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U.S. AGRICULTURE UNDER FERTILIZER AND CHEMICAL RESTRICTIONS

PART 2

by

Azzeddine Azzam,
Glenn A. Helmers, and
Matthew F. Spilker

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Azzeddine Azzam, Glenn Helmers, and Mathew Spilker [1]

Introduction

The recent growth in interest in alternative production methods in U.S. agriculture has evolved because of a growing concern over the role of inorganic fertilizer and chemical use. The increased dependence of agriculture on fertilizer and chemicals is not without its economic underpinnings. Over the past 40 years the real cost of energy-derived inputs has decreased causing a substitution of these purchased or "external" inputs for internally derived inputs in agriculture.

For a wide range of reasons, individuals, including some agricultural producers, have contended that agriculture is too dependent upon external inputs and this resource imbalance must be corrected. From an economic perspective this reasoning suggests that this overdependence exists because the economic framework governing resource use in agriculture does not fully reflect overall social costs and returns nor respond well to potentially higher long-run costs of energy supplies. This disassociation of costs and benefits underlies social concerns over environmental degradation, an overdependence on finite energy supplies, food safety, and a contention that the economic health of rural communities would be enhanced with a less "external-dependent" agriculture. Also, commodity farm programs have recently been criticized for their tendency to encourage intensive inorganic chemical and fertilizer use on program crops and discourage cropping systems which require less chemical use.

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[1] Assistant Professor, Professor and Graduate Assistant. The authors thank Sam Cordes, Dennis Conley, Roy Frederick, James Kendrick, and Jeff Royer for helpful comments and suggestions.

This report is one of two analyses from an ongoing project dealing with farm-level and sectoral-level impacts of restrictions on fertilizers and chemicals in U.S. agriculture. The second analysis (in progress) will examine the role of federal commodity programs and their impact on resource use in agriculture, particularly fertilizer and chemical use.

At the farm level, interest has grown in more sustainable practices because of concerns related to operator health, economic risk, and soil erosion. In addition, some farm operators perceive that net returns from sustainable agriculture are comparable or nearly comparable to conventional agriculture. Also, some farm operators maintain a strong ethical perspective which includes the previously described social concerns as well as a contention that sustainable practices have a significant beneficial impact on the properties of soil.

The economics of sustainable or low-input agriculture may proceed from two analytical perspectives. The first is at the farm firm level. Generally, this setting examines if cost reductions resulting from lower use of inorganic chemicals and fertilizer (which often involve more extensive cropping systems) counterbalance reduced returns. Such analyses may extend beyond simple dollar returns to include other objectives such as risk and soil conservation. In these analyses aggregate effects of widespread use of such systems are usually ignored. The understanding of how a particular practice under widespread participation will affect aggregate variables such as output prices and quantities, and input prices and quantities is presently inadequate. A farm setting is useful to investigate how a particular production method or policy would impact a farm but the aggregation of changes across all farm units and the resulting output prices and input substitution effects resulting from such changes cannot be adequately determined from a farm firm analytical setting. Only in a short run setting can implications (output and input use) from differences resulting from alternative production method for an individual farm be generalized to the sector. For example, a 10 percent reduction in fertilizer and chemical availability could be examined for an individual farm, estimating changes in production methods which would occur and changes in output which would result. Even here, impacts differ from farm to farm. However, in the short run, resource substitution is limited and consumers would have limited time to adjust to product price changes induced by changes in output levels resulting from an alternative production plan.

The other analytical setting is an aggregate perspective constructed around the national and sectoral forces involved with change. Such a setting emphasizes how various market equilibria are impacted as major economic relationships are changed. This type of analysis is appropriate when changes in product demands, technology, or policies occur. Also, as examined in this paper, this analytic method is useful when an input restriction is hypothesized. Aggregate analyses have the advantage of providing for "feedback" equilibria-related effects such as commodity price changes, input price changes, etc.

Policies directed to sustainable agriculture have been viewed as a simultaneous remedy for a number of objectives. It has been suggested that the widespread adoption of sustainable agricultural practices can be expected to reduce agricultural output, a traditional policy objective of agricultural commodity programs. At best such past programs have achieved only partial success in reducing agricultural output. Better erosion control and reduced groundwater contamination are also suggested as benefits resulting from policies encouraging sustainable agriculture.

The implementation of societal concerns regarding conventional agriculture can be viewed from a wide range of policy perspectives. The first is confidence that current problems can be resolved with better application methods, education, and technological advancements in chemical products. This direction suggests that societal concerns over current agriculture can largely be remedied without direct policy actions. It is largely agreed that more potential for this exists in improved chemicals (herbicides, fungicides, and insecticides) than with improved fertilizer materials and application methods. A second direction is the modification of agricultural commodity programs to encourage reduced fertilizer and chemical use in an indirect manner. This would include a) attempts to remove the incentives under the present 1985 Food and Agricultural Act to maintain program yields and base history. Suggestions here have also included the subsidy of nonprogram crops, b) output quotas where reduced agricultural output would reduce input use, presumably including fertilizer and chemicals, c) free market and decoupled programs where target price and loan price incentives on output are removed as well as the removal of current incentives to maintain program base and yield bases.

Another indirect form of policy directed at reductions in fertilizer and chemicals is the encouragement of greater use of other inputs such as cropland by placing land presently retired from production into use. Another would be the encouragement of greater labor use in agriculture.

Finally, there is the direct method of limiting fertilizer and chemical use by restricting allowable use or availability. This can be accomplished by outright restriction or by taxing such products. While most policy discussions do not presently suggest this alternative except for specific products, this policy was investigated in this paper. Regardless of which policy alternative is considered, be it direct or indirect, it is important to consider the aggregate effects on other inputs and total agricultural output of moving toward a more sustainable agriculture (assuming that current fertilizer and chemical products do not significantly change). This research attempts to determine such impacts. There are concerns that restricting fertilizer and chemical use in agriculture will decrease farm production and push food prices up. Moreover, if increased labor or land is required to compensate for the reduction of fertilizer and chemicals, concerns are often expressed about the consequences of such changes. For example, if increased labor is required is that labor really available? If greater land is required will soil erosion problems intensify as more erosion-prone land is employed in production?

Objective

The objective of this study is to estimate the output and input responses to a reduction in agricultural fertilizer and chemicals. Only when the magnitudes of change are known can policy alternatives be placed in a proper perspective. Another way of stating this issue is what adjustment potential is there within agriculture to different production methods? Are the consequences prohibitive or are they relatively minor?

No specific or general policies or prescriptions are intended by this analysis. Such decisions lie outside analyses such as these. However, the results of studies such as these can help to identify and narrow the estimates of effects resulting from policies aimed at reducing fertilizer and chemicals.

Length of Run

In economic adjustment studies the scope of the adjustment period is critical to the interpretation of change. In this study an intermediate length of run is assumed. This allows consumers time to moderate buying behavior by substituting products when the supply of a particular product is reduced. Similarly on the production side, when the supply of a particular resource is reduced (and its price rises) producers substitute other resources for the resource in question. In the very short run, very little adjustment behavior may occur, but greater adjustment occurs in the longer run. The very short run may be considered one year. Again, little adjustment potential exists in a one year period. Producers with a given production plan have almost no alternative when the availability of a resource important to the production process either increases or decreases. In a two to three year period greater adjustment potential exists. Such a period (two to three years) might be termed short run.

Over a four to six year period, consumers are expected to adjust fully to changed product prices. Similarly, producers would have largely responded by substituting resources through alternative production methods. This time period (four to six years) is termed intermediate run. This is the setting for this study. The long run is also a setting in which profits are capitalized into resource values or decreased returns likewise decapitalized. This long-run phenomenon is an economic adjustment which links agriculture to alternative investment opportunities in the entire economy.

A clarity regarding length of run removes many differences in perspective regarding the potential impact of a fertilizer and chemical restriction on U.S. agriculture. In this study an intermediate length of run is analyzed allowing factors of production to adjust and consumers to adjust to higher product prices resulting from reduced output supply. It should be pointed out that a short-run perspective may result in consequences considerably different from this. In the short run, a restriction on fertilizer and chemicals would involve a significant reduction in agricultural production because producers would be unable to substitute other resources for fertilizer and chemicals to the degree seen in this analysis. Similarly, consumers would significantly react to reduced output by bidding product prices up in a significant manner (low short-run elasticity of product demand). For farm program crops under target prices, a considerable latitude exists before reduced supplies would result in short-run price increases exceeding target prices. Thus, for those crops higher market prices would involve lower government costs for commodity programs. Still, consumers would be significantly affected by higher market prices. For nonprogram crops, market prices would be raised increasing farm income and increasing consumer costs. Farm income would increase because the effect of product price increases would be greater than the effect of reduced production. It is assumed in this study that such impacts are not of major interest because 1) policies involving fertilizer and chemical restrictions would likely be phased in and 2) the longer-run consequences to agriculture and consumers are of more significance than short-run impacts.

Methodolgy and Assumptions

The analytical model used for the analysis is an extension of the static, single output, two input model described in Gardner (pp. 129-137) to study the intermediate term adjustment of a multi-output/multi-input sector to an input restriction. The crops considered were feed grains, soybeans, and wheat. The production function for each crop was assumed to be determined by five inputs: land, labor, machinery, fertilizers and chemicals, and "other" inputs. In addition to the production functions of each crop, producer equilibrium in the production of each crop was specified by the equality of the crop-specific marginal value product to the price of the input. Demand for each crop was specified as a function of its own price, and the price of the other two crops. Supply of each input is a function of its price. In total, the system consists of twenty six equations: 3 production functions, 15 implicit derived input-demand equations, 3 output demand equations, and 5 input supply equations.

After taking the total differential of the 26 equations, expressing the differentials in percentage changes, the comparative static system consists of 26 relationships in differential form in twenty six mutually determined percentage change variables: Three output quantities, three output prices, five input prices, and five input quantities for each of the three crops. The relationships among the percentage change variables are determined by three own elasticities of output demand, six cross price elasticities of output demand, five input supply elasticities, the initial share of each input in each crop, the initial share of each crop in each input, and the elasticities of substitution between each pair of inputs in each crop (see the Appendix for the mathematical details of the model and further explanations).

A simplified graphical illustration of the modelled interactions between the input and output markets is presented in Figure 1. The top three panels show the supply and demand schedules for the three crops: feed grains, soybeans, and wheat. The five bottom panels show the supply and derived-demand schedules for the five inputs: land, labor, machinery, fertilizer and chemicals, and another category ("other") aggregating the rest of the inputs. The intersections of the solid lines in all the panels represent the initial equilibria in the output and resource markets. The dashed lines denote hypothetical adjustments to a fertilizer and chemical restriction as shown in panel (g). Note that the magnitude of the shift in the supply functions of the respective outputs (dashed lines) is not only affected by what happens to the price of the substitutes (i.e., the other two outputs) but also by what happens to the prices of the inputs after the fertilizer and chemical restriction. What happens to the prices of the inputs after the fertilizer and chemical restriction depends on the magnitudes and direction of the shift in the derived-demand functions of the respective inputs. The magnitude and direction of the shift in the derived-demand for the inputs hinges on the values of the elasticity of substitution of a particular input and the elasticity of demand of the final output (i.e., substitution and the output effect). If the elasticity if substitution of a resource is equal to the elasticity of demand of the final output we expect its price to remain unaffected. In other words, its elasticity of substitution of a resource is greater (smaller) than the absolute value of the elasticity of demand of the final output, one would expect the derived-demand for that input to shift to the right (left) thus increasing (decreasing) its price. On the demand side of the output, the shift in the respective output demand curves depends on the magnitudes of the cross elasticities of the demand for the outputs.[2]

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[2] Note that a fertilizer quota may be implemented in two ways. It can be imposed either on the suppliers or users of fertilizers. Suppose the government decides that no more than quantity Q_1 of fertilizers can be marketed by the suppliers of the input. Farmers will bid up the price

To summarize, the model allows for a process of rebounding among factor markets, product markets, and factor and product markets. The rebounding between markets makes it rather difficult to predict what the likely impacts would be. The shifts of supply and demand functions in the various panels in Figure 1 are purely hypothetical. In the next section, we provide a summary of the predictions of the model given a 10 percent reduction in the use of fertilizers and chemicals.

Results

In Table 1 the impacts of a ten percent restriction on fertilizer and chemicals are presented. In Table 1 aggregate output changes of feedgrains, soybeans, and wheat, output prices, aggregate inputs by crop, and input prices are shown.

Feedgrain production is maintained with more land (1.743%) employed in feedgrain production but at lower yields (-1.52%). Labor is significantly increased (14.649%) and other inputs increase by 5.95%. Machinery use in feedgrain production is largely unchanged. Fertilizer and chemical use in feedgrain production does not decline by 10%, only aggregate fertilizer and chemical use declines by that level. Feedgrains have the highest use productivity for fertilizer and chemicals of the three crop groups.

For soybeans, production decreased by 2.2% with land use in soybeans declining more than yields increases. Again, labor use rose significantly. Machinery use in soybeans declined but the use of other inputs increased. For wheat the output and input changes are the same direction as for soybeans, differing slightly in

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to P_2 as they scramble for the limited quantity of fertilizer available. Alternatively, if the same quota could somehow be imposed on farmers (users), the suppliers will respond by bidding the price of fertilizer down to P_1. Note that while the quantity of fertilizer used is the same whether the quota is imposed on the suppliers or users, the prices paid by farmers are different. This means that the welfare implications, i.e. who gains or loses under the various scenarios (or their tax equivalent) are different (see Just *et al.*).

magnitude.

Aggregate land use is seen to decline slightly (-1.132%) very similar to machinery use declines (-1.44%). The most significant resource change is for labor which experiences a 14.389% increase. There is clearly a strong substitution impact of labor (and to a lesser degree the "other" resource category) for fertilizer and chemicals, however land and machinery are only slightly impacted but respond in the same direction as fertilizer and chemicals.

These results demonstrate that the three crops are differently impacted by a restriction on fertilizer and chemicals yet overall the aggregate production effects are minor. Soybean prices increase by 2.75%. Market prices for feedgrains and wheat increase slightly. This decline in price is likely to reduce government expenditures on deficiency payments for two program crops.

An income analysis of producers is beyond the scope of this paper. However, some general impacts can be noted. For the feedgrain sector total revenue rises because of greater output and higher market prices. Reduced deficiency payments would probably be more than compensated by higher market returns. For wheat, gross returns are impacted by reduced production and increased market prices along with reduced deficiency payments. For soybeans, gross income is essentially unchanged. The cost side is more complex because the manner in which a fertilizer and chemical restriction is implemented is important to fertilizer and chemical prices. Input levels multiplied by input prices determine total input cost. Changes in those costs can be determined using the results of this study and those input shares. Such an analysis has a complicating feature, however, in that changes in land and labor costs involve asset values for land and operator returns for labor. Thus, changes in these costs can be viewed from different perspectives, one perspective being that increased costs are really increased resource owner returns.

Relative Price Changes

The size of the predicted market price changes induced by a change in fertilizer and chemical reductions can be placed in perspective by examining past commodity price movements. Suppose a dramatic 25% reduction in fertilizer and chemicals is assumed instead of a 10%. For feedgrains, wheat, and soybeans the price increases caused by this restriction are 1.95, 3.9, and 6.88%, respectively. How do these compare to the historical changes in prices induced by other factors? To find out, annual price changes for the 1978-88 period were calculated. The averages (averaging both positive and negative changes) are 16.95, 12.04, and 13.24% for corn, wheat, and soybeans respectively. This includes the changes induced by the drought of 1988 which resulted in price increases of 43.0, 33.8, and 44.0% for the three respective crops. Replacing 1987-88 with 1977- 78 still results in significant price variability (13.0, 10.97, and 9.89% respectively) for 10 historical annual price changes.

The conclusion is that the product price changes estimated in this study as a result of a 25% fertilizer and chemical restriction are of minor magnitude relative to the product price shifts which are annually experienced. Of course the product price increases estimated here are permanent shifts (assuming no factors change). While such shifts should not be ignored, there is little justification for concern that fertilizer and chemical reductions in agriculture would cause major problems with food price increases in the long run.

To put the results in proper perspective, however, the reader should be reminded that the results are the "creature" of the assumed parameters, namely the own- and cross-price elasticities of demand, the elasticities of input supply as well as the elasticities of substitution between all pairs of inputs. More importantly, the fact that fertilizer and chemicals were lumped into one input also affects the results. Lumping fertilizer and chemicals into one input was dictated by the available elasticities of substitution in the literature. The authors could not find any applied production research which has treated the two inputs separately.

To investigate how sensitive the results are to further disaggregation of the inputs, elasticities of substitution were estimated using the data given by Capalbo and Vo and these were used to estimate the impact of a fertilizer and pesticides reduction on aggregate farm output. The reasoning is that if the results are robust (not in a statistical sense) the output effects of a restriction on fertilizer and pesticides, when not lumped into one input, should not depart dramatically from the previous results. The results show small output changes resulting from fertilizer and pesticide restrictions (in the neighborhood of .20 and -.86% for program and non-program crops). What remains unknown, however, is how the chemical and fertilizer restrictions interact with current and alternative government programs. Our plan for the future is to explore these issues after updating the parameter estimates.

Conclusions and Limitations

This research has found that reductions in fertilizer and chemicals have only minor impacts on U.S. feedgrain, soybean, and wheat markets. Output of feedgrains is actually found to increase very slightly while output of soybeans and wheat declines little. Land and machinery use decreases but labor increases in response to a restriction on fertilizer and chemicals. There are differential impacts by crop type although these differences are not dramatic.

Contrary to some perspectives, reducing fertilizer and chemicals in U.S. agriculture allows output to be largely unaffected through significant resource substitution of other resources for fertilizer and chemicals.

The results of this research must be cautiously considered when considering wide changes in fertilizer and chemical restrictions. Confidence can be placed in the accuracy of results up to the neighborhood of 20 to 30% resource changes.

As wider changes in fertilizer and chemicals or other inputs are considered, the structural forces surrounding resource change may be different from that shown here.

Naturally, the comparative static model described above has advantages as well as limitation when compared to other models, namely econometric and programming models. Unlike econometric models, the model used in this study does not take into account the dynamic aspects of the problem. However, it offers some insights on the important components to be considered if such dynamic analysis is pursued. Econometric as well as programming models, on the other hand, by their sheer size and data requirements, make difficult to assess their underlying economic properties (see Hertel). More importantly, the econometric modeling efforts known to the authors rarely consider responses in input markets.

Appendix

The complete set of equations describing the three sector (feed grains, soybeans, and wheat) equilibria is as follows:

$$C = C(N_C, L_C, M_C, F_C, R_C) \tag{1}$$

$$S = S(N_S, L_S, M_S, F_S, R_S) \tag{2}$$

$$W = W(N_W, L_W, M_W, F_W, R_W) \tag{3}$$

$$C = D_C(P_C, P_S, P_W) \tag{4}$$

$$S = D_S(P_C, P_S, P_W) \tag{5}$$

$$W = D_W(P_C, P_S, P_W) \tag{6}$$

$$\begin{aligned}
P_N &= P_C \frac{\partial C}{\partial N_C} = P_S \frac{\partial S}{\partial N_B} = P_W \frac{\partial W}{\partial N_W} \\
P_L &= P_C \frac{\partial C}{\partial L_C} = P_S \frac{\partial S}{\partial L_B} = P_W \frac{\partial W}{\partial L_W} \\
P_M &= P_C \frac{\partial C}{\partial M_C} = P_S \frac{\partial S}{\partial M_B} = P_W \frac{\partial W}{\partial M_W} \\
P_F &= P_C \frac{\partial C}{\partial F_C} = P_S \frac{\partial B}{\partial F_B} = P_W \frac{\partial W}{\partial F_W} \\
P_R &= P_C \frac{\partial C}{\partial R_C} = P_S \frac{\partial B}{\partial R_B} = P_W \frac{\partial W}{\partial R_W}
\end{aligned} \tag{7}$$

$$N = M(P_N) \tag{8}$$

$$L = L(P_L) \tag{9}$$

$$M = M(P_M) \tag{10}$$

$$F = F(P_F) \tag{11}$$

$$R = R(P_R) \tag{12}$$

The first four equations specify the production function for feedgrains (C), soybeans (S), and wheat (W), respectively. The argument in the respective production functions are the levels of the five inputs specific to each crop: Land (N), labor (L), machinery (M), fertilizer and chemicals (F), and another category aggregating the rest of the inputs (R). Equations 4-6 are the respective output demand functions for each crop. Each demand function consists of own price and the prices of the other two crops. Producer equilibrium in the production of the four crops is shown by 7 where the marginal value product of each crop-specific level of input is equated to the price of that input. This implies 15 implicit crop-specific derived demand functions. Note that this specification implies that the prices of inputs are the same for all crops. The final set of functions, 8-12, are the supply functions for each of the five inputs. The quantity of each input is specified as a function of its own price. The slopes of the output demand and input supply functions in the system are assumed to have the normal signs and the production functions are linear homogenous.

To proceed with analyzing the system's displacement from equilibrium to an exogenous shock, take the total differential of the system of equations shown above and convert the results into percentage changes. Denoting the percentage change in a variable x, $\frac{dX}{X}$ by EX, the production function block can be expressed as follows:

$$EC = S_{N_C}EN_C + S_{L_C}EL_C + S_{M_C}EM_C + S_{F_C}EF_C + S_{R_C}ER_C \quad (13)$$

$$ES = S_{N_S}EN_S + S_{L_S}EL_S + S_{M_S}EM_S + S_{F_S}EF_S + S_{R_S}ER_S \quad (14)$$

$$EW = S_{N_W}EN_W + S_{L_W}EL_W + S_{M_W}EM_W + S_{F_W}EF_W + S_{R_W}ER_W \quad (15)$$

where S_{I_J}, for I=N,L,M,F,R and J=C,S,W, is the share of each Ith input in the total cost of producing the Jth crop, i.e $\frac{P_I.I}{P_J.J}$.

Using the same procedere the output demand equations, 5 through 8, become:

$$\begin{aligned} EC &= \eta_{CC}EP_C + \eta_{CS}EP_S + \eta_{CW}EP_W && (16) \\ ES &= \eta_{SC}EP_C + \eta_{SS}EP_S + \eta_{SW}EP_W && (17) \\ EW &= \eta_{WC}EP_C + \eta_{WS}EP_S + \eta_{WW}EP_W && (18) \end{aligned}$$

where η_{IK}, is each crop's own price elasticity of demand (for $I = K$) , and the cross price elasticity of demand for $(I \neq K)$.

Total differentiation of producer equlibrium in corn production gives:

$$\begin{aligned} EN_C &= \gamma^C_{NN}EP_N + \gamma^C_{NL}EP_L + \gamma^C_{NM}EP_M + \gamma^C_{NF}EP_F + \gamma^C_{NR}EP_R && (19) \\ EL_C &= \gamma^C_{LN}EP_N + \gamma^C_{LL}EP_L + \gamma^C_{LM}EP_M + \gamma^C_{LF}EP_F + \gamma^C_{LR}EP_R && (20) \\ EM_C &= \gamma^C_{MN}EP_N + \gamma^C_{ML}EP_L + \gamma^C_{MM}EP_M + \gamma^C_{MF}EP_F + \gamma^C_{MR}EP_R && (21) \\ EF_C &= \gamma^C_{FN}EP_N + \gamma^C_{FL}EP_L + \gamma^C_{FM}EP_M + \gamma^C_{FF}EP_F + \gamma^C_{FR}EP_R && (22) \\ ER_C &= \gamma^C_{RN}EP_N + \gamma^C_{RL}EP_L + \gamma^C_{RM}EP_M + \gamma^C_{RF}EP_F + \gamma^C_{RR}EP_R, && (23) \end{aligned}$$

where $\gamma^J_{IM} = S_{I_J}(\sigma^J_{IM} + \eta_{JJ})$ with σ^j_{IK} the Allen partial elasticity of substitution between input I and K (Allen) used in the production of the Jth crop. [3]

Finally, total differentiation of the input supply equations, 8 through 12, gives the following relationships:

$$\begin{aligned} EP_N &= \frac{SN_C}{\epsilon_N}EN_C + \frac{SN_S}{\epsilon_N}EN_S + \frac{SN_W}{\epsilon_N}EN_W && (24) \\ EP_L &= \frac{SL_C}{\epsilon_L}EL_C + \frac{SL_S}{\epsilon_L}EL_S + \frac{SL_W}{\epsilon_L}EL_W && (25) \\ EP_M &= \frac{SM_C}{\epsilon_M}EM_C + \frac{SM_S}{\epsilon_M}EM_S + \frac{SM_W}{\epsilon_M}EM_W && (26) \\ EP_F &= \frac{SF_C}{\epsilon_F}EF_C + \frac{SF_S}{\epsilon_F}EF_S + \frac{SF_W}{\epsilon_F}EF_W && (27) \\ EP_R &= \frac{SR_C}{\epsilon_R}ER_C + \frac{SR_S}{\epsilon_R}ER_S + \frac{SR_W}{\epsilon_R}ER_W && (28) \end{aligned}$$

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[3] producer equilibria in the production of soybeans and wheat are algebraically the same execept for the change in superscripts to denote the crop. This means the model consists of 10 additional equations which are not shown here.

where ϵ_I for I=N,L,M,F,R is the Ith input elasticy of supply, and SI_J is Jth crop's share in the total utilization of the Ith input in all three sectors.

The comparative static system shown above consists of 26 equations in 26 mutually determined percentage variables: 3 output quantities, 3 output prices, 5 inputs prices, and 5 input quantities for each of the three crops. The relationships among the percentage change variables are determined by 3 own-price elasticities of demand, 6 cross-price elasticities of output demand, 5 input supply elasticities, 5 input-cost shares for each crop, 3 (quantity) shares of each crop in each input, and 15 elastiticties of substitution between each pair of inputs for each crop.

To operationalize the model, data on the elasticities of substitution were obtained from Binswanger and were assumed identical for all crops. Crop-specific elastiticities of substitution were not available in the literature. Estimates of the own- and cross-price elasticities of demand were obtained from various sources. Estimates for the input supply elasticities were obtained from floyd. More recent estimates of input supply elasticities were not available.

To solve for comparative statics of exogenous shocks, the system must be arranged in the matrix form $\mathbf{Ax} = \mathbf{b}$, where $\mathbf{A}$ is the matrix of known coefficients, $\mathbf{x}$ is the vector of the unknown variables (in percentage changes), and $\mathbf{b}$ is the vector containing policy instruments. A restriction on fertilizer and chemicals, as is the case in this example, can either be represented as a quantitative restriction (in percentage) in the demand equation or supply equation of fertilizer and chemicals (for a two output two input example, see Gardner).

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Table 1
Estimated Aggregate Effects of a 10 Percent Reduction in Fertlizer and Chemicals on Output, Output Prices, Input Use, and Input Prices (In percent)

	Commodity Production and Prices		
	Feed Grains	Soybeans	Wheat
Production	.19	-2.20	-1.26
Output	-1.52	1.50	.99
Price	.78	2.75	1.56

	Input Use and Input Prices				
	Land	Labor	Machinery	Fertilizer and Chemicals	Other
Prices	-11.32	7.19	-.48	10.13	.01
Use in Feedgrains	1.74	14.65	.09	-8.62	5.95
Use in Soybeans	-3.64	12.19	-2.97	-13.73	4.42
Use in Wheat	-2.23	15.48	-2.85	-11.30	5.68
Use in Aggregate	-1.12	14.38	-1.44	-10.0	5.49