Energy Alternatives in U.S. Crop Production

By Kerry Webb and Marvin Duncan

A dramatic result of the 1973 Arab oil embargo and the quadrupling of imported oil prices has been a marked shift in the way U.S. citizens view their energy consumption. These events and subsequent OPEC price actions have brought into clear focus the importance of wise use of both domestic and imported energy sources. American farmers are particularly aware of the impact of higher prices and threatened supply shortages, despite the fact that agricultural production uses only 4 or 5 per cent of all energy consumed annually in the United States.[1] Agricultural producers function in a very competitive environment and find it difficult to pass along to consumers increases in production costs such as fuel price increases. Additionally, timely operations are increasingly important to farmers, which suggests that fuel supply shortfalls during critical periods, such as harvest time, could sharply reduce agricultural output.

This article discusses the opportunities farmers may have to substitute other inputs for energy in production. A mathematical model is used to assess the potential substitutability among agricultural inputs at both national and regional levels. Some policy implications of the empirical evidence are also discussed.

ENERGY DEPENDENCE

Ready access to low-cost energy has revolutionized the way Americans live. Nowhere has this revolution been more pronounced than in agriculture, where the sizable increase in output during the last 70 years is due largely to the increased use of energy on the farm. Farmers' access to abundant low-cost chemical and mechanical energy supplies has been the key factor in the development of today's highly sophisticated agricultural production methods. U.S. farmers are currently using over 4.4 million tractors, 3 million trucks, and 500,000 combines. More than 35 million acres are being irrigated using pump systems. Over 20 million tons of fertilizer and 400,000 tons of pesticides are being used annually by the nation's farmers. All of these items require energy in some form-either as a fuel for operation or as a primary ingredient for its manufacture. As a result, energy has become a basic raw material in agricultural production.

Throughout this century, agriculture's demand for energy has always been satisfied. Even during periods of war, farmers have

[1] Marvin Duncan and Kerry Webb, "Energy and American Agriculture," *Economic Review*, Federal Reserve Bank of Kansas City, April 1978.

received special consideration for their energy requirements. Moreover, energy—and particularly petroleum-derived fuels—has been priced so that it has been profitable for farmers to use increasing amounts in their production. Indeed, for most of this century, the price of energy relative to many other inputs has been decreasing.

ENERGY SHORTAGE

In spite of recent legislative movements to shore up the U.S. energy program, the United States still faces a rather delicate supply situation. The winters of 1976 and 1977 showed how uncertain the supply of natural gas has become. The coal strike of 1978 could have had disastrous results if it had lasted much longer. Moreover, recent international events highlight the uncertain status of foreign oil supplies. Domestic strife in Iran has temporarily disrupted oil production in that country. OPEC crude oil price increases of 14.5 per cent during 1979 will add measurably to U.S. trade deficit problems and price inflation. Thus, dependendence upon foreign energy supplies creates the potential for economic hardship and a high degree of uncertainty regarding energy availability.

Agriculture can be affected by energy supply disruptions just as can every other sector in the economy. For example, petroleum products refined from crude oil provide over 75 per cent of the direct on farm energy used in crop production. In 1977, 45 per cent of the crude oil going to U.S. refineries was imported and roughly 75 per cent of the imported oil came from OPEC nations.. Thus, about one-third of the direct energy used on U.S. farms comes from foreign lands and about one-fourth comes from the OPEC countries.

Although agriculture does have high priority in times of fuel rationing, political developments or other disruptions in some of these countries could have very damaging effects upon agricultural production—at least during limited time periods. This fact has been emphasized by U.S. Secretary of Agriculture Bob Bergland:

> The biological nature of agriculture is such that operations must be performed during rather critical time periods, or serious losses in production can occur. The delay of a few hours in energy supplies could mean death for poultry in environmentally controlled housing. For other operations such as corn planting, the delay of planting by a week can reduce yields per acre by 7 to 14 bushels. In wheat harvest, the delay of a few days for combine fuel can reduce a crop from 50 bushels per acre to 5, depending on the weather.[2]

In addition to supply shortages, rising energy prices may also mean that farmers will need to find ways to conserve the energy that is available and to substitute other inputs for energy. From 1972 to 1977, average prices paid by farmers for fuel and energy increased 87 per cent. Table 1 shows the prices that farmers have paid for various fuels, both commonly measured and when all fuels are converted to an equivalent energy unit of 1 million Btu. In the future, increasing demand from other sectors of the economy, the deregulation of natural gas and oil prices, and the reduction in petroleum reserves is likely to continue to put upward pressure on energy prices.

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[2] Bob Bergland, Secretary of Agriculture, Statement before the Subcommittee on Rural Development, Senate Committee on Agriculture, Nutrition and Forestry, July 26, 1978.

Table 1
AVERAGE ANNUAL PRICES PAID BY FARMERS FOR VARIOUS FUELS

Year	Gasoline ($/gal.)	Diesel ($/gal.)	L.P. ($/gal.)	Natural Gas* ($/1000 c.f.)	Electricity† (¢/Kwh)
	Common Measurement				
1972	.310	.190	.156	.473	2.23
1973	.337	.226	.169	.525	2.31
1974	.465	.365	.302	.693	2.66
1975	.498	.391	.304	1.040	3.07
1976	.532	.413	.331	1.397	3.35
1977	.556	.447	.414	1.785	3.68
	Dollars/1,000,000 Btu				
Year					
1972	2.48	1.36	1.64	.45	6.53
1973	2.69	1.61	1.78	.50	6.77
3974	3.72	2.61	3.18	.66	7.79
1975	3.98	2.79	3.20	.99	9.00
1976	4.25	2.95	3.48	1.33	9.82
1977	4.53	3.19	4.36	1.70	10.78

'Natural gas used in agricultural production, such as powering irrigation pumps, is priced at the industrial users' rate.

†Midyear price.

SOURCE: Agricultural Prices Annual Summary 1977; Agricultural Statistics 1977; Gas Facts 1978, American Gas Association.

ENERGY SUBSTITUTION: THE MODEL

As present sources of agricultural energy become more expensive and less plentiful, the development of alternative production processes will become increasingly important. Such processes may permit the substitution of other inputs for farm energy. Estimates of substitutability can be obtained through the use of mathematical models where the results can serve as guidelines at both the farm and national policy levels in evaluating appropriate responses to farm energy shortages. A number of researchers have developed models which assess the substitutability of energy in U.S. manufacturing using both time series and cross-sectional data.' Although such aggregate models provide only a very broad assessment of input-output relationships, they offer valuable insights into energy policy alternatives.

3 See D.B. Humphrey and J.R. Moroney, "Substitution Among Capital, Labor and Natural Resource Products in American Manufacturing,"Journal of Political Economy, Vol. 83, No. 1, 1975, pp. 57-82; or E.R. Berndt and D.O. Wood, "Technology, Prices and Derived Demand for Energy," *The Review* of Economics and Statistics, August 1975, pp. 259-68.

The model used in this study assumes there is a mathematical expression called a production function which relates the flow of agricultural crop output to the services of four farm inputs: (1) land, (2) hired labor, (3) mechanical energy—which consists of energy used in constructing farm machinery plus the energy used to fuel farm operations, and (4) chemical energy—which represents the energy used in the production of fertilizers and other agricultural chemicals. While other inputs, such as water and operator labor, play a major role in agricultural production, the costs of the four selected inputs represent more than 75 per cent of the total costs associated with the growing of crops in the United States. Moreover, aggregate production functions with these types of broad inputs are more adaptable to the limited amount of available data. For this study, national and state data were primarily developed from the 1974 **Census of Agriculture** and several U.S. Department of Agriculture publications.[4]

As in any econometric study, certain assumptions were made regarding the proper use of the model and the data. Since data were used from only those farms which, according to the **Census of** Agriculture, were primarily engaged in crop production, it was assumed that all of the inputs were specifically used for that purpose. However, it is possible that some of the inputs were actually used in livestock production on those same farms, but these inputs could not be eliminated from the model due to data limitations. On the other hand, there may also have been some inputs used to grow crops on those farms which are primarily engaged in livestock production. If so, these inputs were not counted within the model framework. This type of data aggregation may not reflect the actual substitution possibilities involved with the growing of a single crop by itself. Consequently, while a more specific model (wheat production, for example) may be appropriate, data limitations prevent that type of research.

Despite the simplifying assumptions mentioned, the model and data appear appropriate for the generalized results sought. Moreover, even generalized information on potential substitutability among agricultural inputs can be very useful to farmers and to the firms providing the inputs.

A production function, as indicated earlier, was used to estimate the effect each of the four inputs has on the level of output. In its simple form, a production function expresses how much output can be gained from given quantities of specified inputs. For example, a very simple production function might take the form:

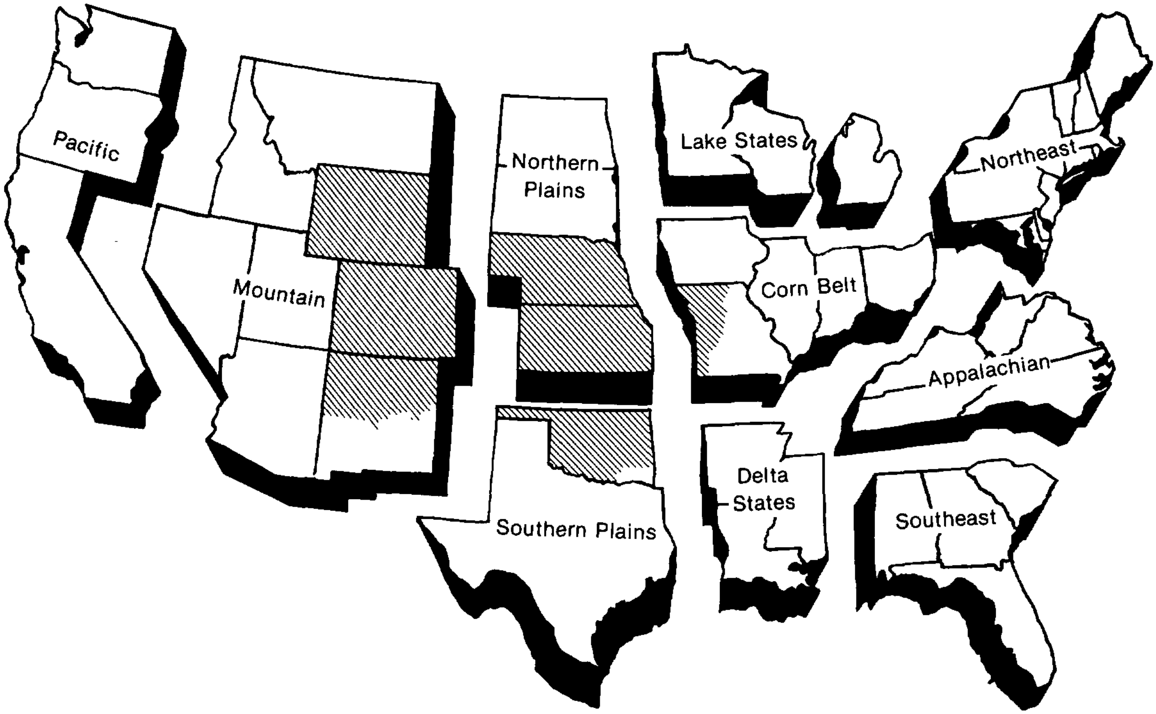
$$Z = aX + bY$$

where Z represents output (i.e., bushels of corn), X and Y denote levels of inputs (i.e., labor hours and tons of fertilizers, respectively) and a and b are parameters that show how much a change in each input affects output. Thus, if "a" were estimated to be 0.5, it would indicate that as the number of labor hours increased by 1, corn production would increase by ½ bushel. And, if "b" were estimated to be 2.4, it would indicate that if 1 additional ton of fertilizer were used, corn production would increase by 2.4 bushels.

The production function used in the model is somewhat more complex than the simple input-output relationship just noted. A very general form for the production function

[4] ***1974 Census of Agriculture.*** U.S. Department of Commerce; ***Energy and U.S. Agriculture: 1974 Data Base,*** U.S. Department of Agriculture; ***Farm Labor,*** U.S. Department of Agriculture, February 28, 1975; ***Agricultural Rices,*** U.S. Department of Agriculture, October 1977; ***Agricultural Prices Annual Summary, 1974.*** U.S. Department of Agriculture.

Figure 1
FARM PRODUCTION REGIONS



Shaded area represents Tenth Federal Reserve District.

SOURCE: U.S. Department of Agriculture.

(known as the **translog** production function) was actually used so as to place no specific restrictions on the estimates of substitutability among the inputs. Table 3 in the Appendix shows the estimated parameters and additional statistical information that was obtained from the actual model used.

The input substitution possibilities were calculated using the parameter values and the means of the input variables. To introduce regional differences of input substitution, there were 12 sets of means used with the parameter values. One set represents the mean levels of the inputs from all 48 continental states. Another set is made up of states which comprise the Tenth Federal Reserve District.[5] The remaining 10 sets are based on the U.S. Department of Agriculture Farm Production Regions delineated in Figure 1.

MODEL RESULTS

Table 2 shows the elasticities of input substitution. These elasticities are pure num-

5 The Tenth Federal Reserve District includes Colorado, Kansas, Nebraska, Wyoming, most of New Mexico and Oklahoma, and 43 counties in western Missouri.

Table 2
ELASTICITIES OF SUBSTITUTION

Region	Land and Hired Labor	Land and Mechanical Energy	Land and Chemical Energy	Hired Labor and Mechanical Energy	Hired Labor and Chemical Energy	Mechanical Energy and Chemical Energy
	Elasticities of Substitution Between					
United States	.77	1.36	.78	1.91	.27	1.19
Tenth District	– .79	1.37	.74	2.01	.29	1.02
Northeast	1.00	1.35	.84	2.12	.23	1.48
Appalachian	.90	1.35	.87	1.99	.25	1.31
Southeast	1.06	1.33	.92	1.97	.26	1.38
Lake States	.47	1.37	.80	1.98	.23	1.16
Corn Belt	– .15	1.39	.80	2.26	.05	1.16
Delta States	.94	1.35	.85	2.00	.25	1.33
Northern Plains	-2.19	1.37	.72	2.05	.60	.96
Southern Plains	.44	1.35	.76	1.79	.31	1.06
Mountain	.70	1.34	.65	1.67	.36	.99
Pacific	1.03	1.35	.72	1.98	.18	1.42

bers which measure the degree or relative ease with which substitution between two inputs may take place, when the prices and quantities of all other inputs remain constant. Thus, the degree of substitutability between one input pair can be compared to the substitutability of another input pair. If the elasticity is positive, the inputs are said to be substitutes for each other. For example, suppose 10 men with shovels were required to dig a large trench. If a machine could dig the trench equally well, it would then be regarded as a substitute input in the production of the trench. A larger positive number reflects a larger degree of substitutability. If the elasticity is negative between a pair of inputs, the inputs are called complements. In this case, the two factors are not likely to replace each other in production. Indeed, a decrease (increase) in the use of one of the inputs would suggest a decrease (increase) in the use of the other. Both inputs, then, would be partly replaced by other factors in order to maintain output. Thus, if the men digging the trench were laid off, their shovels would also be retired. In this case, the labor and the shovels would be complements, and would both be replaced by the machine.

Generally, the results in Table 2 show that each pair of inputs are substitutes, at least to some degree. The table also shows that the substitution possibilities between hired labor and machinery (mechanical energy) hold the greatest potential, whereas the hired labor and fertilizer (chemical energy) tradeoffs would produce relatively less satisfactory results. The only complementary situation involves the land-hired labor relationship, which occurs only in the Tenth District states and in the Corn Belt and Northern Plains region.[6]

[6] One possible explanation of this is that the marginal productivity of labor is very low or negative in those states which make up the specific regions. Marginal productivity is defined as the change in output resulting from a 1-unit change in the amount of one input while the other inputs are held at fixed levels. Alternatively, the crops grown in one region may not provide the substitution possibilities that crops grown in other regions provide.

The regional results illustrate differences in input substitutability. As shown in Table 2, the elasticity of substitution between land and mechanical energy is quite constant around 1.35 throughout all regions of the United States. However, the results for land-hired labor, hired labor-chemical energy and for mechanical-chemical energy are quite variable from region to region.

The regional differences may be primarily due to differences in the agricultural production patterns that occur across regions. For example, the relatively high elasticity of substitution between hired labor and mechanical energy in the Corn Belt (2.26) may be associated with large-scale corn and soybean production. The lower elasticity in the Mountain States (1.67) may reflect smaller scale and more specialized types of crop production, including widespread use of irrigation. Nonetheless, relatively low elasticities of substitution for most input pairs in the Mountain region suggests a production pattern and input mix that is relatively inflexible. Similarly, the elasticities of substitution between mechanical and chemical energy suggest such a substitution in the Northeast may be substantially easier than in the Northern Plains. Moreover, the ease of replacing hired labor with chemical energy (or vice versa) is also rather limited throughout all regions. Thus, if agriculture were to make large-scale changes in its production input mix, regional differences should probably be considered.

The elasticities of substitution between input pairs in the Tenth District states are generally very similar to those for the United States. One major exception is found in the case of land and hired labor. For the United States, these inputs are substitutes, while for the Tenth District they are complements and, as a consequence, would not be expected to substitute for each other.

It should be noted that these substitution elasticities may change if the relative prices of inputs change or if the productivity of a particular input increased. However, given the production and price relationships in 1974, these estimates appear quite reasonable when compared with other research findings.[7]

POLICY OBSERVATIONS

The model's results are of a general nature and can best be used to point out policy opportunities in the event economic or political circumstances force farmers to consider market changes in the mix of resources used in agricultural production. Within the framework of the model, a number of policy observations are possible.

Input Substitution

The model's results confirm the general assertion that acreage allotment and set-aside programs are not particularly effective means for limiting crop output.[8] Mechanical energy and chemical energy are readily substituted for land in the production process. Consequently, even moderate cutbacks in acreage are easily offset by utilizing more machinery and chemicals (including fertilizer) to increase production per acre and thus maintain total production. Conversely, if the energy inputs in machinery and chemicals were cut back for some reason, flexibility exists to maintain substantial production by farming more acres less intensively. Finally, the larger elasticity number for the mechanical energy-land substitution indicates that substitution is markedly

[7] See Hans Binswanger, "A Cost Function Approach to the Measurement of Elasticities of Factor Demand and Elasticities of Substitution," *American Journal of Agricultural Economics.* May 1974, pp. 377-86.

[8] D. E. Hathaway, *Government and Agriculture: Public Policy in a Democratic Society* (New York: Macmillan Co., 1963), pp. 296-301.

easier between that pair of inputs than between chemical energy and land.

The model's results also indicate that mechanical energy (machinery) is the most flexible input of the four included in the model. Mechanical energy readily substitutes for hired labor quite uniformly across all production regions, although the substitutability is highest in the major food and feed grain producing regions. Somewhat more diversity is found across regions when mechanical energy-chemical energy substitution is examined. Nonetheless, mechanical energy would be quite a satisfactory substitute for many kinds of chemical energy, should spot shortages of chemicals occur within a growing season or over a limited number of growing seasons. For example, cultivation could at least partly substitute for chemical weed control. Conversely, if agriculture were faced with fuel shortages, total crop output could be maintained by diverting some petroleum stocks to the production of chemicals and fertilizers.

The degree of substitutability between mechanical energy and chemical energy is quite important. Some researchers have suggested that agriculture should return to less energy-intensive production practices to conserve energy.[9] Thus, by using more land and labor, more energy could be saved. The results of this research indicate, however, that the substitution of nonenergy inputs for energy inputs is limited by both regional production differences and by the type of energy for which the substitution is made. For example, if conserving mechanical energy is important, both land and hired labor (both nonenergy inputs) would be better substitutes than chemical energy.[10]

[9] Michael J. Perelman, "Mechanization and the Division of Labor in Agriculture," *American Journal of Agricultural Economics,* Vol. 55, No. 3, August 1973, pp. 523-26.

[10] The results, however, indicate that chemical energy may be a better substitute for mechanical energy than land in the Northeast, Southwest, and Pacific regions.

On the other hand, if chemical energy conservation is given priority, the use of mechanical energy is always a more realistic substitute than are the two nonenergy inputs (land and hired labor). Thus, the substitution of one form of energy for another may be more practical than using nonenergy-consuming substitutes. These results suggest caution for those who urge widespread shifts from energy-based inputs to human-labor inputs in agricultural production. This finding also adds support to the intuitive assertion by agricultural producers that it is impractical to make significant substitutions of labor for many energy inputs.

On balance, it appears that agricultural producers do have a surprising amount of flexibility to substitute inputs while maintaining output levels in the event that restrictions on energy availability occur. In the case of some inputs, effective substitution can occur within a production season, as in mechanical-chemical energy substitution. Other kinds of substitution are of a longer term nature and could occur over several years, as in shifting to less intensive production practices.

CONCLUSION

The use of energy in agriculture has allowed for large increases in output and productivity, and has provided the nation with a steady supply of food at reasonable prices. However, present U.S. agricultural production is heavily dependent upon energy availability. Due to the possibility of energy shortages or rising energy prices, farmers may be forced to use other inputs as substitutes for energy.

The empirical evidence presented here suggests that farmers using conventional inputs do have some substitution alternatives to maintain production. The evidence also suggests that a national energy policy for agriculture should be somewhat modified to incorporate regional production differences. Moreover, even without large-scale shifts in production methods, there are ways in which farmers can conserve energy. Better management and more efficient operations will become increasingly important as energy prices escalate. Finally, caution is suggested for those who urge widespread shifts from energy-based inputs to human-labor input in agricultural production.

APPENDIX

For this study, a translog production function was used to estimate the required parameters. It takes the form

$$\ln Q = \ln a_0 + \sum_i a_i \ln X_i + \tfrac{1}{2} \sum_i \sum_j b_{ij} \ln X_i \ln X_j$$

where ln represents the natural logarithm, Q denotes output, a_0 is the intercept coefficient, a_i and b_{ij} are the coefficients to be estimated and X_i and X_j are the levels of the various inputs. The specification and restrictions of this model allow the parameters to be estimated using full information maximum likelihood estimation applied to a system of three marginal productivity equations. For a review of the procedure, see the article by Humphrey and Moroney as listed in footnote 3.

Table 3 shows the estimated parameter values (the a_i's and b_{ij}'s from the translog equation) obtained from the model. By themselves, the parameter values have little economic meaning but, when used in the appropriate calculations, the substitution possibilities among the four inputs can be examined.

Table 3
ESTIMATED PARAMETER VALUES AND T-STATISTICS*

	j Component				
	Intercept	Land†	Hired Labor	Mechanical Energy	Chemical Energy
Land	.227873†	.059126			
Hired Labor	−.361154	−.023888	.084573		
	(-5.25715)		(12.9384)		
Mechanical Energy	.483268	.007482	−.04002	.077721	
	(4.70931)		(-6.9187)	(6.01868)	
Chemical Energy	.650013	−.04272	−.020665	−.045183	.108568
	(4.88893)		(-2.66588)	(-4.29044)	(6.30154)

*Critical values with 135 degrees of freedom are $t_{.05} = 1.96$ and $t_{.01} = 2.57$.

†Implied estimates computed using the mathematical constraints placed on the model.

NOTE: The parameters were estimated using three marginal productivity equations representing hired labor, mechanical energy, and chemical energy. The adjusted coefficient of determination (R^2) and F-test values for each equation are, respectively: hired labor, .771 and 39.44; mechanical energy, .710 and 28.85; chemical energy, .357 and 7.11. Each of the F values is significant at a 1 per cent level.

The t-statistics (shown in parentheses) indicate that all of the estimated parameters are statistically significant. An estimated parameter with a t-statistic greater than 2.57 in this case indicates that there is only a 1 per cent chance that the actual parameter value is zero. It should be noted that the actual parameter value may not be the same as the estimated value. This is true because the estimated value is obtained using a sample of an entire population of observations. Thus, the larger the t-statistic (regardless of its sign), the better the estimated value is in approximating the actual value.