001*	*0.059*	*-0.001*	*0.058*	-0.000	0.143	-0.000	0.15
Crop acres	0.00001	0.148	0.00001	0.134	*0.00001*	*0.085*	*0.00001*	*0.084*
% land owned	0.000	0.304	0.000	0.27	0.000	0.252	0.000	0.239
RR acres	0.000	0.53	0.000	0.522	0.000	0.532	0.000	0.514
Yield diff	**0.0000**	**0.037**	**0.0000**	**0.035**	*0.0000*	*0.054*	**0.0000**	**0.048**
Yield CV	**-0.358**	**0.006**	**-0.366**	**0.006**	**-0.314**	**0.007**	**-0.319**	**0.007**
Herfindahl	0.074	0.124	0.073	0.135	0.056	0.22	0.056	0.229
% Custom Ap.	0.000	0.489	0.000	0.519	0.000	0.580	0.000	0.588
CRD Weed Rst	**-0.002**	**0.016**	**-0.002**	**0.015**	*-0.001*	*0.053*	*-0.001*	*0.057*
IL*	**0.057**	**0.040**	**0.058**	**0.038**				
IN	**0.078**	**0.042**	**0.078**	**0.043**				
KS	**0.179**	**0.001**	**0.182**	**0.001**				
s (Scale)	0.332		0.043		0.335		0.043	
Likelihood Ratio Test Statistic	91.302	0.000	90.689	0.000	61.875	0.000	61.168	0.000
d.f.	32		32		15		15	

* Only significant state effects reported. Boldface denotes significance at 5% level.
Italics denotes significant at 10% level

In regressions with state effects, the number of years of farming experience was negatively associated with the number of BMPs adopted, suggesting that younger farmers tend to adopt more BMPs. Separate models estimated by target crop did not perform well and so are not reported here—for the separate corn and soybean models, the null hypothesis of all zero coefficients (except for the constant) could not be rejected at the 5% level of significance.

In sum, younger, more educated growers who expect to obtain higher than average yields practiced a greater number of BMPs often or always. Growers in regions with greater percentage yield variability practiced fewer BMPs. The relationship between local resistance episodes and grower BMP adoption was mixed. Growers in crop reporting districts with more counties reporting resistance practiced fewer BMPs. Yet, growers farming in counties reporting resistance, tended to adopt more BMPs. This latter relationship was not significant, however.

Cotton growers and larger operators appeared to adopt more BMPs, but this affect was attenuated by including state-specific effects. The attenuating effect of state variables may come from the fact that there was no overlap of growers in surveyed cotton and corn states and only a small overlap between surveyed cotton and soybean growers. Hence, there is a relatively high correlation between the state dummy variables and the cotton grower dummy variable.

Ordered Probit Results

Table 4 reports results for separate ordered probit regression for each of the ten BMPs results. The dependent variable is the frequency of practicing a given BMP. The dependent variable = 1 if always, = 2 if often, = 3 if sometimes, = 4 if rarely, and = 5 if never. Because the dependent variable increases in value as adoption becomes rare, a negative regression coefficient means that the explanatory variable *increases* the frequency of BMP use.

Table 5 summarizes results of the ordered probit regressions by explanatory variable. It reports the variables that had significant effects (at the 10% level) on adoption of each weed BMP. Results are summarized with and without state effects, with the data pooled across all three crops. A plus sign (+) after a variable indicates that increasing the variable increases adoption of the BMP, while a minus sign (–) indicates that increasing the variable decreases adoption of the BMP. For example, "Scout after (+)" for "Years of Education" means more grower education increased the probability of scouting after herbicide applications more frequently. These effects are opposite in sign to the respective coefficients in Table 4 because the dependent variables were defined to have larger values for less frequent (see note, Table 4).

Table 4. Ordered probit regressions for frequency of BMP adoption with state effects

Dependent Variable: = 1 if always, = 2 if often, = 3 if sometimes, = 4 if rarely, = 5 if never

Note: Because the dependent variable increases in value as adoption becomes rare, a negative regression coefficient means that the explanatory variable increases the frequency of BMP use.

	Scout Before		Scout After		Clean Field		Control Early		Control Escapes	
	Estimate	Sig.	Estimate	Sig.	Estimate	Sig.	Estimate	Sig.	Estimate	Sig.
Education	-0.019	0.393	-0.047	0.027	-0.016	0.467	-0.030	0.167	0.011	0.584
Years Farm	0.004	0.241	0.000	0.954	-0.001	0.694	-0.009	0.004	0.005	0.090
Crop Acres	0.000	0.273	0.000	0.271	0.000	0.357	0.000	0.676	0.000	0.371
% owned	-0.002	0.058	-0.002	0.115	0.002	0.066	0.001	0.661	0.001	0.499
RR acres	-0.001	0.299	-0.001	0.332	0.000	0.746	0.000	0.493	-0.001	0.602
Yield Diff	-0.002	0.065	-0.002	0.089	-0.001	0.307	-0.001	0.256	-0.004	0.001
Yield CV	1.249	0.078	1.765	0.010	-0.085	0.905	0.357	0.606	2.024	0.003
Herfindahl	0.253	0.326	-0.003	0.990	0.287	0.280	-0.163	0.530	-0.167	0.500
% Custom Ap	0.001	0.206	0.002	0.017	0.002	0.100	0.001	0.330	0.002	0.016
CRD Weed Rst	0.000	0.965	0.002	0.624	0.006	0.233	0.008	0.084	0.011	0.012
Soybean	-0.113	0.259	-0.016	0.868	0.127	0.214	0.140	0.167	-0.121	0.216
Cotton	-0.605	0.027	-0.207	0.419	-0.298	0.307	0.274	0.303	-0.203	0.423
Raise Lstock	0.033	0.682	0.187	0.016	-0.022	0.788	0.093	0.244	0.078	0.310
Resist Concern	-0.017	0.829	0.070	0.351	-0.102	0.194	-0.029	0.709	0.050	0.502
Cnty Weed Rst	0.041	0.817	0.020	0.910	-0.003	0.989	0.009	0.963	-0.140	0.415
AL	0.144	0.726	0.105	0.781	-0.316	0.497	-0.239	0.543	-0.358	0.379
AR	-0.232	0.566	-0.443	0.257	-0.414	0.335	-1.327	0.002	-0.479	0.217
GA	0.582	0.098	-0.185	0.587	-0.029	0.939	-0.589	0.097	0.541	0.104
IL	0.033	0.818	-0.151	0.288	-0.155	0.305	-0.003	0.983	0.325	0.023
IN	0.104	0.599	-0.171	0.387	-0.322	0.135	-0.228	0.267	0.171	0.392
KS	-0.789	0.018	-0.602	0.048	-0.807	0.032	0.150	0.600	-0.139	0.632
LA/MS	0.027	0.949	-0.387	0.335	-0.185	0.683	-1.127	0.012	0.247	0.518
MN	-0.139	0.397	-0.116	0.467	0.360	0.025	-0.050	0.761	0.387	0.016
MO	0.015	0.934	-0.182	0.309	-0.365	0.067	-0.299	0.110	0.249	0.167
NE	-0.046	0.787	-0.183	0.273	0.274	0.104	0.194	0.243	0.456	0.006
NC/SC/VA	0.243	0.503	-0.826	0.026	-0.479	0.261	-0.812	0.026	0.508	0.128
ND	-0.210	0.447	-0.043	0.867	0.144	0.582	0.240	0.345	0.523	0.044
OH	-0.010	0.966	-0.037	0.866	0.037	0.875	-0.189	0.412	0.368	0.093
SD	0.292	0.137	0.205	0.287	0.407	0.039	-0.422	0.046	0.189	0.349
TN	0.397	0.417	-0.060	0.899	-1.236	0.059	-1.287	0.013	-0.369	0.438
TX/OK	0.223	0.442	-0.175	0.517	0.438	0.152	-0.198	0.475	0.333	0.216
WI	0.281	0.319	0.016	0.954	0.544	0.057	-0.527	0.108	0.340	0.235
LogL	2171.693	0.008	2233.117	0.000	2250.851	0.000	1930.829	0.005	2328.532	0.000

Likelihood Ratio significance of test of null hypothesis that all regression coefficients of explanatory variables = 0.

Table 4 (cont.). Ordered probit regressions for frequency of BMP adoption with state effects

Dependent Variable: = 1 if always, = 2 if often, = 3 if sometimes, = 4 if rarely, = 5 if never

Note: Because the dependent variable increase in value as adoption becomes rare, a negative regression coefficient means that the explanatory variable increases the frequency of BMP use.

	Clean Equipment		New Seed		Different Modes		Suppl. Tillage		Label Rate	
	Estimate	Sig.	Estimate	Sig.	Estimate	Sig.	Estimate	Sig.	Estimate	Sig.
Education	0.035	0.085	-0.050	0.113	-0.043	0.029	0.038	0.062	-0.019	0.459
Years Farm	0.001	0.646	-0.002	0.730	0.007	0.017	0.007	0.018	-0.005	0.243
Crop Acres	0.000	0.862	0.000	0.386	0.000	0.449	0.000	0.279	0.000	0.648
% owned	0.001	0.341	0.000	0.827	0.001	0.483	0.001	0.239	-0.002	0.148
RR acres	0.002	0.255	-0.007	0.000	0.003	0.059	0.002	0.117	-0.003	0.063
Yield Diff	-0.001	0.438	-0.003	0.072	-0.002	0.025	0.000	0.573	0.001	0.352
Yield CV	-0.181	0.776	0.853	0.357	1.392	0.027	1.334	0.037	0.288	0.713
Herfindahl	-0.296	0.213	0.087	0.809	-0.040	0.865	-0.175	0.463	-0.271	0.383
% Custom Ap	-0.001	0.183	0.001	0.289	-0.001	0.201	0.001	0.508	-0.002	0.145
CRD Weed Rst	0.000	0.927	0.008	0.195	0.002	0.596	0.004	0.406	0.004	0.499
Soybean	-0.140	0.141	0.195	0.213	0.451	0.000	0.221	0.019	-0.039	0.740
Cotton	-0.443	0.068	-0.520	0.350	-0.142	0.545	-0.005	0.984	-0.242	0.422
Raise Lstock	0.003	0.971	-0.070	0.550	-0.135	0.064	-0.040	0.595	0.107	0.245
Resist Concern	0.192	0.007	-0.194	0.078	-0.087	0.211	0.156	0.028	0.181	0.040
Cnty Weed Rst	-0.058	0.731	-0.237	0.414	-0.421	0.012	0.232	0.182	0.029	0.895
AL	-0.262	0.470	0.663	0.342	-0.096	0.789	0.726	0.066	-0.738	0.150
AR	-0.135	0.717	-0.277	0.625	0.558	0.127	-0.715	0.059	-0.508	0.304
GA	-0.505	0.110	0.988	0.113	-0.098	0.751	-0.122	0.698	-0.038	0.922
IL	-0.034	0.805	-0.286	0.204	-0.023	0.864	-0.373	0.006	-0.173	0.283
IN	-0.400	0.034	-0.565	0.087	0.092	0.619	-0.200	0.292	-0.201	0.391
KS	-0.743	0.006	-0.444	0.404	-0.362	0.179	0.046	0.866	-0.170	0.600
LA/MS	0.178	0.621	1.113	0.088	0.027	0.938	0.303	0.409	-0.381	0.415
MN	-0.383	0.012	-0.103	0.670	0.016	0.916	-0.036	0.813	-0.398	0.036
MO	0.213	0.232	-0.760	0.033	-0.118	0.485	0.142	0.419	-0.280	0.188
NE	-0.376	0.019	-0.323	0.237	-0.061	0.700	0.103	0.520	-0.379	0.055
NC/SC/VA	0.051	0.874	0.133	0.850	-0.341	0.284	0.235	0.476	-0.792	0.077
ND	-0.740	0.002	-0.272	0.518	0.398	0.101	-0.212	0.386	-0.039	0.894
OH	-0.367	0.084	0.111	0.720	-0.181	0.390	-0.030	0.889	-0.997	0.002
SD	-0.355	0.061	0.331	0.223	0.412	0.026	-0.212	0.257	-0.048	0.828
TN	0.395	0.386	0.781	0.309	0.512	0.246	-0.120	0.795	-0.543	0.364
TX/OK	-0.575	0.024	1.110	0.047	0.456	0.067	-0.866	0.001	-0.045	0.885
WI	-0.383	0.166	-0.083	0.845	-0.567	0.044	0.315	0.256	-0.593	0.120
LogL	2962.88	0.000	904.41	0.000	2977.61	0.000	2912.70	0.000	1380.85	0.076

Likelihood Ratio significance of test of null hypothesis that all regression coefficients of explanatory variables = 0.

Table 5. Significant variables from ordered probit regressions and their effect on the frequency of adopting weed BMPs

Explanatory Variable	Ordered Probit – No State Effects		Ordered Probit – State Effects	
Targeted Soybeans	Control early (–)	Different modes (–)	Different modes (–)	Suppl. tillage (–)
Targeted Cotton	Scout before (+) Scout after (+) Suppl. tillage (+)	Clean equipment (+) New Seed (–)	Scout before (+)	Clean equipment (+)
Years of Education	Scout after (+)		Scout after (+) Different modes (+)	Clean equipment (–) Suppl. tillage (–)
Years Farming	Control early (+)	Different modes (-)	Control early (+) Control escapes (–)	Different modes (–) Suppl. tillage (–)
Total Crop Acres	Scout before (+)			
% Farmland Owned	Scout before (+)		Scout before (+)	Clean field (–)
% Roundup Ready Acres	New Seed (+) Different modes (–) Suppl. tillage (–)	Label rate (+) Clean field (–)	New Seed (+) Different modes (–)	Label rate (+)
% Yield Difference	Control escapes (+)	Different modes (+)	Scout before (+) Scout after (+)	New Seed (+) Different modes (+)
County Yield CV	Scout after (–) Different modes (–)	Control escapes (–)	Scout before (–) Scout after (–) Suppl. tillage (–)	Control escapes (–) Different modes (–)
Herfindahl Index	Clean field (–)	Suppl. tillage (+)		
% Custom Applications	Scout after (–)	Control escapes (–)	Clean field (–)	Control escapes (–)
Resistance in CRD	Control escapes (–)	Different modes (–)	Control early (–)	Control escapes (–)
Resistance in County	Different modes (+)		Different modes (+)	
Resistance Concern	Clean field (+) Clean equipment (–) New Seed (+)	Different modes (+) Suppl.tillage (–)	Clean equipment (–) New Seed (+)	Suppl. tillage (–) Label rate (–)
Raised Livestock	Scout after (–) Different modes (+)		Scout after (–)	

Growers can choose between always, often, sometimes, rarely, or never. The (+) sign means that the variable increases the probability of practicing more frequently (on this spectrum), relative to less frequently. In the count data regressions, targeted cotton producers were more likely to adopt more BMPs often or always, but including state-specific effects attenuated this cotton-grower effect. This pattern repeats itself with frequency of adoption of individual BMPs. Targeted cotton producers appear to have a higher probability of more frequent adoption of a number of individual BMPs in the ordered probits. However, once we include state effects, the statistical significance of these relationships declines. In both ordered probits, soybean producers use herbicides with different modes of action less frequently. In the count data regression, a negative association existed between being a soybean producer and the number of BMPs adopted always or often, but the association was not significant.

The probit regressions also show that growers who expect yields higher than the county average are more likely to use herbicides with different modes of action. In contrast, growers in counties with greater yield variability less frequently used herbicides with different modes of action, practiced weed scouting, and controlled weed escapes. The positive impact of expected yield and the negative impact of yield variability are consistent with the count data regressions.

A higher percentage of acreage planted to Roundup Ready seed varieties was associated with greater use of new seed and less frequent rotation of herbicides with different modes of action. Roundup Ready acreage was associated with more frequently following herbicide label rates. Growers expressing a concern about resistance in the open-ended questions used supplemental tillage and cleaned equipment less frequently, but used new commercial seed more frequently. Growers operating in a county with reports of weed resistance more frequently used herbicides with different modes of action.

Conclusions

Although cotton growers adopted BMPs somewhat more frequently, BMP adoption patterns were remarkably similar across crops. For all three crops, adoption rates of the same three BMPs were low. These were cleaning equipment, using herbicides with different modes of action, and supplemental tillage. The other seven BMPs were practiced frequently (often or always) by all three grower types.

Generalized Poisson and negative binomial regression results suggest that factors significantly and positively associated with adopting more BMPs are: (a) having more education; (b) having less experience (perhaps being younger?); (c) growing cotton; (d) expecting higher yields relative to the county average; (e) farming in counties with lower coefficient of variation for yield. In the ordered probit, farming in a county with a larger coefficient of variation of target crop yield *reduced* the probability of frequent adoption of several BMPs. In contrast, the ratio of a grower's expected yield to the county average yield *increased* the probability of frequent adoption of BMPs. These results suggest that yield risk is an important factor discouraging BMP adoption and that there may be some form of "good manager" effect at work, where growers with higher yields (or at least higher expected yields) than their neighbors tend to adopt more BMPs more frequently.

The survey data suggests that most growers are frequently adopting most BMPs. Extension efforts may thus be more effective by targeting a minority of growers (and a few practices). In particular, counties with a high coefficient of variation of crop yield would be areas to look for low BMP adoption.

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