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Restricting Pesticide Use: The Impact on Profitability by Farm Size

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Abstract

A sample of 226 cash grain farms in the Lake States-Corn Belt region are analyzed to estimate the impact of restricting pesticide use on profits. These 226 farms are classified into small, medium, and large farms according to their sale revenues. The results suggest the existence of pest management practices that could substantially reduce pesticide use without incurring economic losses. The reductions in profits associated with gradual reductions in pesticide expenditure appear to increase with farm size.

Key Words: farm pesticide use, farm size, frontier analysis, profit.

Increased pesticide use has contributed to the modernization of agriculture, which is characterized by major changes in production techniques, shifts in input use patterns, and an impressive record of productivity growth. Pesticide use in agriculture, however, has also caused rising concerns about the safety of residues in food and water, as well as other potential health and environmental risks. As a consequence, growth in pesticide use has also been accompanied by increasing regulatory pressures.

Between 1964 and 1991, pesticide use in agriculture increased from 320 million pounds of active ingredients (a.i.) to 817 million pounds of a.i. (Aspelin et al.). Corn and soybeans lead other crops, by a substantial margin, in terms of total pesticide use (table 1). Herbicides account for the bulk of pesticide use, representing over 80 percent of pesticides applied to major crops. Herbicide use on corn and soybeans grew, respectively, from 26 and 4 million pounds of a.i. in 1964 (Osteen and Szemredra) to 210 and 70 million pounds in 1991. This increase in herbicide use can be attributed to

three factors: larger crop acreage, increased shares of corn and soybean acres being treated with herbicides, and higher application rate per treated acre.

Corn acreage increased from 66 million planted acres in 1964 to 76 million acres in 1991, and soybean acreage increased from 32 to 70 million acres during the same period of time. The percentage of corn and soybean acres being treated with herbicides increased substantially prior to 1971 and has stabilized since to about 95 percent in recent years (figure 1). Between 1966 and 1991, herbicide application rate increased from 1.23 to 2.94 pounds of a.i. per treated acre of corn, and from 1.03 to 1.23 pounds of a.i. for each treated acre of soybeans.¹ Corn acres have also been treated with substantial amounts of insecticides, receiving 28 million pounds of insecticide a.i. in 1991 compared to 16 million pounds in 1964. The percentage of corn acres being treated with insecticides increased drastically from 10 percent in 1964 to 38 percent in 1976, and then declined to 30 percent in 1991. Soybeans receive very little

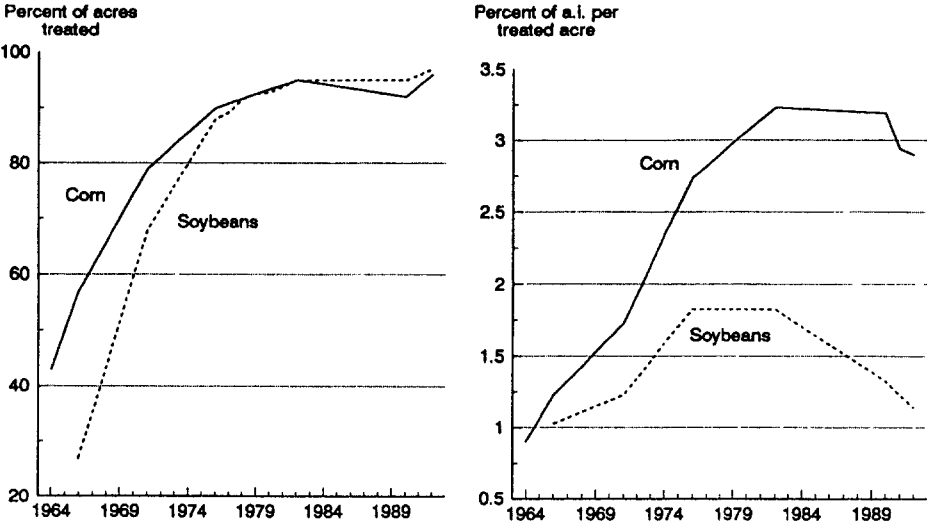
*The authors are agricultural economists with the U.S. Department of Agriculture, Economic Research Service. Helpful comments from two anonymous referees are gratefully acknowledged. The views expressed are the authors' and do not necessarily represent policies or views of the U.S. Department of Agriculture or Economic Research Service.

Table 1. Pesticide Use on Major U.S. Crops, 1991

Crops	Herbicides	Insecticides	Fungicides
----- 1,000 pounds active ingredients -----			
Row Crops:			
Corn	210,200	23,036	0
Cotton	26,032	8,159	701
Grain Sorghum	14,156	1,140	0
Peanuts	4,510	1,913	8,114
Soybeans	69,931	445	0
Total	324,829	34,693	8,815
Small Grains:			
Rice	16,092	309	426
Wheat	13,561	208	73
Total	29,653	517	499
Vegetables:			
Potatoes	2,547	3,597	3,172
Other vegetables	4,496	4,261	12,527
Total	7,043	7,858	15,699
Fruits:			
Citrus	6,331	4,145	3,750
Apples	411	3,841	4,349
Total	6,742	7,986	8,099
1991 Total	368,267	51,054	33,112

Source: USDA, ERS. *Agricultural Resources and Environmental Indicators*.
Agr. Handbook 705. December 1994.

Figure 1. Herbicide use on Corn and Soybeans



Source: USDA,ERS. *Agricultural Resources and Environmental Indicators*.
Agr. Handbook 705. December 1994.

insecticides, with only 2 percent of planted acres being treated in 1991 (USDA 1992).

As a response to such a high level of agricultural pesticide (and chemical fertilizer) use in recent years, interest in alternative approaches to food and fiber production has increased. Changes in production practices have been advocated under such *nom de plumes* as sustainable agriculture, alternative agriculture, and low-input sustainable agriculture. These unconventional production systems seek to increase reliance on non-chemical pest control to reduce, but in most cases not totally eliminate, pesticide use in agriculture. At the same time, public debates on reducing agricultural chemical use through regulation or policy changes have intensified.

Reduction of pesticide use, initiated by regulation or otherwise, will affect farm financial performance, the mix of outputs produced, and resource allocation. The impact of reducing pesticide use on farm financial performance is an important piece of information in evaluating means and strategies for reducing pesticide use. The amount by which profits decline when farmers switch to less chemical-intensive production can also be viewed as a measure of the incentive that farmers might need to adopt environmentally harmonious production technologies.

The distribution of the financial impacts of reduced pesticide use by farm size is of importance to policy makers. Many are concerned about the effect technological and policy changes will have on family farms and rural life. Accordingly, this study evaluates the consequences of reducing pesticide use on profitability of small, medium, and large cash grain farms in the Corn Belt-Lakes States production region.

Methodology

Numerous studies have been conducted to determine the costs and benefits associated with pesticide use. The literature has been annotated and reviewed (Osteen et al.; McCarl; Fox et al.). A variety of analytical methods have been applied to assess the costs associated with banning or reducing pesticide use. These are: partial budgeting (Delvo), economic surplus models (Ferguson et al.), farm-

level linear programming (Cashman, et al.), spatial equilibrium linear programming (Burton and Martin; Taylor and Frohberg), econometric simulation (Knutson et al.; Norton and Bernat; Osteen and Kuchler; Taylor et al.), and a computable general equilibrium model (Rendleman). None of the above-mentioned methods is readily equipped to assess the impacts by farm size of reducing pesticide use. In fact, this issue has received little attention in the literature.

We employ the data envelopment analysis (DEA) approach to analyze the impacts of constraining pesticide use on farming profitability. The DEA approach, as outlined in Färe et al. (1985), is a non-parametric approach requiring no assumptions about the functional form of a model. This approach also lends itself easily to applications based on data collected in a complex (multiframe, stratified) survey, which is the type of data used in this study. Standard econometric techniques can be used to analyze data from a simple random survey. Another major motivation for employing the DEA approach here is the ability to assess the impacts and the distribution of the impacts of imposing constraints, as discussed below.

DEA utilizes a linear programming (LP) framework to identify farms that are not dominated by others (i.e., efficient farms) in terms of a specific evaluation criterion. Possible criteria include output maximization, cost minimization, or profit maximization. Profit maximization is chosen in this study. A linear combination of these efficient farms establishes a frontier, which can be used to predict the maximum attainable profit for each farm when "best practices" are adopted.

To illustrate, suppose there are four farms (A, B, C, and D) being analyzed, and their input-output relationships are depicted in figure 2. Among these four farms, only farm D is technically inefficient because more output could have been produced given the input used. Farms A, B, and C are technically efficient and a linear combination of them forms a production frontier. By following the practices of farms B and C, farm D can improve its output to D' and achieve technical efficiency. Output and input prices can be used to establish the hyperplanes HH', II', and JJ', which individually show the same level of profit corresponding to

different combinations of output produced and input used. The hyperplane HH' is tangent to the production frontier at point C, indicating that farm C is not only using the optimal input mix (i.e., achieving the allocative efficiency or locating on the expansion path) but also producing the maximum-profit level of output (i.e., achieving the scale efficiency). The profit level indicated by the hyperplane is thus the maximum attainable profit for farm D. The difference between the actual and the maximum attainable profits can be decomposed into three components: technical, allocative, and scale inefficiencies.

To assess the impacts of constraining pesticide use on profit, the LP model is solved with and without a pesticide use constraint. Without the constraint, the LP solution establishes the benchmark profit frontier, whereas the constrained model generates the constrained profit frontier. A comparison of the two frontiers provides a measure

of the profit loss associated with the pesticide use constraint. For example, if the input use for farm D in figure 2 were to be limited to no more than x' , the constraint would have caused the maximum attainable profit to decline by the distance HI.

Recent applications of the above approach to agriculture-related issues include Färe et al. (1991), Whittaker and Morehart, and Fernandez-Cornejo. A brief synopsis of the LP model used is described here. Suppose there are $k = 1, \dots, K$ farms, each of which uses M inputs to produce N outputs. Both output prices $r = (r_1, \dots, r_n) \in \mathbb{R}^n_+$ and output quantities $u = (u_1, \dots, u_n) \in \mathbb{R}^n_+$ are observed. Total input expenditure, $x = (x_1, \dots, x_m) \in \mathbb{R}^m_+$ is known, but input prices and quantities are not observed (a data limitation of the study). The maximum attainable profit for a particular farm j can be obtained by solving the following linear programming model:

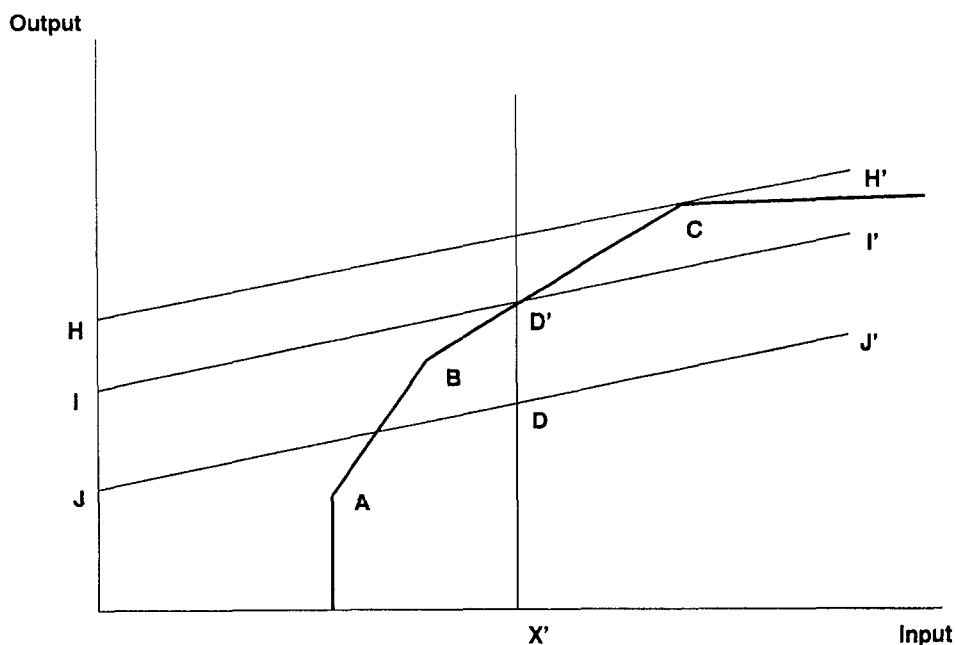
$$\begin{aligned} \pi^j(r, x_f^j) &= \max_{(u_n, x_v, z)} \sum_{n=1}^N r_n u_n - \sum_{i=1}^I x_{vi} & j = 1, \dots, K \\ \text{s.t.} \quad & \sum_{k=1}^K z^k u_n^k \geq u_n, & n = 1, \dots, N, & \text{(output)} \\ & \sum_{k=1}^K z^k x_{vi}^k \leq x_{vi}, & i = 1, \dots, I, & \text{(variable costs)} \\ & \sum_{k=1}^K z^k x_{fi}^k \leq x_{fi}, & i = I+1, \dots, M, & \text{(fixed costs)} \\ & \sum_{k=1}^K z^k = 1, & z \in \mathbb{R}^K_+. \end{aligned}$$

where π^j is total profit of the j th farm, r_n is the n th output price, u_n is the n th output quantity, x_{vi} is the i th variable input expenditure, and x_{fi} is the i th fixed input expenditure. The vector z measures input use intensity and serves to form a frontier by connecting linearly "best-practice" farms.

The objective function specifies profit (i.e., return to fixed inputs and management) as the evaluation criterion. The first set of constraints (for outputs) identify the maximum attainable outputs. The second set of constraints (for variable inputs)

determine the minimum possible variable inputs. The third set of constraints require that the linear combination of "best-practice" farms will use the amount of fixed input not exceeding the amount available to the farm in question. The last constraint (i.e., summing z to one) allows the technology to have increasing, constant, and decreasing returns to scale.

The objective function is solved for each farm with the complete data set on all farms being used to formulate the constraints. That is, the LP

Figure 2. Frontier analysis

model is solved K times, once for each farm, while the constraints compare the input/output mix for each farm with all other farms in the sample. Each LP solution generates the "best practice" input/output mix that yields the maximum profit for each farm.

To assess the impact of imposing an expenditure constraint on input j , the set of constraints for variable inputs need to be modified as:

$$\sum_{k=1}^K z^k x_{vj}^k \leq x_{vj}, \quad i = 1, \dots, I, \quad (\text{variable costs})$$

$$x_{vj} \leq E, \quad (\text{constrained variable cost})$$

where the expenditure on the j th variable input is bounded by the value E .

Data

The data come from the 1990 soybean version of the Farm Costs and Returns Survey (FCRS) conducted by the USDA. The FCRS is a multiframe, stratified survey, where the sample is drawn from stratified list and area frames. The 1990 soybean survey obtained detailed information

on the costs and returns of soybean production as well as similar, less detailed information on the production of all other commodities on the farm.

There were 826 soybean producing farms enumerated in the survey. After eliminating those farms with more than \$100 in livestock sales or with irrigation expenses, 226 cash grain farms were analyzed.² The subset of FCRS data represented 84,053 cash grain farms in the Lake States-Corn Belt production region including Illinois, Indiana, Iowa, Michigan, Minnesota, Missouri, Nebraska, Ohio, and Wisconsin. Over 90 percent of these farmers' income, on average, came from corn, soybean, and wheat production.

The 226 farms were classified into small, medium, and large farms. Small farms are defined as those with sales of less than \$40,000, a threshold that commonly distinguishes commercial from noncommercial farms. Medium-size farms had sales of at least \$40,000 but below \$150,000. Farms with sales of \$150,000 or more are classified as large farms. The numbers of small, medium, and large farms are 72, 78, and 76, respectively. The median soybean and corn outputs are, respectively, 1,426 and 3,528 bushels for small farms, 8,025 and 22,738 bushels for medium farms, and 16,050 and 61,320 bushels for large farms.

Table 2. Sample Characteristics (Median Values) of Farms in the 1990 FCRS Soybean Survey

Variable	Farm Size		
	Small	Medium	Large
Soybean Acreage (acres/farm)	39.50	207.50	416.50 ^b
Corn Acreage (acres/farm)	32.50	187.50	648.50
Labor Expenses (\$/acre)	125.84	86.52	54.44
Fertilizer Expenses (\$/acre)	30.40	36.98	33.09
Seed Expenses (\$/acre)	19.48	20.10	20.77
Pesticide Expenses (\$/acre)	21.39	29.88	25.60
Soybean Pesticide (\$/acre)	19.28	20.12	20.51
Other Pesticide (\$/acre)	20.19	43.16	28.00
Fuel Expenses (\$/acre)	15.62	12.88	14.37
Machinery Repairs (\$/acre)	23.11	17.38	14.74
Building Repairs (\$/acre)	9.78	3.88	1.17 ^a
Tool Costs (\$/acre)	8.31	3.00	3.33
Custom Work Cost (\$/acre)	11.78	3.94	4.20 ^b
Business Expenses (\$/acre)	121.06	137.28	126.45
Number of Farms	72	78	76

^a Null hypothesis of equality rejected at 10% significance level.

^b Null hypothesis of equality rejected at 5% significance level.

Table 2 summarizes the characteristics of the sample farms with respect to their uses of fixed and variable inputs. Because the distributions of these characteristics are markedly asymmetrical, their means are no longer good representations of the "center of gravity". Consequently, median values are used.

Land is considered as a fixed input in the DEA analysis, but its allocation among crops is treated as a decision variable.³ The median soybean and corn acres planted are, respectively, 39.5 and 32.5 for small farms, 207.5 and 187.5 for medium farms, and 416.5 and 648.5 for large farms. Some of the farms planted wheat, but the majority of the sample farms did not produce any wheat (the median wheat acres are zero for all farm sizes).

Variable inputs are classified into 11 items: labor, fertilizers, seed, pesticides, fuel, machinery repairs, tools, building maintenance, transportation, custom services, and business expenses. Variable input use is measured in value terms. In estimating the maximum attainable profit for each farm, variable input use is allowed to change for all three crops. On a per acre basis, labor expenses led other variable input expenses, and labor expenses declined with farm size. The decline was statistically significant at a 5 percent level.

Pesticide expenditures are reported for five categories: insecticides; herbicides; fungicides; desiccants, defoliants, and growth regulators; and other pesticides. The median per-acre pesticide expenses for soybean production ranged from \$19.28 for small farms, to \$20.12 for medium farms, and \$20.51 for large farms. While this shows a slight increase with farm size, the differences were not statistically significant. Corn accounted for the bulk of the production of other crops, and the per-acre pesticide expenditures for other crops were greater than those for soybeans, especially among medium and large farms. In terms of pesticide expenditures for all crops, the median per-acre figures were \$21.39 for small farms, \$29.88 for medium farms, and \$25.60 for large farms. Because median values are reported, pesticide expenditures for all crops cannot be broken down arithmetically into expenditures for soybeans and other crops (mainly corn and wheat).

Results

Eight levels of constraints on per-acre pesticide expenditures are analyzed: \$6, \$10, \$14, \$18, \$22, \$26, and \$30. The impacts of pesticide expenditure constraints on profit are summarized in table 3. Corn and soybean production under various pesticide expenditure constraints are shown in table

Table 3. Profits and Pesticide Expenditures

	Per-Acre limits on pesticide expenditures (\$)						
	30	26	22	18	14	10	6
Small farms							
Profit \$/acre ^a	163.51	162.75	162.54	157.61	148.16	136.26	117.57
Incremental change \$/acre	0.0	-0.76	-0.21	-4.93	-9.45	-11.90	-18.69
Incremental change %	0.0	-0.46	-0.13	-3.03	-6.00	-8.03	-13.72
Medium farms							
Profit \$/acre ^a	181.66	182.24 ^b	181.62	168.50	153.65	138.92	123.88
Incremental change \$/acre	0.0	0.58	-0.62	-13.12	-14.85	-14.73	-15.04
Incremental change %	0.0	0.32	-0.34	-7.22	-8.81	-9.59	-9.83
Large farms							
Profit \$/acre ^a	154.23	153.21	146.50	135.88	126.04	117.71	99.31
Incremental change \$/acre	0.0	-1.02	-6.71	-10.62	-9.84	-8.33	-18.40
Incremental change %	0.0	-0.66	-4.38	-7.25	-7.24	-7.60	-15.63

^a Per-acre profits are estimated medians.^b The associated (unreported) standard deviations suggest that per-acre profits are not statistically different for the three levels of pesticide expenditures: 30, 26, and 22 dollars per acre.**Table 4.** Soybean and Corn Production under Different Pesticide Expenses

		Best-Practice Per-Acre limits on pesticide expenses (\$)			
	Actual	No Limit	22	14	6
Small Farms					
Corn (bushels)	3,528	2,358 (100)	2,358 (100)	3,468 (147)	5,069 (215)
Soybeans (bushels)	1,426	3,875 (100)	3,875 (100)	2,829 (73)	1,714 (44)
Medium Farms					
Corn (bushels)	22,738	13,444 (100)	13,497 (100)	21,337 (159)	29,205 (217)
Soybeans (bushels)	8,025	19,562 (100)	19,512 (100)	13,887 (91)	8,472 (43)
Large Farms					
Corn (bushels)	61,320	77,094 (100)	64,401 (84)	57,597 (75)	46,091 (60)
Soybeans (bushels)	16,050	25,583 (100)	53,464 (131)	22,656 (89)	12,399 (48)

Note: Numbers in the parentheses represent the percent of the production relative to the best-practice, no pesticide constraint production.

4. Results of DEA analyses are known to be sensitive to outliers which outperform other farms in terms of profit maximization. Solutions for all farms under all pesticide use restrictions were carefully examined and no outliers were detected.

Under no pesticide expenditure constraint, the median best-practice profit for small farms was \$164 per acre. This profit could be achieved by

allocating more resources toward soybean production and less toward corn production such that soybean and corn outputs for small farms were, respectively, 3,875 and 2,358 bushels per farm, compared to the actual outputs of 1,426 and 3,528 bushels (table 4). Similarly, the best practices for medium farms also called for more soybean production (19,562 bushels vs. 8,025 bushels) and less corn production (13,444 bushels vs. 22,738) and

resulted in a median profit of \$182 per acre. Large farms produced more of both soybeans and corn, an evidence of technical inefficiency, in order to achieve the best-practice profit of \$154 per acre.

None of the efficient farms spent more than \$30 per acre on pesticides. Therefore, a \$30 per acre constraint on pesticide expenditure was not binding. When the constraint was tightened at \$26, only rather small impacts on the maximum attainable profit were experienced by all farm sizes. As shown in table 2, the median per-acre pesticide expenditures were \$26 for large farms, \$30 for medium farms, and \$21 for small farms. The results hence suggest the availability of practices which could substantially reduce pesticide use without incurring significant economic losses.

Restricting pesticide expenditure to \$22 from \$26 also had negligible impacts on the economic performance of small and medium farms, but resulted in a profit reduction of almost \$7 per acre (4 percent) among large farms. Reallocation of resources toward soybean production, the best-practice prescription for small and medium farms under no pesticide constraint, was also suggested for large farms to minimize the adverse economic impacts of lowering pesticide expenditure below \$26 per acre.

Profit reductions began to amplify, especially among medium and large farms, when pesticide expenditures were restricted to below \$22 per acre. A \$4 reduction from \$22 in per-acre pesticide expenditures caused medium and large farms' profits to decline, respectively, by \$13 and \$11 per acre, implying a marginal revenue of over \$2 for each dollar of pesticide expenditure over the range of \$18-\$22 per acre. However, the same reduction in pesticide expenditures had smaller effects on the profitability of small farms. These findings suggest that pesticide dependence increases with farm size.

When pesticide expenditures were tightened further below \$18 per acre, all farms experienced substantial reductions in profits. Reductions in profits exceeded \$2 per acre for the loss of each dollar worth of pesticides. Further, the marginal reductions in profits, in terms of percentage, increase with limitations on pesticide expenditure for all farm sizes. The prescriptions for resource

reallocation to minimize profit reductions, however, differ by farm size.

The results suggest that, as pesticide use was progressively reduced, corn provided a better return than soybeans for each dollar worth of pesticides on small and medium farms. Consequently, corn production on small and medium farms soared at the expense of soybean production. Under the same restrictions on pesticide use, large farms, however, were required to cut back both corn and soybean production in order to minimize profit reductions.

Summary

Many interest groups, including the production agricultural community, have registered a strong interest in switching to alternative production practices and systems using fewer agricultural chemicals in order to improve the safety of food supply and to arrest environmental degradation. When a shift to a low-input production practice reduces profit, no incentive exists to voluntarily adopt the practice. Insufficient technical and economic information on alternative practices also contributes to low adoption rates. Information about the profitability impact of adopting alternative practices is helpful to public decision-makers seeking to encourage adoption by offering appropriate financial incentives.⁴

This study examined the impact of restricting pesticide use on profits among a subset of cash grain farms, who produced soybeans and other crops (mainly corn) in the Corn Belt-Lake States region in 1990. A linear programming approach was utilized to identify maximum attainable profits for each farm if it adopts best practices. The linear programming model was solved with and without restrictions on pesticide use. The resulting decline in maximum attainable profits attributable to the constraint can be viewed as an estimate of the size of subsidies needed to induce farmers to adopt less chemical intensive practices. Farmers were also classified into three sizes in terms of their gross revenues to analyze the change in maximum attainable profits by farm size. Under the current regulatory situation, limiting pesticide expenditure on a per acre basis is not a

viable policy option due to enforcement difficulties. The approach undertaken in this study does produce useful information.

The results suggest that limiting pesticide expenditures to no more than \$22 per acre had almost no impact on profits among small and medium farms and had limited impacts on large farms. The median per-acre pesticide expenditures were \$20, \$30, and \$26 for small, medium, and large farms, respectively. There are pest management practices currently in use which can substantially reduce pesticide use without incurring significant profit reductions.

As pesticide expenditures were further tightened below \$22 per acre, substantial reductions in profits were predicted, especially among medium

and large farms. The results also suggest that the adverse impacts of restricting pesticide expenditures increased with farm sizes. As pesticide expenditures were progressively restricted, small and medium farms needed to allocated more resources toward corn production and less toward soybean production, even though corn uses more pesticides than soybeans. To minimize profit reductions associated with limited pesticide expenditures, large farms needed to reduce input used and hence output produced for both corn and soybeans.

This study only addresses the relationship between profit and pesticide expenditure. Future studies are needed to examine the factors causing the uneven-distributed impacts by farm size and to identify the pest management practices used by efficient farms. The approach taken by Fernandez-Cornejo worth considering.

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Endnotes

1. According to the eight USDA pesticide surveys conducted over the past three decades, herbicide application rates on soybeans peaked during the late 1970's and early 1980's. In the late 1980's, several new soybean herbicides (e.g., chlorimuron, imazaquin, and imazethapyr) were introduced to replace alachlor. These new herbicides are applied at rates ranging from 0.02 to 0.1 pounds of a.i. per acre as compared with 2.0 pounds of a.i. for alachlor, causing herbicide application rates on soybeans to decline since the late 1980's.

2. One of the reasons for excluding farms with livestock operations from the analysis is that returns may fluctuate widely between years. Furthermore, the best practices of a non-irrigated cash grain farm may not closely resemble those practiced by an irrigated farm or an integrated grain and livestock enterprise.
3. Treating land allocation among crops as a decision variable or not greatly affects the results in absolute terms. This is because over 90 percent of the sample farms received government payments from corn production. Participation in the commodity programs requires that land used to grow a program crop is tied to the base acreage of the farm. This program stipulation was incorporated in a separate analysis in which the allocation of land among crops is set at the observed ratio. Results of the analysis are available upon request from the authors.
4. In a DEA framework, the pesticide input constraint can be expressed in quantity terms or for only those pesticides of interest. The survey collected pesticide data only in terms of expenditures for the five specified categories (pesticide use by active ingredient was not collected). Consequently, pesticide use is measured as a single item and expressed in expenditure terms. Herbicide expenditures dominate other pesticide expenditures in soybean and corn production.